

**MEETING OPTIMALLY THE ENVIRONMENTAL CHALLENGE:
A METHODOLOGY FOR THE LEAD INDUSTRY**

A thesis submitted for the partial fulfilment of the degree of
Doctor of Engineering in Environmental Technology

by

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Volume II

Faculty of Technology
Brunel University

February 2001

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10. MIM Case Study

10.1. Purpose and Frame of Reference

This study provides quantitative inventories and potential human health and environmental effect assessments, plus additional qualitative analyses, attributed to:

1. the refined primary Pb and Pb alloys produced by MIM Holdings Limited companies, from their cradle as raw materials, through all processes and stages to the final products (i.e. at the *cradle-to-gate scale*),
2. the comprising production streams (i.e. at the *process stream scale*), and
3. the various comprising processes (i.e. at the *individual process scale*).

Hence, this case study addresses the ‘national (global)’ scale identified in Figure 4.1 of chapter 4, as well as other smaller scales.

Demonstrations are provided of how

- the assessments can be used to compare the relative inventories and potential human health and environmental effects of different refined Pb production throughputs conducted by MIM Holdings Limited companies,
- the assessments may be applied practically for environmental performance indicator setting at different decision scales, and
- such information aids decision makers, both within MIM Holdings Limited, its subsidiary companies and those charged with regulating it, in identifying ‘best’ environmental practice.

The uncertainties underlying all of the above assessments are also examined. To help guide decision making deliberations based on these and other similar assessments, consideration is given, for each assessment, of how such uncertainties should influence the decision making of all relevant parties. These considerations resolve around two suppositions, which are that:

- decisions have to be made even though those making the decision may be faced with considerable uncertainty, and
- decision makers would want to make the ‘best’ decision(s) possible (leading to the adoption of the ‘best’ environmental practice), given available evidence.

The overall aim of this case study is to provide MIM Holdings Limited, and its subsidiary companies, with a series of inventories, assessments and approaches, to address existing and likely future environmental challenges in the most effective manner. The approaches developed herein, are intended to act as cradle-to-gate scale, process stream scale and individual process scale elements within a new overarching strategy developed by the author to help MIM, and its subsidiary companies, to meet these challenges. Therefore, whilst the assessments and approaches may be applied solely at these three scales, they in fact are posited within this strategy. This differs from existing strategies for dealing with environmental concerns in being fundamentally holistic and in providing a more multi-dimensional way of thinking about and dealing with environmental matters. Hence, for them to demonstrate their full capabilities, they should not be applied in isolation of the wider picture.

The approaches developed in this study are also intended to be applicable generically for the rest of the lead industry and for other industry sectors facing comparable challenges. In addition, the intention is for the assessments and approaches developed in this case study to become adopted as part of the normal environmental management practices within MIM Holdings Limited, and its subsidiary companies. They are, therefore, viewed as providing a starting point to be progressively articulated and improved upon with time.

Note that wherever possible, the data were collected by the author from site personnel. Where other sources of data have been used, this is identified explicitly. In both instances, however, the reliability of the data and their influence on the usefulness of conclusions based upon such data are assessed. Note also, that although this research has been sponsored by MIM Holdings Limited, the arguments and conclusions, which have been drawn, are those of the author. They may not, therefore, necessarily coincide with those of the company.

At the end of the case study, the main elements of the arguments are summarised and specific conclusions and recommendations are made.

10.2. Nature of the Business and History

MIM Holdings Limited is an Australian based international minerals processing and mining company, with about 8,000 employees world wide [MIM Holdings Ltd. (2000a)]. It is a major global producer of refined copper, gold, zinc, lead and silver. It also mines coking and steaming coal, and operates its own coke production plant.

MIM Exploration (MIMEX), part of MIM, conducts exploration for high value mineral deposits. Currently, MIMEX is focusing on high priority terrains in Australia (especially north-west and north-east Queensland), Argentina and Mexico. It also has specific exploration targets in Namibia and Brazil [MIM Holdings Ltd. (2000a)].

MIM Process Technology, also part of MIM, markets a range of minerals processing technologies, which include:

- the Jameson Cell (for the removal of metals from aqueous effluents),
- the Isasmelt furnace (for metals smelting, especially copper),
- the Isa Mill (for ore grinding) [MIM Holdings Ltd. (2000a)].

In addition, Copper Refineries Pty. Ltd (a subsidiary company within the MIM group) markets the Isa process for copper refining [MIM Holdings Ltd. (2000a)].

Table 10.1 below, indicates that the major activities of MIM take place in Australia (in the Northern Territory (N.T.) and Queensland (Qld.)), Germany, Argentina and the United Kingdom.

Country	Site and Area	Major activities
Argentina	Alumbrera	Copper-gold mining
Australia	Abbot Point, Qld.	Coal port for exports from Newlands and Collinsville mines
	<i>Bowen, Qld.</i>	<i>Metallurgical and nut coke production</i>
	Brisbane, Qld.	Head office
	<i>Collinsville, Qld.</i>	<i>Steaming and coking coal production</i>
	Dalrymple Bay, Qld.	Coal port for coking coal from Oaky Creek coal mine
	Ernest Henry, Qld..	Copper-gold mining and concentrate production
	George Fisher, Qld.	Zinc-lead-silver mine project
	<i>Hilton, Qld.</i>	<i>Zinc-lead-silver ore mining</i>
	<i>McArthur River, N.T.</i>	<i>Zinc-lead-silver ore mining and concentration</i>
	<i>Mount Isa, Qld.</i>	<i>Zinc-lead-silver ore mining, concentration and smelting; copper ore mining and concentration</i>
	Newlands, Qld.	Steaming and coking coal production
	Oaky Creek, Qld.	Steaming and coking coal production
	Ravenswood, Qld.	Gold mining
	<i>Townsville, Qld.</i>	<i>Copper smelting; management of port operations and materials from/to Mount Isa</i>
Germany	Duisberg	Zinc-lead concentrate smelting and lead bullion production
Japan	-	Metals and coal marketing
United Kingdom	<i>Avonmouth</i>	<i>Zinc, mixed and lead concentrate smelting; lead bullion, refined cadmium and zinc production</i>
	<i>Northfleet, Kent</i>	<i>Refined primary lead and lead alloys, plus refined primary silver and silver doré production.</i>
	Wakefield, Yorkshire and Northfleet, Kent	Secondary lead recycling and refined secondary lead and lead alloy production
Notes:		
Italics indicate activities which have been modelled as part of the case study.		
Only some of the activities at Townsville have been modelled.		
Additional operations have also been modelled (as indicated in sections 10.3 and 10.4).		

Table 10.1: Geographical locations of the principal activities of MIM Holdings Limited [Modified from MIM Holdings Ltd. (1998, 2000, 2000a)]

In common with many global mining groups, MIM acts as a holding company, with a number of subsidiary companies operating within the group umbrella. Whilst the day-to-day and other operation specific decisions fall within the remit of these companies, MIM adopts a strategic role, in its capacity as the agent of shareholders, strongly influencing such decisions through the setting of their bounds [Cowell et al. (1999)]. Hence, the different activities listed in Table 10.1 are conducted by various different subsidiary companies, operating within the group, some which are owned jointly with other companies. For example, MIM owns 75% of Collinsville Coal Pty. Ltd. and 70% of McArthur River Mining Pty. Ltd.

Table 10.1 also indicates that the major focus of MIM's principal activities is in Australia. Figure 10.1 below, indicates their approximate geographical location.

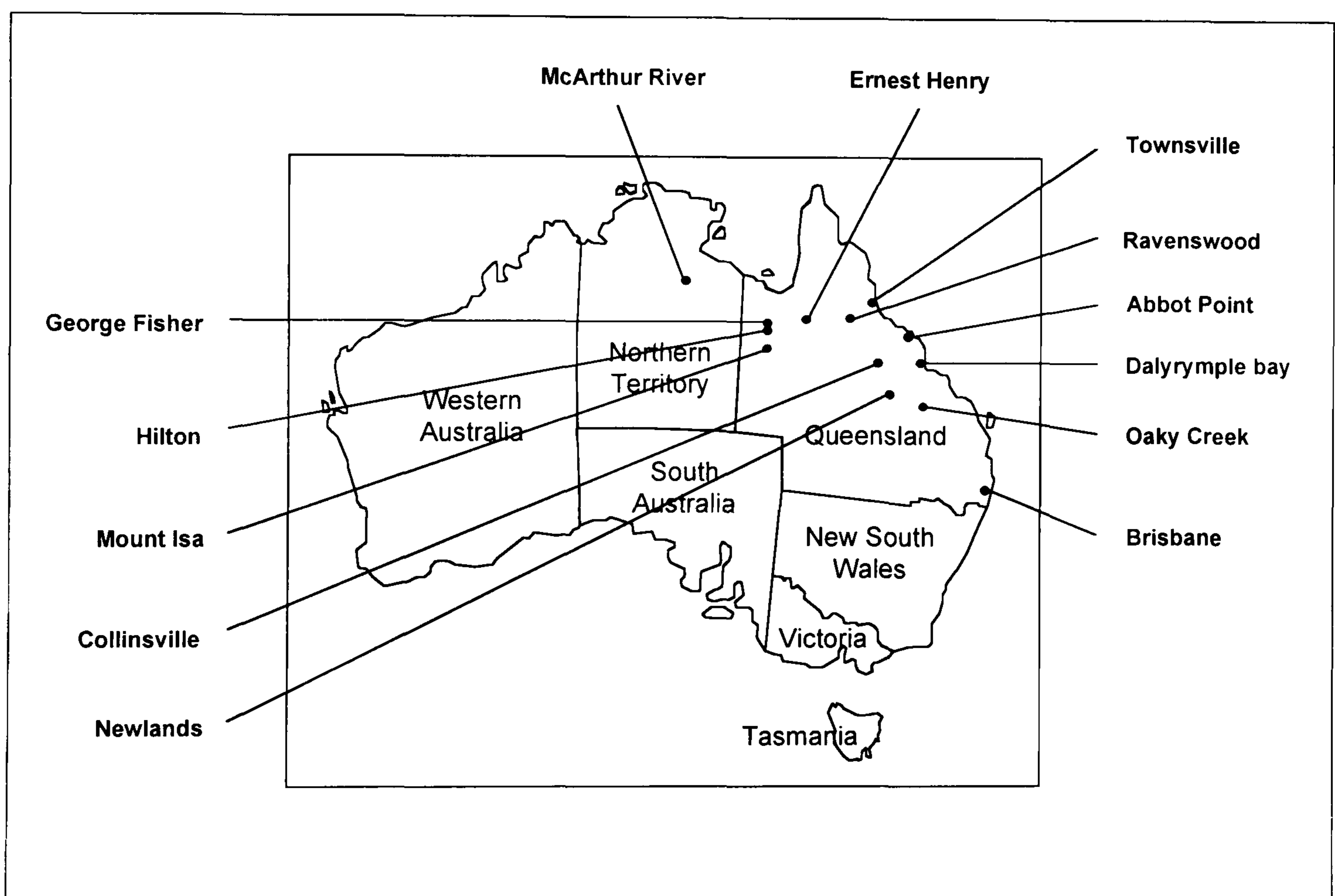


Figure 10.1: Approximate geographical locations of the MIM Holdings Limited Australian operations [Modified from MIM Holdings Ltd. (1998)]

Of these areas, the greatest concentration of MIM activities is at Mount Isa, Qld. Operations there, date back to 1923 when John Campbell, a lone prospector, discovered lead ore in the locality. Currently, the underground mine at Mt. Isa is the largest in

Australia and one of the largest in the world [MIM Holdings Ltd. (2000a)]. The outputs from Mt. Isa alone, make it the third largest producer of lead, fifth largest producer of silver, and the tenth largest producer of copper and zinc [MIM Holdings Ltd. (2000a)]. Mt. Isa is also one of the few places in the world where copper, zinc, lead and silver all occur in close proximity.

Current activities at Mt. Isa are associated with the copper stream and zinc-lead-silver stream throughputs. Copper stream activities include:

- the mining of copper ore in the Copper, Deep Copper and Enterprise mines,
- copper concentrate production from the ores, and
- smelting of the concentrate to remove the sulphur and iron impurities.

The copper cathode produced from the smelting process, is then railed to the Townsville copper refinery. This refinery, which uses the Isa Process to produce 99.99% pure copper anode, has recently been expanded and now has a capacity of 270,000 tonnes per year [MIM Holdings Ltd. (2000a)].

Zinc-lead-silver stream ores are mined not only at Mt. Isa, but also at the Hilton and George Fisher mines, which are about 20 km north of the city. However, the zinc and lead concentrate production processes for all three ore sources take place within the Isa central processing complex. The zinc concentrate, thus produced, is railed to the port at Townsville and sold on to external customers. However, the lead concentrate is smelted at Mt. Isa to produce an 'Isa crude lead bullion'. This is then also railed to the port of Townsville. From there, it is shipped to Britannia Refined Metals Limited (BRM) at Northfleet, UK, where it undergoes final refining.⁷⁹ BRM is also an MIM company.

In 1999, the major sources of sales revenue for the MIM group were: copper 31%, zinc 23%, coal 23%, lead 8%, by-product gold 8% silver 6%, and Ravenswood gold 1% [MIM Holdings Ltd. (2000a)]. These revenues were derived from its three major business areas, namely:

⁷⁹ BRM primary lead refining operations, including the Isa crude lead bullion throughput, have been modelled in detail in this case study. A detailed description of BRM operations has been provided in section 9.2.2.1 of the BRM case study (chapter 9).

1. copper-gold,
2. zinc-lead-silver, and
3. coal [MIM Holdings Ltd. (2000a)].

These are summarised briefly below.

1. Copper-gold:

Copper and gold are mined at Mt. Isa and Ernest Henry (both in Qld., Australia), and at Alumbraera (Argentina). Smelting of both the Ernest Henry and Mt. Isa materials is conducted at Mt. Isa, and the subsequent refining at Townsville (both in Qld., Australia). Gold is also mined at Ravenswood, Qld., Australia.

The copper stream at Mt. Isa has recently been expanded. This expansion has involved:

- an upgrade of the copper smelter to a capacity of around 250,000 tonnes of copper anode per year, and
- the opening of the Enterprise mine at Mt. Isa, a new copper ore source [MIM Holdings Ltd. (2000a)].

The Ernest Henry copper-gold mine (owned jointly between MIM 51% and Pasminco 49%) began operations in 1997. Extraction of the ore is by an open cut operation. The mine plant has a capacity to produce approximately 350,000 tonnes of concentrate per year, containing 350,000 tonnes of copper and 120,000 Troy ounces of gold. The concentrate, which is produced on-site, is transported by road to Mount Isa for smelting [MIM Holdings Ltd. (2000a)].

Nolan's open cut gold mine at Ravenswood is approximately 90 km south of Townsville. It is owned and managed by Carpentaria Gold Pty. Ltd. (MIM 50.1%) and Haomina Mining N.L. (49.9%). Operations are expected to terminate at Nolan's mine in 2000/2001. However, MIM will continue to mine gold in the adjacent Sarsfield area [MIM Holdings Ltd. (2000a)].

The Alumbreira mine, in the north-west of Argentina, is one of the largest open cut copper and gold mines in the world. MIM owns 50% of the operating and management company, Minera Alumbreira Limited (MAA). The other 50% is shared between North Limited of Australia and Rio Algom of Canada. Alumbreira began commercial production in 1998. A 15 year mine plan was issued in 1999, which provides for an average production rate of 178,000 of contained copper in concentrate, and 590,000 Troy ounces of gold.

2. Zinc-lead-silver:

The lead component of this stream is the primary focus of this case study. Operations are reviewed in detail in section 10.3. However since 1998, the principal period of focus in the modelling, the George Fisher Mine has commenced operation. It utilises the existing Hilton mine infrastructure and exploits ore bodies adjacent to the Hilton mine itself. MIM Holdings Ltd. (2000a) note that a recent study has indicated it has the potential to “sustain a high level of production for 10 years”.

Future iterations of the modelling will, therefore, need to take full account of this change.

3. Coal:

MIM mines coking coal at Oaky Creek, Qld., steaming coal at Newlands, Qld., and both coking and steaming coal at Collinsville, Qld. All three mines are situated in Queensland's Bowen Basin.

The Oaky Creek coal mine is a joint venture between MIM (75%), Sumitomo (15%) and Itochu (10%). It comprises three underground operations which produce 7 million tonnes of coking coal per year. All raw coal is washed prior to being transported to port facilities at Dalrymple Bay and Gladstone, Qld. [MIM Holdings Ltd. (2000a)].

The Newlands and Collinsville mines are a joint venture between MIM (75%) and Itochu (25%) [MIM Holdings Ltd. (2000a)]. The Newlands mine produces 7 million tonnes of steaming coal per year from both underground and open cut operations [MIM Holdings

Ltd. (200a)], and the Collinsville mine 3 to 4 million tonnes per year from open cut operations [MIM Holdings Ltd. (2000)].

The output from Newlands and a proportion of the output from Collinsville is sent to Abbot Point, a deep water port facility dedicated to handling coal from these two sources. In addition, a proportion of the steaming coal from Collinsville is sent by rail to Mica Creek power station (MCPS), which is near Mt. Isa, and a proportion of the coking coal is sent by rail to Bowen Coke Limited (BCL), at Bowen, Qld., where it is converted into nut and metallurgical coke. The metallurgical coke produced at BCL is then transported to Mt. Isa where it is used in smelting operations.

The Collinsville coal mine, Bowen coke works and the transports of coal and coke to and from these facilities are modelled in the case study. Hence, a more detailed description of the operations is provided in section 10.3.

10.3. Life cycle of MIM primary lead products

10.3.1 Overview

There are two distinct sources of ore and sequences of production processes, under the direct control of MIM, which have been modelled in detailed. These are:

- 1) The McArthur River/BZL stream (whose ore source is at McArthur River).
- 2) The Hilton/Mt. Isa stream (whose ore sources are at Hilton and Mt. Isa).

Whilst the final refining of both streams takes place at BRM in Northfleet, Kent, UK, the production sequences and supply chains for the two streams are separate. This is because the refining processes for the two streams take place in different facilities on the site. Also, even though the facilities for the extraction and treatment of the silver by-product from the two streams are shared, processing of the two streams is conducted separately. Hence, the two streams are, in effect, entirely separate right up until the point where the refined lead and lead alloys are produced.

Figure 10.2 indicates the main sequences of processes which are involved. It also shows some of the major ancillary processes which have been modelled using site specific data.

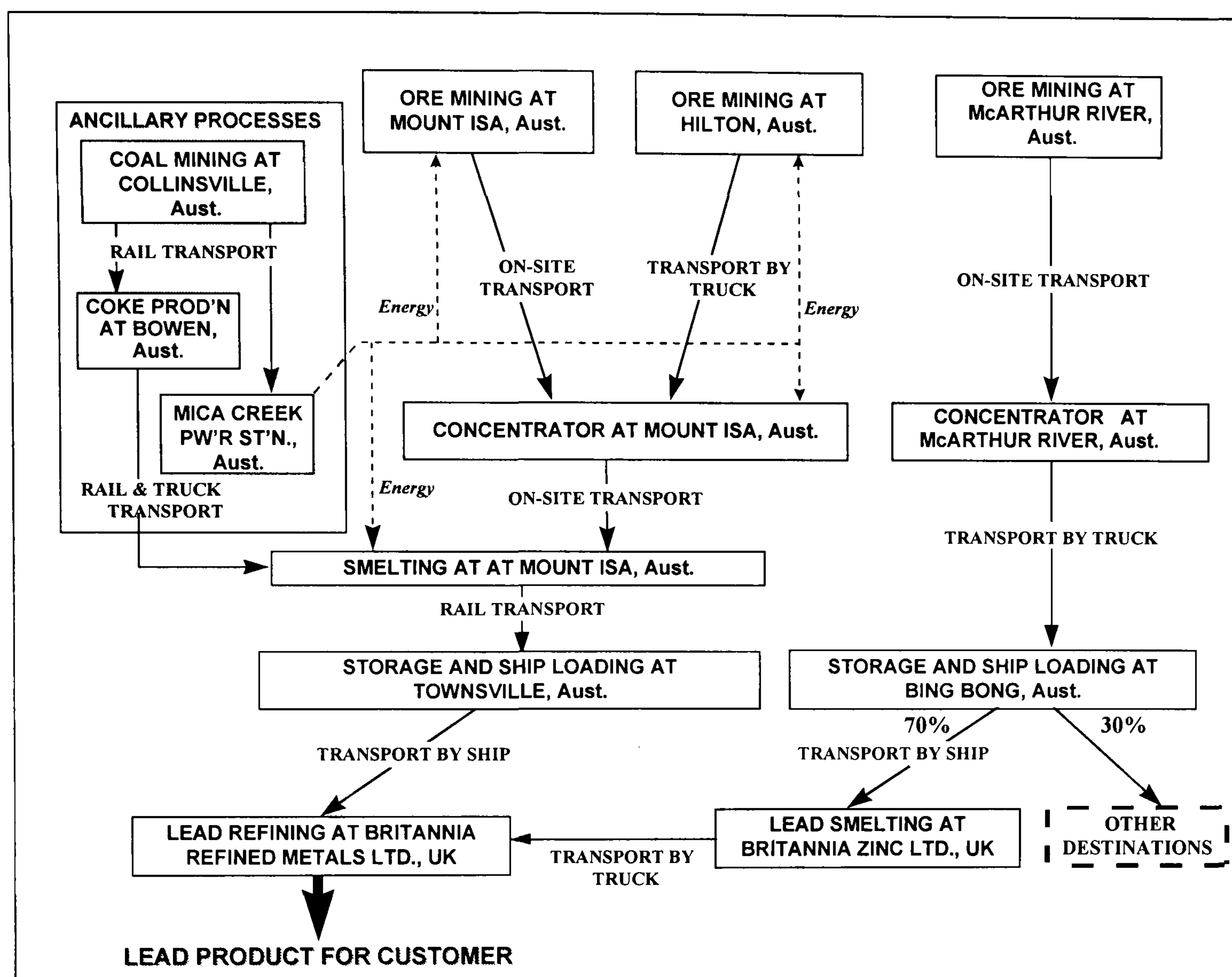


Figure 10.2: Summary of the major modelled processes in the life cycle of MIM lead products

Details of the processes and the manner in which they have been modelled is provided in sections 10.3.2 and 10.3.3, which consider the McArthur River/BZL streams and the Hilton/Mt. Isa streams respectively.

The production of refined primary lead and lead alloys from bullion from the two streams is reviewed in the BRM case study in section 9.3.1 of chapter 9. Hence, a review of these processes and an explanation of the manner in which they have been modelled is not provided in this chapter. Since the modelling of the BRM operations in this case study and in the BRM case study is exactly the same, it should be referred to for process and modelling information.

The main purposes of the modelling, with respect to the McArthur River/BZL and Hilton/Mt. Isa streams, are to:

- model, in detail, the McArthur River/BZL and Hilton/Mt. Isa stream processes, and
- identify in both the foreground and background systems, the environmental burdens, resource consumptions and the potential environmental impacts associated with each of these processes and with the stream as a whole.

It is necessary, therefore, in the foreground modelling to account not only for the exchanges associated with the main processes themselves, but also for all other associated:

- transport steps,
- overheads and
- other directly associated processes, such as site electricity generation.

The aim is to produce a modelling approach, which will be used by MIM companies for ongoing environmental management. Hence, the disaggregation of the McArthur River/BZL and Hilton/Mt. Isa stream operations, into the individual processes as indicated above, has been conducted in consultation with personnel not only at the site level (with those charged with managing the individual processes), but also at the executive management level within MIM (with those charged with overseeing the entire cradle-to-gate life cycle of MIM's lead products). This approach was adopted by the author, because these groups of people are intended to be the principal users of the model and one of the aims throughout has been to build a structure which best reflects their needs.

The background part of the system, associated with the streams, consists of those production processes (for ancillary materials and fuels) and those waste handling processes, not directly under the control of MIM companies. As with the processes under direct control, each ancillary production process is modelled back its respective 'cradles', as raw materials. Similarly, each the ancillary waste handling process is also modelled forward to its respective 'graves', as final wastes. Such modelling is conducted, using LCI data modules, intended to represent the average environmental burdens and resource

consumptions, and potential environmental impacts associated with each of these background processes.

Crude Pb bullion produced by MHD, at Duisberg in Germany, is also refined by BRM. In the current modelling, this has been treated as being in the background, and not the foreground part of the system, even though MHD is an MIM company. This occurred, because at the time when the data collection was first planned, the author had been led to believe that MIM were to sell their interests in MHD. Since this has not happened, MHD bullion production operations should be included within the foreground, in future iterations of the modelling.

10.3.2. McArthur River/BZL stream⁸⁰

The output from McArthur River stream operations is bulk concentrate⁸¹ with a typical assay of Zn: 44.5%, Pb: 12.0%, Cu: 0.85%, Cd: 0.12% and S: 28.0% by mass.⁸² The concentrate is shipped principally to BZL, Avonmouth, UK (approximately 70% by mass of output), but also to Pasminco at Cockle Creek, N.S.W., Australia and various other processing facilities. The ore, from which the McArthur River bulk concentrate is obtained, is mined underground at McArthur River, N.T., Australia and bulk concentration is also conducted, on the surface, at the site. The bulk concentrate is then transported by road train to port facilities at Bing Bong, on the coast of the Gulf of Carpentaria, N.T., Australia. Here, it is stored in a dedicated warehouse. The ships which transport the concentrate to the UK and to other processing facilities around the world, anchor 30 km out to sea in the Gulf. They are loaded, at anchor, with the concentrate by a purpose-built self-unloading barge, which ferries the concentrate from the warehouse at Bing Bong to the waiting ships. Transport of the bulk concentrate to the UK and its further processing by BZL are considered in sections 10.3.2.4 and 10.3.2.5 respectively.

⁸⁰ To reflect, broadly, the terminology used by the companies involved, the stream is known as the 'McArthur River stream', and the 'BZL stream' when referring Australian and UK operation respectively.

⁸¹ Bulk concentrate is also known as mixed concentrate.

⁸² Source: BZL concentrate usage plan for 1999. This was enclosed in volume 3 of the Portfolio, but has not been included with this copy of the thesis.

Figure 10.3 indicates the locations of the McArthur River stream Australian operations.

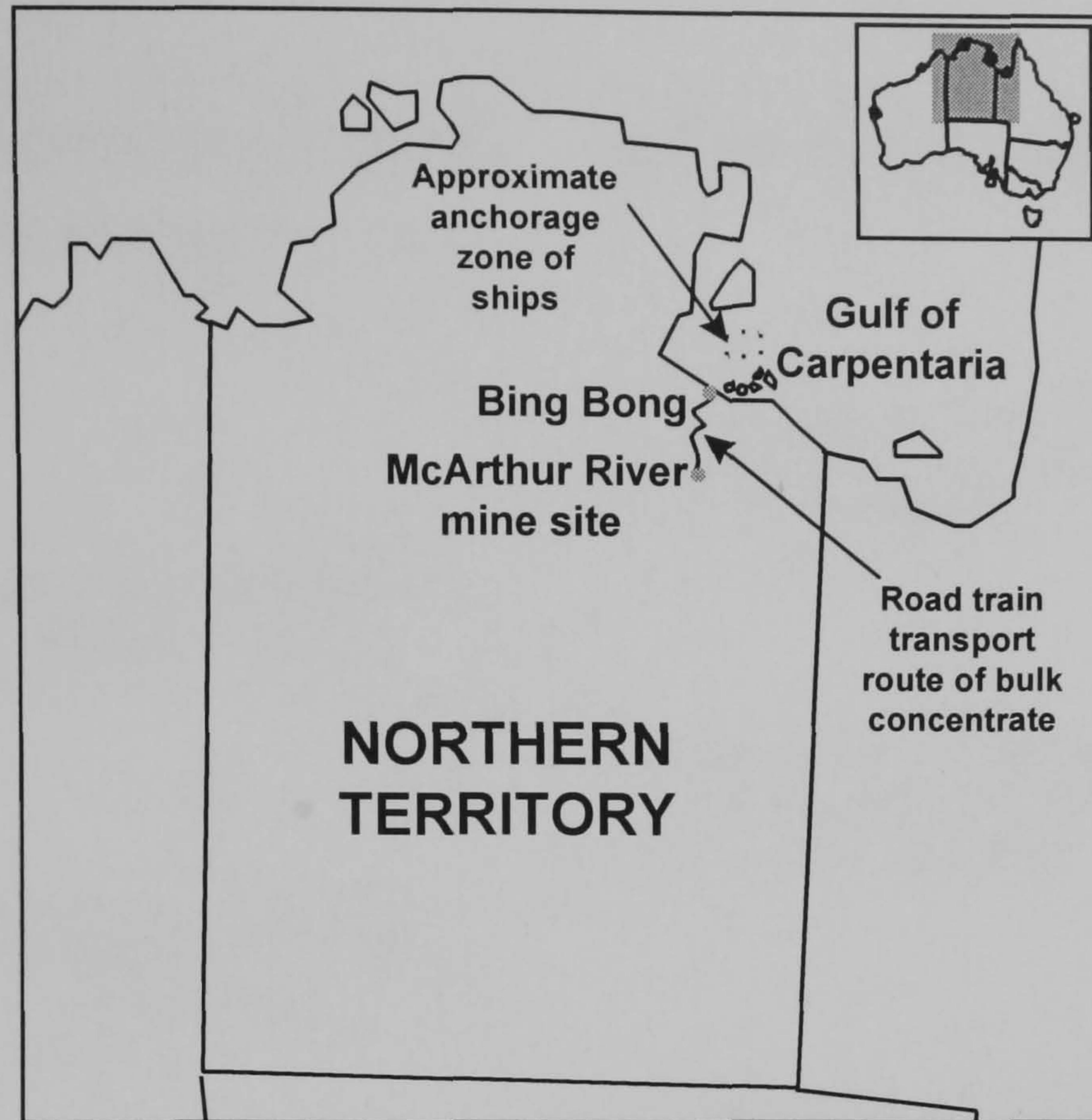


Figure 10.3: McArthur River stream operations in the Northern Territory of Australia

The overall processing sequence may be summarised as in Figure 10.4.

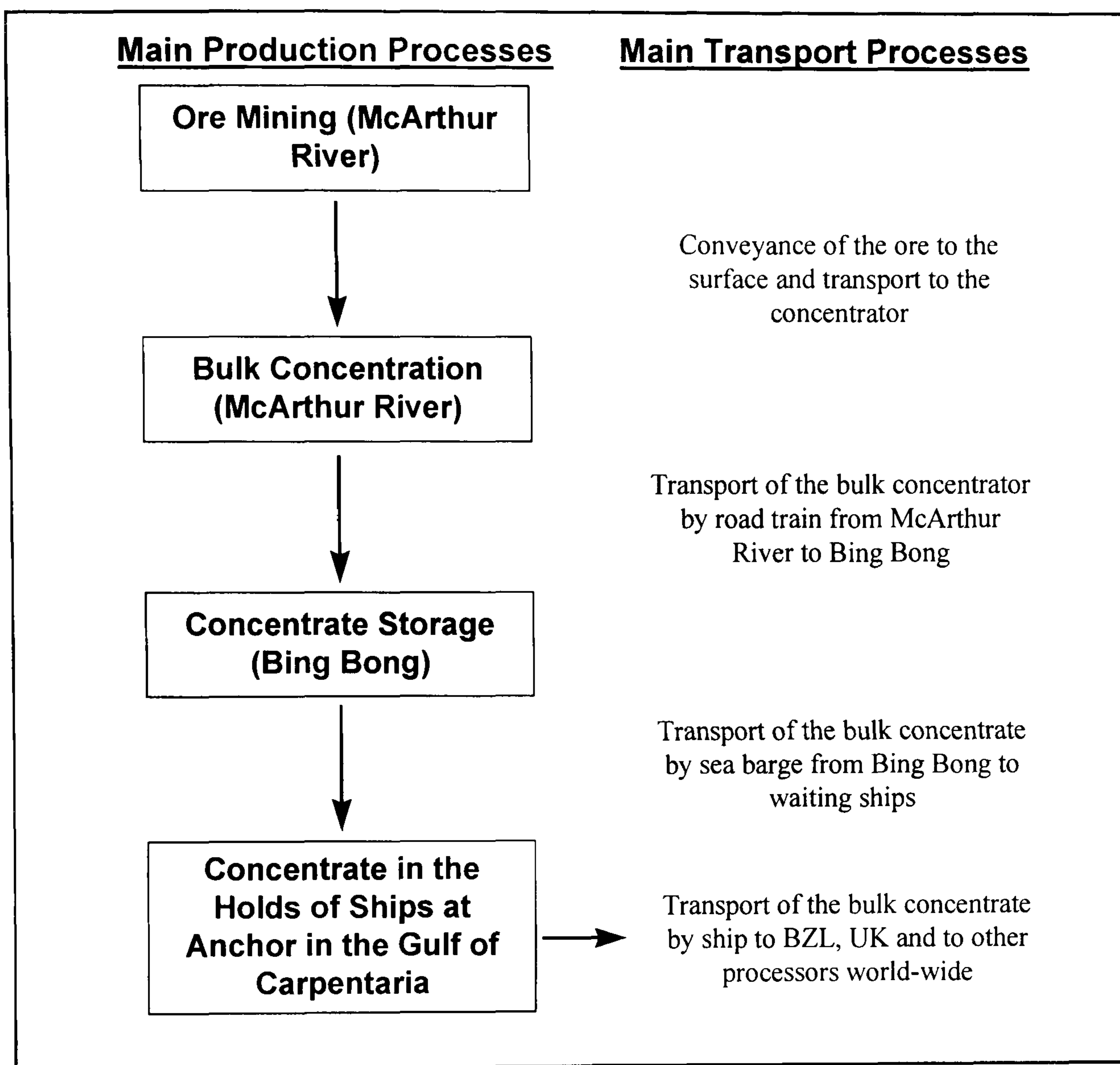
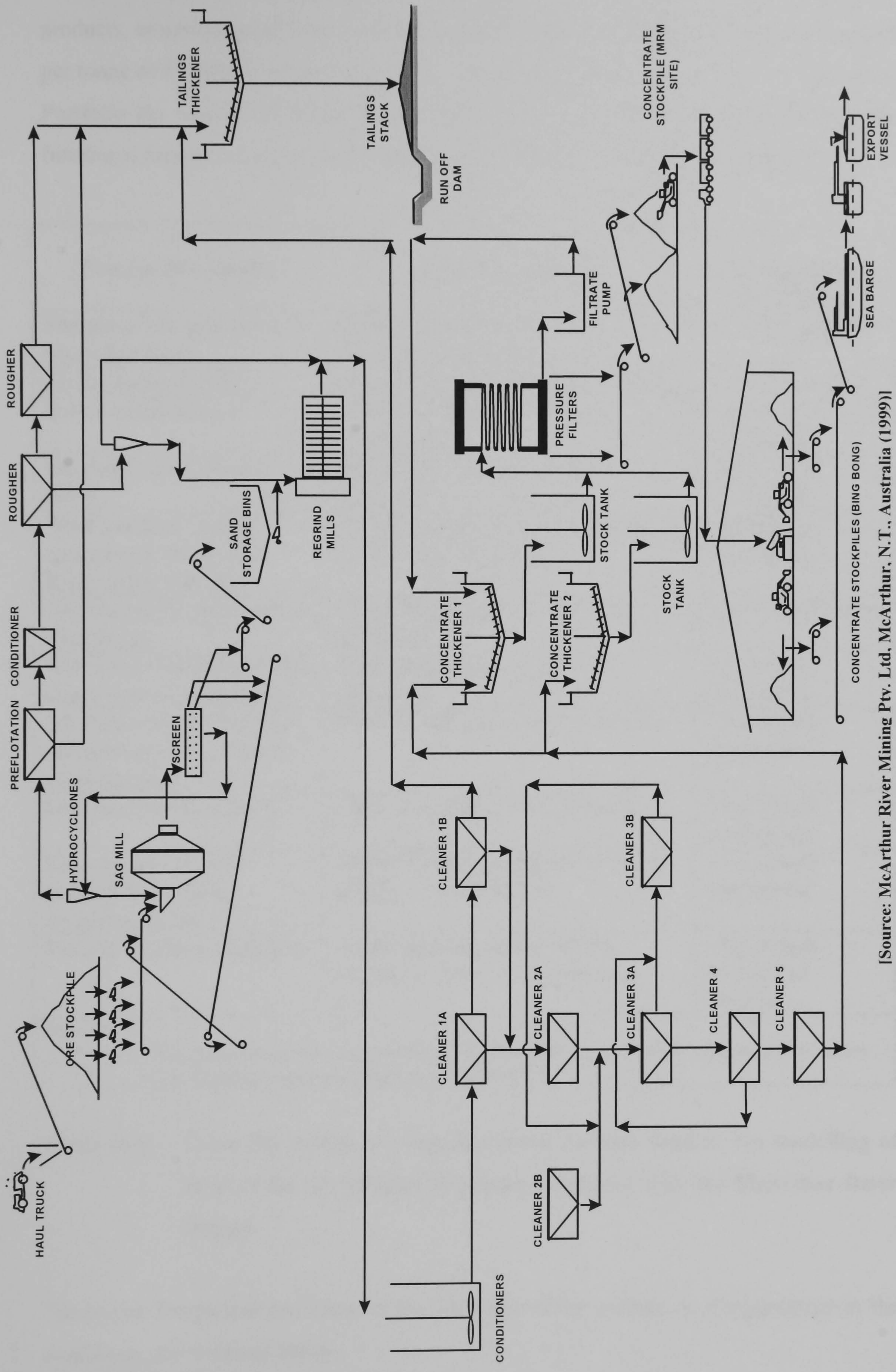


Figure 10.4: Summary of main McArthur River stream processes in Australia

These processes are indicated schematically in Figure 10.5 overleaf.



[Source: McArthur River Mining Pty. Ltd, McArthur, N.T., Australia (1999)]

Figure 10.5: Main processes comprising the McArthur River stream

The gross inputs (i.e. consumptions) and outputs (i.e. products, co-products and by-products, emissions and wastes), as well as the respective normalised inputs and outputs per tonne of functional output are given in the input/output Excel files, also enclosed in the Portfolio (in volume 3). These contain the data used for the life-cycle modelling. The functional outputs are different for each modelled process, as indicated in Table 10.2.

Process description	Excel file name (s)	Functional unit description
Site electricity generation at McArthur River	MRM, McArthur River -site electricity production	1 MJ of electricity
Zn-Pb-Ag ore mining	MRM, McArthur River -Ore mining	1 kg of mined ore
Bulk concentration	MRM, McArthur River -Bulk concentration	1 kg of bulk concentrate
Overheads at McArthur River	MRM, McArthur River -site overheads	1 kg of bulk concentrate
Road transport of bulk concentrate (McArthur River to Bing Bong)	Included within: MRM, McArthur River -Transport data	1 kg of bulk concentrate
Site electricity generation at Bing Bong	CMS, Bing Bong -site electricity generation	1 MJ of electricity
Warehouse handling of bulk concentrate at Bing Bong	CMS, Bing Bong -wharf side operations	1 kg of bulk concentrate
Sea barge transport of bulk concentrate (Bing Bong to awaiting ship)	CMS, Bing Bong -barge operations	1 kg of bulk concentrate
Overheads at Bing Bong	CMS, Bing Bong -site overheads	1 kg of bulk concentrate
Sea transport of bulk concentrate to BZL, Avonmouth, UK	MRM Mixed Concentrate Shipping to BZL - Transport data	1 kg of bulk concentrate
Various ancillary transports	All are detailed within: MRM, McArthur River -Transport data	1 kg of each transported material ¹
<p>Note:</p> <p>1 These include both the transports for materials required by each major process, and the return of the empty transport containers, where applicable.</p>		

Table 10.2: Excel file names and the functional outputs used in the modelling of each of the foreground processes associated with the McArthur River stream

The major foreground processes of the McArthur River stream, as disaggregated in the modelling, are reviewed below.

10.3.2.1. Ore mining, bulk concentration and other associated processes at McArthur River

The McArthur River mine, bulk concentrator and mine camp, which are operated in McArthur River Mining Pty. Ltd. (MRM), are owned jointly between MIM (70%) and ANT Minerals (30%). The latter are a consortium of several Japanese companies). The site was brought into production in 1995 [MIM Holdings Ltd. (2000)].

a) Site electricity generation:

Electric power for the site is provided by a natural gas power plant, which has a generation capacity of 22MW and consists of six gas turbine generator sets and one gas engine generator set. The power plant is wholly owned and operated Energy Developments Limited [EDL (1999)]. Gas is supplied by high pressure pipeline from the Palm Valley field, in the Amadeus Basin (N.T.).

b) Ore mining:

The zinc-lead-silver ore, which is mined underground and hauled to the surface, is contained within stratiform deposits of sphalerite (ZnS) and included galena (PbS) [Perkins and Bell (1998)]. The ore is fine grained, with a typical P_{80} of $7\mu\text{m}$ and a P_{50} of $3\mu\text{m}$. Also associated with the ore, are significant quantities of pyrite (FeS_2), silicon dioxide (SiO_2), chalcopyrite (FeS_2) and feldspar (Al_2O_3). Currently, the higher grade No. 2 ore body is being selectively extracted. However, it is planned, that the No. 3 and No. 4 ore bodies, which are between 170 and 400 metres below the surface, will also be mined in due course [MIM Holdings Ltd. (2000)].

Access to the ore is by two declines. One is used by personnel and for the transport of equipment, whilst the other is equipped with a conveyor, to transport the ore to the surface. Mining development is by the room and pillar technique, using drill and blast methods [MIM Holdings Ltd. (2000)]. Mucking is by diesel powered low profile loaders. These tip

the broken ore into 50 tonne haul vehicles, which then transport it to an underground crusher. This reduces the particles to less than 200 mm diameter [MIM Holdings Ltd. (2000)]. The crushed ore is then conveyed to the surface. Mullock (the non-ore overburden material, which has to be removed to gain access to the ore itself) is deposited, as a fill, in worked out areas. Currently, all fill is dry fill.

Quantities of various supply materials are also used for the construction and maintenance of the mine shafts etc. underground. They are, however, heterogeneous in their composition and mass. Hence, it has not been possible to model them, currently. Nevertheless, they are a significant concern.

Mine ventilation is achieved using atmospheric air driven through the workings by fans via a single down cast vent. There are two exhaust (i.e. up cast) vents. Monitoring of the composition of the exhaust emissions from these vents is not conducted. This is because they are not currently considered to be of major concern. However, general monitoring of dust fall out around the site is conducted on a routine basis.

The MRM water balance sheet (as of October 1998)⁸³ indicates that approximately 65m³ of water are extracted from underground per 147 tonnes of ore mined⁸⁴ (i.e. approximately 0.44 m³/tonne of ore mined). This is sent to a decant pond, and 55 m³ are returned back underground (i.e. 0.37 m³/tonne). In addition, 91 m³ of water per 147 tonnes of ore mined (i.e. 0.63 m³/tonne of ore mined) are obtained from bore holes and/or from the tailings run off area and conveyed to the decant pond. The balance of the water (i.e. 101 m³ per 147 tonnes, which is equivalent to 0.69 m³/tonne) is used by the concentrator.

c) Bulk concentration:

The mined ore is stockpiled prior to being processed by the bulk concentrator, which has a capacity to treat 150 tonnes of ore per hour [MIM Holdings Ltd. (2000)]. Grinding of the ore is a two stage two stage process. Initial grinding takes place in the semi-autogenous

⁸³ This was enclosed in volume 3 of the Portfolio, but has not been provided with this copy of the thesis.

⁸⁴ The data are cited per tonne of ore processed by the concentrator. However, as the stockpiles of ore waiting to be processed by the concentrator are kept relatively low, the amount of ore mined and processed, over the course of a year, are considered here to be equal.

grinding (SAG) mill, which reduces the particle size to 46 μm approximately.⁸⁵ The output from the mill is then screened. The various coarser particle size fractions are conveyed either directly to storage bins, and subsequently processed further in regrind mills, or are returned directly to the SAG mill for further grinding. The finer fraction from the screening, however, is conveyed to hydrocyclones. Here, the larger sized particles are again separated off and returned to the SAG mill for further grinding, whilst the finer fraction, is processed via a flotation circuit.

The stages in this circuit consist of preflotation, followed by conditioning and roughening. These cause the 'value' containing particles (i.e. those containing zinc-lead-silver compounds) to be wetted selectively and to attach themselves to bubbles, which move through the agitated slurry. The resulting froth (which contains the raw concentrate) is collected in the rougheners. Flotation is conducted using 16 m^3 mechanical flotation cells, and the bubbles in the slurry are caused by air being passed through it at a rate of 70 to 90 m^3 per minute [MIM Holdings Ltd. (2000)]. The non-value containing particles remain in the water column.

The particles comprising the concentrate are further reduced, by the regrind mills, to a typical particle size of 8 μm approximately.⁸⁶ They are then further conditioned, cleaned and thickened to a dense slurry, using two 25 m diameter high rate thickeners. Storage of the bulk concentrate, thus produced, is within two 423 m stock tanks [MIM Holdings Ltd. (2000)].

The main reagents used in flotation are:

1. Sodium isobutyl xanthate (SIBX), which acts as a collector for sphalerite and galena.
2. Methyl isobutyl carbinol (MIBC), which acts as a frother.
3. Copper sulphate, which acts as an activator for the sphalerite.
4. Baymin and Tanigan, which are used for the depression of pyrite.
5. Quicklime, which is used for pH adjustment.

⁸⁵ This is the mean of the monthly average measurements calculated by the author from data recorded by MRM for the calendar year 1998.

⁸⁶ This is the mean of the monthly average measurements calculated by the author from data recorded by MRM for the calendar year 1998.

Finally, the concentrate is passed through pressure filters, to lower their water content. This is conducted using two 132 m² Larox pressure filters, which de-water the concentrate to 12% moisture approximately [MIM Holdings Ltd. (2000)]. After filtration, the concentrate (which is a 'bulk concentrate') is stockpiled, on-site, prior to being conveyed to Bing Bong by road train. The tailings (the non-value waste particulate materials), which are produced from preflotation, roughening and concentrate cleaning, are allowed to settle in a 20 m diameter tailings thickener prior to final disposal in the 380 Ha tailings run off dam area [MIM Holdings Ltd. (2000)].

The process of bulk concentration requires significant quantities of water. Most is provided through the extensive recycling system for process water, which ensures that in excess of 80% of such water is recycled [MRM (1998)]. However, 101 m³ per 147 tonnes of ore processed (i. e. 0.63 m³/tonne of ore processed) are also needed. As indicated earlier, this is obtained from the underground workings, from bore holes and/or from water reclaimed from the tailings run off dam. In addition, the water balance sheet (as of October 1998) indicates that 3 m³ of water per 147 tonnes of ore processed (i.e. 0.02 m³/tonne of ore processed) are entrained, as moisture, within the ore feed material to the concentrator. The vast majority of water losses from the concentrator are through the tailings stream, as it accounts for 97 m³ per 147 tonnes of ore processed (0.66 m³/tonne of ore processed),. Though, as noted above, some of this water may be reclaimed. In addition, 7 m³ per 147 tonnes of ore processed (0.048 m³/tonne of ore processed) leave entrained, as moisture, within the bulk concentrate.

d) Overheads of McArthur River site operations:

The overheads, which have been modelled separately in the LCA, are the fresh water and electricity consumptions associated with the mine camp at McArthur River. Currently, due to insufficient data, waste water emissions are not modelled.

e) Ancillary transports:

Natural gas transport to McArthur River is by gas pipeline. All other ancillary transports to the site are by road (at least in the final leg of their journeys to the site, where journeys are multi-stage). Several substances are transported to the site via the MIM mining and processing complex at Mt. Isa, Qld., Australia. However, many substances are also transported to the site direct from their suppliers.

All ancillary transports have been modelled as separate atoms.

10.3.2.2. Transport of bulk concentrate from MRM, McArthur River to CMS, Bing Bong

Until July 1998, both the road haulage of the concentrate from McArthur River to Bing Bong and the stockpile management and barge loading operations at Bing Bong were conducted by Universal Transport Operations (UTO). Carpentaria Shipping Services (CSS) operated the sea barge (i.e. the bulk carrier), which ferries concentrate between Bing Bong and the waiting vessels [MRM (1998)]. In July 1998, however, the contracts were modified as follows. The contract for road haulage of the concentrate was awarded to Hampton Transport Services Pty. Ltd. (HTS) and CSS (now called Carpentaria Management Services (CMS)) were awarded the contract for all of the other functions.

MRM, HTS and CMS have a 'No Spills Policy' for all concentrate handling operations. In this policy, a spill is defined as the loss of concentrate or fuel into the external environment. Hence, equipment and operating procedures have been designed to avoid such spills for the range of expected normal operating conditions and for some extraordinary conditions, including a 1 in 100 year average return interval storm event [MRM (1998)]. MRM, HTS and CMS are also committed to monitoring systematically and reviewing the performance of operations in regard to this 'No Spills Policy' [MRM (1998)].

Thus, to minimise spillage, the loading of the road trains, which convey the bulk concentrate from the MRM site to Bing Bong:

- is conducted under cover,
- the road trains are positioned pre-determined marks to ensure correct alignment of the trailers,
- there are spillage plates on the concentrate load barrier to contain any spillages within the shed,
- the front end loader bucket is sized to the requirements of the various sizes of the trailers,
- there is a ‘weigh-in-motion’ scale on the front end loader to advise operators on the amount of product being loaded, and
- the road trains (and all other vehicles) leaving the loading compound have to pass through a wheel wash [MRM (1998)].

The road trains consist of six purpose designed, covered side-tipping trailers with a payload of 140 tonnes approximately [MRM (1998)]. After delivery, the road trains return unladen to the mine site. The distance each way between the mine site and Bing Bong is 120 km approximately.

10.3.2.3. Bulk concentrate handling and other associated processes at Bing Bong

At Bing Bong, the main processes modelled are:

- the wharf side handling operations at Bing Bong,
- site electricity generation at Bing Bong,
- ocean barge transport of the bulk concentrate from Bing Bong to ships at anchor in the Gulf of Carpentaria, and
- overheads associated these activities.

The transports of ancillary materials are also modelled separately.

a) Wharf side handling of bulk concentrate:

On arrival at Bing Bong, the road trains are driven onto the central ramp, which divides the covered shed into two. To minimise spillage the trailers are designed, so that when each discharges its cargo to a bay (either to the left or to the right of the ramp), it extends past the ramp edge, which thereby minimises spillage onto the ramp itself.

Other features of handling operations designed to minimise spillage, and hence to comply with the 'No Spills Policy', are:

- the road trains are aligned in pre-determined marked positions for tipping,
- the trailer tarpaulin system is inspected to ensure no concentrate is caught up in the system,
- there are written tipping instructions, and
- all vehicles leaving the compound have to pass through a wheel wash [MRM (1998)].

In addition, boot brushes are fitted at all pedestrian exits from the shed, to minimise the amount of concentrate being carried out on the boots of personnel.

The shed holds typically about 40,000 tonnes, though on occasion it may hold more than this.

Run off from the concentrate storage area is directed to the site run off pond. Up until the 1998/99 wet season, evaporation had been the only method by which water is removed from this pond. However, CMS has been investigating the possibility employing controlled spray irrigation on certain designated areas of the lease.

The ocean going barge, 'MV Aburri', is moored adjacent to the shed in a specially dredged berth. Bulk concentrate is picked up within the shed by a bucket wheel. This feeds concentrate onto a series of covered conveyors and then into a discharge boom, which reaches from the quay side and into the hold of the vessel [MRM (1998)]. An "Autodock" system secures the 'MV Aburri' in a set position relative to the wharf using a hydraulic claw and swing arm, which guarantees the precise location of the barge under the loading

chute. The loading process is managed by computer process control systems [MRM (1998)].

b) Site electricity generation at Bing Bong:

Electric power for the Bing Bong facility is produced using a diesel powered generator.

c) Overheads of operations at Bing Bong:

The only overheads, which have been modelled separately, are fresh water consumptions. Currently, due to insufficient data, waste water emissions are not modelled. Also, it has not been possible to disaggregate electricity consumptions associated with overheads from the total electricity consumption at Bing Bong.

d) Ocean barge transport of the bulk concentrate from Bing Bong to ships at anchor in the Gulf of Carpentaria:

The bulk concentrate carrier, 'MV Aburri', has a capacity of 3,500 tonnes, though it is usually loaded with about 3,200 tonnes. The barge is able to self-load from a discharge chute (connected by the aforementioned series of covered conveyors to the wharf side shed) at a rate of 1000 tonnes per hour. It is also able to self-unload at sea into ships anchored in the Gulf of Carpentaria, at a similar rate. The capacity of the receiving ships varies from about 6,400 to 45,000 tonnes [MRM (1998)].

The barge shuttles the concentrate from Bing Bong to the receiving ships, which anchor in a designated transfer offshore transfer zone (Latitude 15⁰15' - 15⁰23' / Longitude 136⁰25' - 136⁰35'). The zone is 30 km, approximately, from the shore and has an average depth, at low tide, of 14.75 m (range 13 - 16.5 m) [MRM (1998)]. Once the barge reaches the waiting ship, it discharges the concentrate into the ship's hold using its boom [MRM (1998)].

e) Ancillary transports:

All ancillary transports to the site are by road (at least in the final leg of their journeys to the site, where journeys are multi-stage). Several substances are transported to the site via the MRM site at McArthur River and some also via the MIM mining and processing complex at Mt. Isa, Qld., Australia. However, some substances are transported to the site direct from their suppliers.

All ancillary transports have been modelled as separate atoms.

10.3.2.4. Transport of bulk concentrate by shipping from the Gulf of Carpentaria, Australia to BZL, Avonmouth, UK

The ships transporting the MRM bulk concentrate to BZL, Avonmouth, UK are Panama type ships and their route is via the Suez Canal. Other details on the actual route have not been ascertained by the author. However, the route and distance have been estimated on the assumption the ships will tend to follow, as much as possible, the recognised shipping lanes.

10.3.2.5. Sintering and smelting at BZL, Avonmouth, UK, and associated processes

The product and co-product outputs from the processing operations at Britannia Zinc Limited (BZL), Avonmouth, UK are:

- BZL crude lead bullion (with a typical assay of Pb: 96.15%, Cu: 3.1%, Ag: 0.4%, Bi: 0.16%, As: 0.16%, In: 0.014%, Au: 0.0013% by mass)⁸⁷,
- refined zinc,
- refined cadmium and
- sulphuric acid.

The crude bullion is further processed by Britannia Refined Metals Ltd. (BRM) at Northfleet, Kent, UK. The other co-products and by-products are sold to customers external to the MIM group. However, a proportion of the refined zinc and refined cadmium are used by BRM.

Figure 10.6 indicates the geographical location of the BZL operations in the UK.

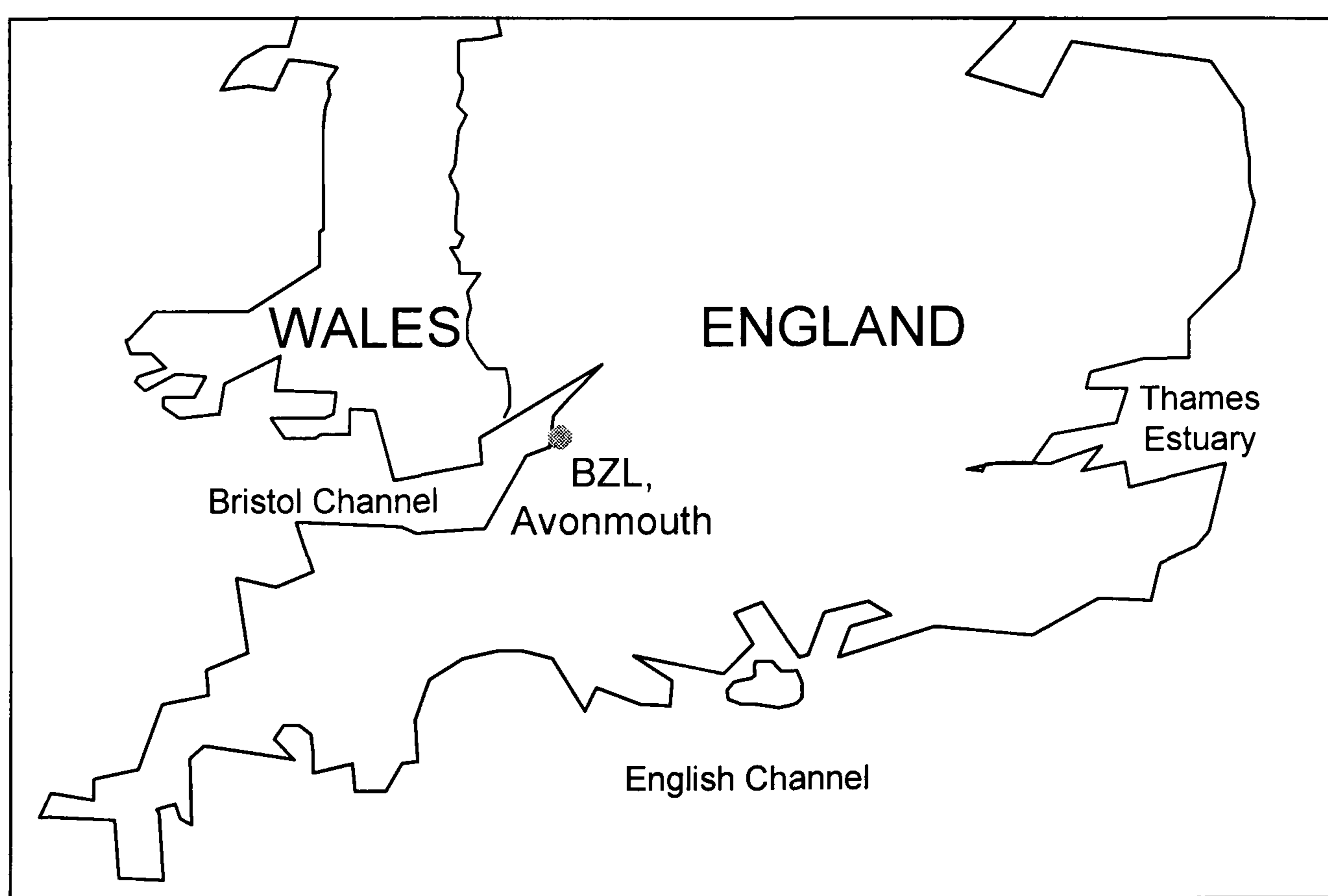


Figure 10.6: Location of BZL operations in the UK

⁸⁷ Calculated by the author from average assay data for the calendar year 1998, supplied by Phil Moore, BRM, Northfleet, Kent, UK. The Pb concentration is not measured directly by BRM. Therefore, it has been assumed to comprise the remainder, after deducting the contributions to the total of the other measured substances.

The processes at BZL, which are modelled, are summarised in Figure 10.7. However, they are highly integrated, with a large number of recycle streams both within and between them [UK EA (1999)].

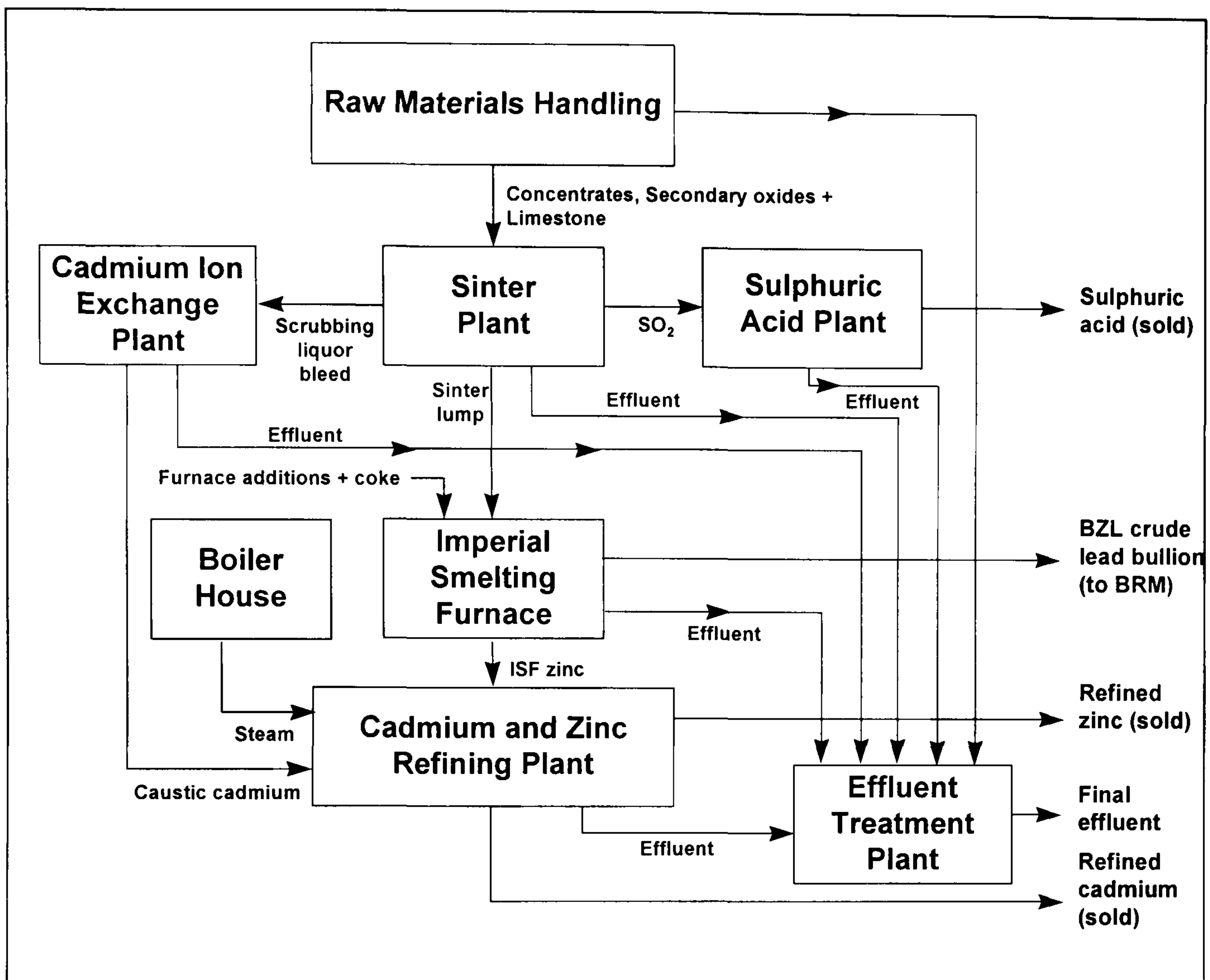


Figure 10.7: Main production processes modelled for Britannia Zinc Limited

The main purposes of the modelling, with respect to the BZL operations, are to:

- model, in detail, the BZL production and ancillary transport processes, and
- identify in both the foreground and background systems, the environmental burdens, resource consumptions and the potential environmental impacts associated with each of these processes and with the stream as a whole.

The Excel files, modelling each of the foreground processes and the names of their functional outputs are indicated in Table 10.3.

Process description	Excel file name(s)	Functional unit description
Raw materials handling	BZL, Avonmouth - Raw Materials Handling	1kg of sinter feed materials
Sinter production	BZL, Avonmouth - Sinter Process	1 kg of sinter lump and SO ₂ exhaust gas combined ¹
ISF zinc and crude lead production in Imperial smelting furnace	BZL, Avonmouth - Imperial Smelting Process	1 kg of ISF zinc and BZL crude lead bullion combined ¹
Sulphuric acid production	BZL, Avonmouth - H ₂ SO ₄ Plant	1 kg of sulphuric acid
Cadmium ion exchange	BZL, Avonmouth - Cd Ion Exch. Plant	1 kg of caustic cadmium
Steam production by boiler house	BZL, Avonmouth - Boiler House	1 kg of steam
Cadmium and zinc refining	BZL, Avonmouth - Cd & Zn Refinery	1 kg of refined zinc and refined cadmium combined ¹
Effluent treatment in on-site plant	BZL, Avonmouth - Effluent Treatment	1 litre of final effluent from BZL
Overheads associated with sulphuric acid production	BZL, Avonmouth - Overheads (H ₂ SO ₄ production)	1 kg of sulphuric acid produced
Overheads associated with refined cadmium production	BZL, Avonmouth - Overheads (refined Cd production)	1 kg of refined cadmium produced
Overheads associated with refined zinc production	BZL, Avonmouth - Overheads (refined Zn production)	1 kg of refined zinc produced
Overheads associated with BZL crude lead bullion production	BZL, Avonmouth - Overheads (Pb crude production)	1 kg of BZL crude lead bullion produced
Various ancillary transports	All are detailed within: BZL, Avonmouth - Transport data	1 kg of each transported material ²
Notes:		
1	These are combined according to the relative mass proportions of each of the outputs.	
2	These include both the transports for materials supplied by each major process, and for the disposal of wastes.	

Table 10.3: Excel file names and the functional outputs used in the modelling of each of the foreground processes at BZL

In addition to these foreground processes, it has also been necessary to model separately one of the background processes. This is the transport, compaction and disposal of office waste. This differs from the general practise which has been adopted for this case study. This is to model background processes using life-cycle inventory (LCI) data modules, which are intended to represent the average environmental burdens, resource consumptions and potential environmental impacts associated with each of these background processes. However, a suitable complete LCI data module for waste paper disposal was not available. Hence, it has been necessary to construct such background data using publically available data sources.

The major foreground processes associated with BZL, as disaggregated in the modelling, are reviewed below.

a) Raw Materials Handling:

The raw materials considered here are those used by the sinter plant. They consist of the following:

- zinc concentrates,
- lead concentrates,
- MRM bulk concentrate,
- mixed concentrates (other than MRM bulk concentrate), and
- limestone.

Over 75% of the feed materials for BZL are imported concentrates. These are unloaded from ships in the docks, about 1.5 km from the smelter, by kangaroo cranes equipped with clam type grabs to handle the concentrate [HMIP (1993)]. The raw materials handling process is considered to commence with the placing of concentrates onto the No. 1 conveyor [UK EA (1999)]. They are then transferred by a series of conveyors from the docks to storage bunkers at the BZL facility. The conveyors incorporate an automatic weighing facility. Also, all but the first two sections are covered and the transfer points between the belts are sealed to minimise the escape of dusts. There are 10 sections of belt [HMIP (1993)].

Limestone is delivered by road transport.

Materials are crushed to break up any lumps and are transferred to the sinter plant by conveyors, as required [UK EA (1999)].

b) Sinter plant:

The sinter plant prepares the feed materials into a suitable chemical form for the extraction of the metals in the Imperial smelting furnace. The process involves the feed materials being desulphurised and agglomerated into large lump form [UKEA (1999)].

The feed materials, consisting of concentrates, recycled sinter fines and other process materials, are proportioned and mixed, conditioned using small quantities of water and zinc sulphate [HMIP (1993)] and are then conveyed to the updraught sinter machine. Figure 10.8 is a simplified sketch of such a machine. Here, the material is ignited by a gas/oil burner and is roasted at up to 1200⁰C, whilst at the same time passing over a series of windboxes [UK EA (1999)]. The latter blow air through the mix, which causes the contained sulphur to be oxidised to sulphur dioxide, as given by:



The reaction is exothermic and the heat generated is sufficient to cause the material to partially melt and fuse. It is then broken into large lumps, screened, crushed and separated into two streams:

- the lumps (suitable for feeding into the Imperial smelting furnace) and
- the fines (which are recycled back into the sinter feed after mixing with dewatered sludge from gas cleaning equipment in different sections of the BZL complex) [UK EA (1999), HMIP (1993)].

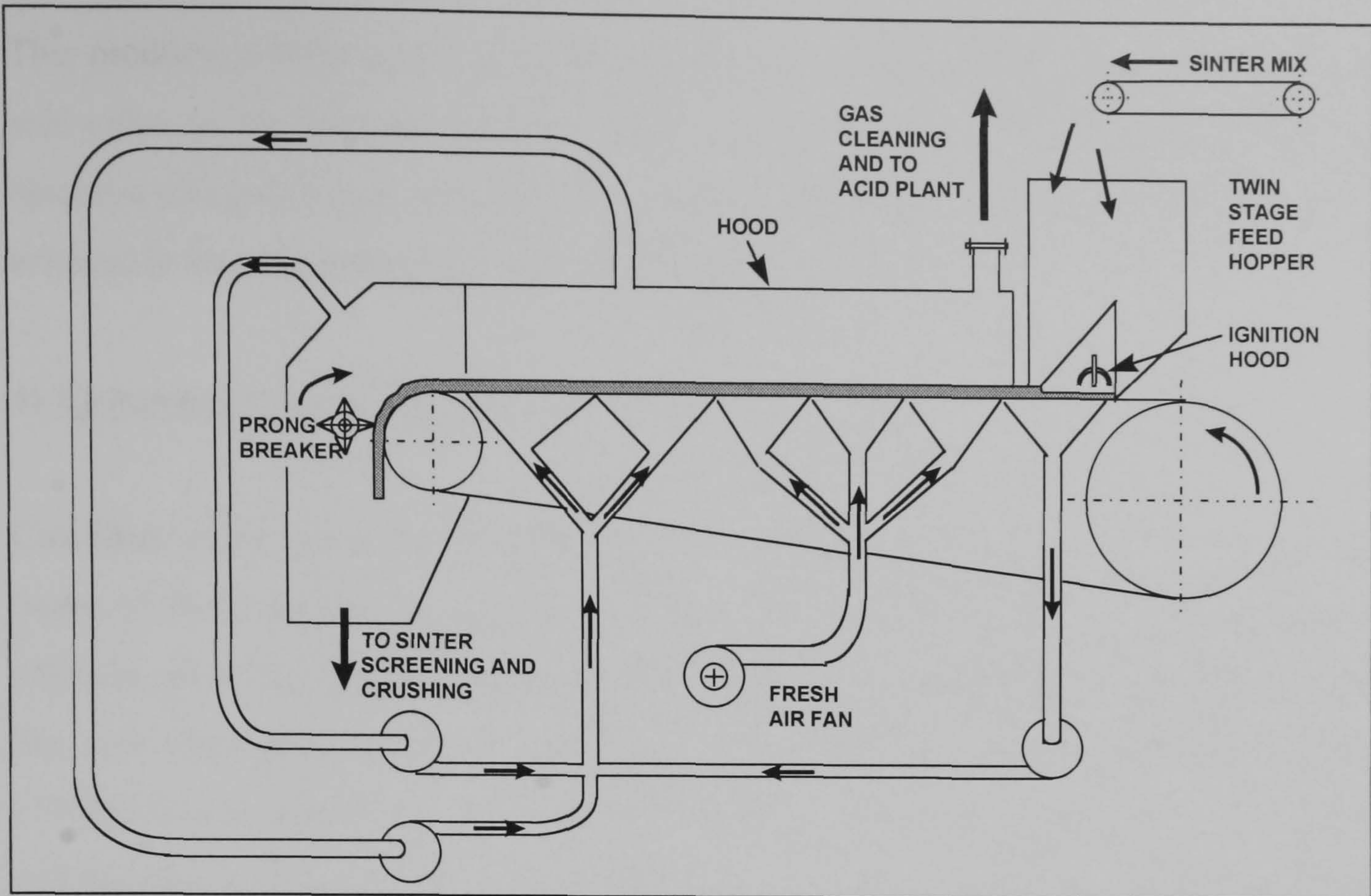
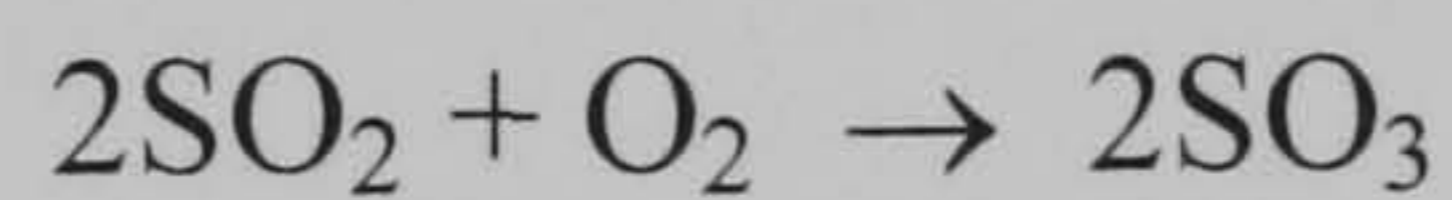


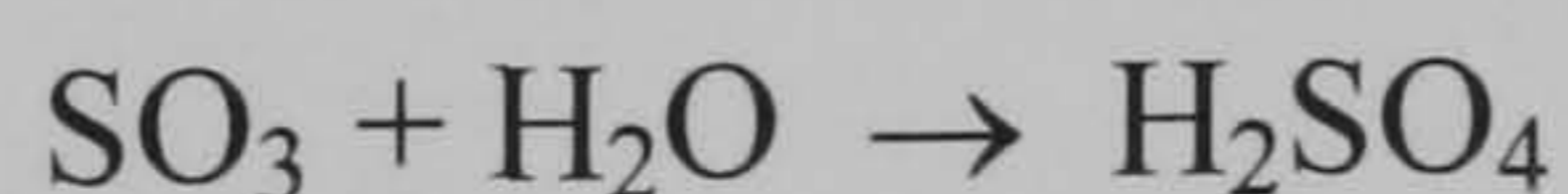
Figure 10.8: Sketch of a simplified updraught sinter machine [HMIP (1993)]

c) Sulphuric acid plant:

The exhaust gases from the sinter plant, which are hot (500°C), and dusty, are cooled and cleaned by wet scrubbing, packed tower cooling and electrostatic precipitation. Mercury in the gases is removed as calomel (mercurous chloride) which is precipitated and removed from the liquor. The gases are then dried by contact with 96% sulphuric acid and then are passed to the converter, where the sulphur dioxide is oxidised to sulphur trioxide [HMIP (1993)]. i.e.



The converter contains five beds of packed catalyst at between 420 and 440°C . Up to 98.5% conversion is obtained. This meets sulphuric acid in the absorber where the sulphur trioxide reacts with water to produce additional acid according to the following reaction:



This produces a 96% brown coloured sulphuric acid [HMIP (1993)]. The sulphuric acid is sold either in this form as 'black' acid (due to the presence of carbonaceous matter) or is bleached using hydrogen peroxide. The exhaust gases from the acid plant are demisted and released to the atmosphere through a 92.5 m stack.

d) Cadmium ion exchange plant:

Cadmium in the sinter feed material tends to be volatilised during the sintering process. Some of these species are soluble in the acidic vapour of the exhaust gas scrubber. In addition, all of the sludges produced in the sinter plant gas cleaning systems are pumped to the acid plant plant thickener where yet more cadmium is taken into solution [HMIP (1993)]. The sludge is recycled to the sinter plant and the liquor is treated by ion exchange and displacement to produce crude cadmium metal sponge. This then furnaced with caustic soda and cast into ingots of caustic cadmium, which are transported to the cadmium and zinc refinery [UK EA (1999)]. The caustic liquor resulting from this process is sent to the on-site effluent plant for treatment.

e) Imperial smelting furnace:

The Imperial smelting furnace is a modified blast furnace, which extracts, simultaneously, zinc and lead from sintered concentrates. A proportion of non-sintered furnace additions (secondary zinc bearing materials of various origins) may also be used [UK EA (1993)]. Figure 10.9 shows, schematically, the main features of the furnace.

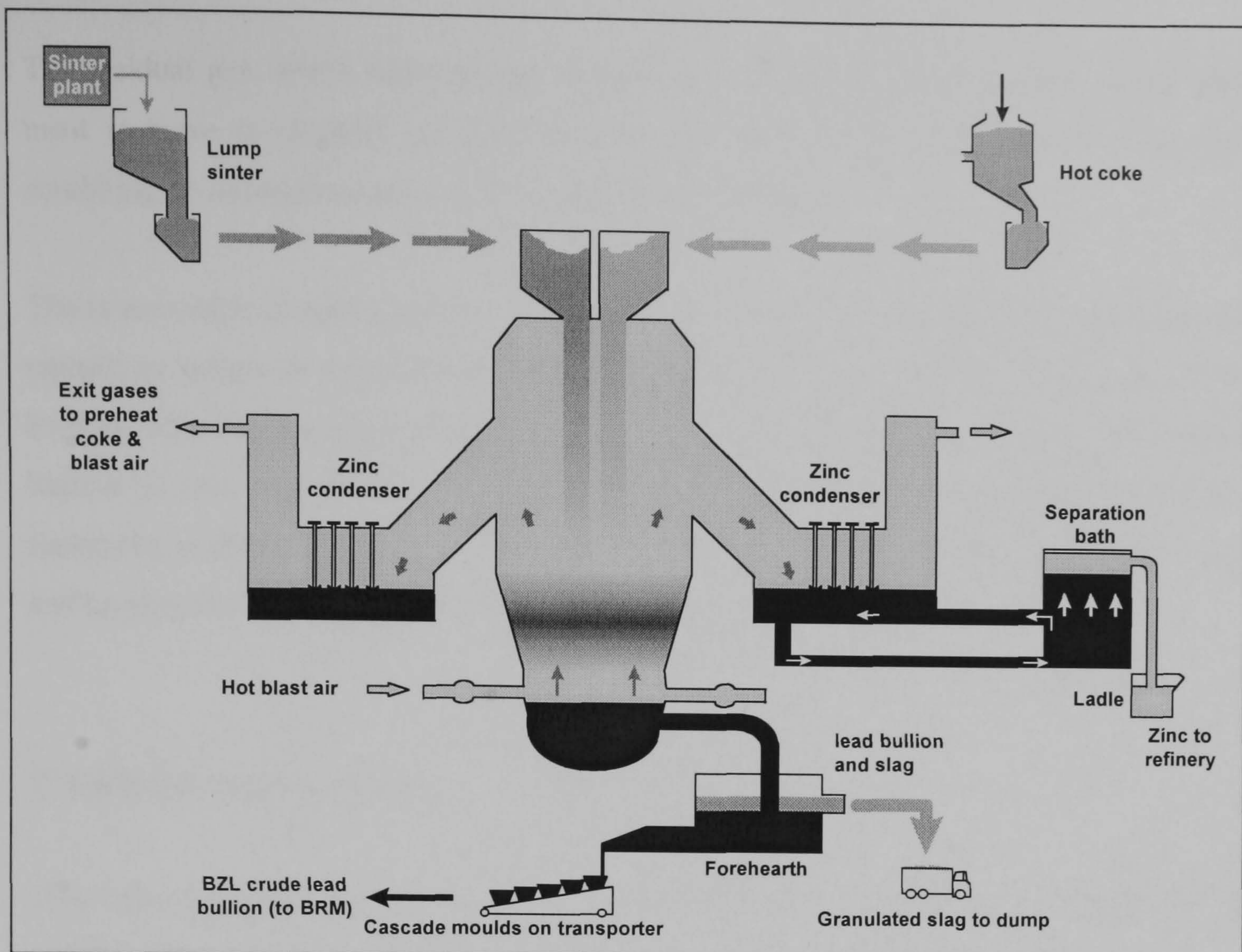
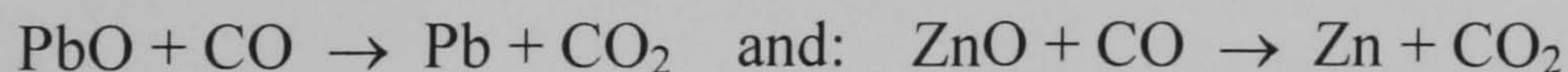


Figure 10.9: Schematic diagram of the Imperial smelting furnace [BZL (2000)]

The metal feedstocks plus coke, preheated to 1000°C, are fed in through the top of the furnace, via a double bell system to prevent the escape of exhaust gases. Preheated hot blast air (at 900 - 1000°C) is forced through water cooled tuyeres in the lower half of the furnace shaft [HMIP (1993)]. This causes the coke to be converted to carbon monoxide, which reduces the zinc and lead oxides to their elemental forms [UK EA (1999)]. i.e.



At the temperatures involved, the zinc is volatilised and leaves the furnace along with the excess carbon monoxide through two side off-takes. It is then fed into a lead splash condenser (there is one for each off-take), where a shower of molten lead quenches the gases to about 550°C and causes the zinc to condense and be absorbed into the molten lead [HMIP (1993)]. The zinc (known as ISF zinc) is collected continuously from the condensers and is tapped using ladles [UK EA (1999)]. Any cadmium which may be present in the feed is also volatilised in the furnace and is collected along with the ISF zinc.

The residual gas, which still contains 20-30% carbon dioxide, is cleaned and cooled and most is burnt to pre-heat the blast air and coke. Excess gas is discharged, after wet scrubbing, to atmosphere via a 61 m stack [UK EA (1999)].

The non-volatile components, however, pass down to the base of the furnace shaft and are tapped, by means of a special forehearth arrangement. This separates the BZL crude lead bullion, from the slag (containing iron oxides, silica, lime, alumina and arsenic). The crude bullion is cast into blocks of 2 tonnes approximately. It is subsequently transported (primarily to BRM) for refining. The slag is granulated, quenched using recirculated water and is deposited in a licensed on-site disposal facility.

f) Cadmium and zinc refinery:

The refinery purifies the ISF zinc and caustic cadmium into saleable products [UK EA (1999)]. Figure 10.10 indicates schematically the processes involved.

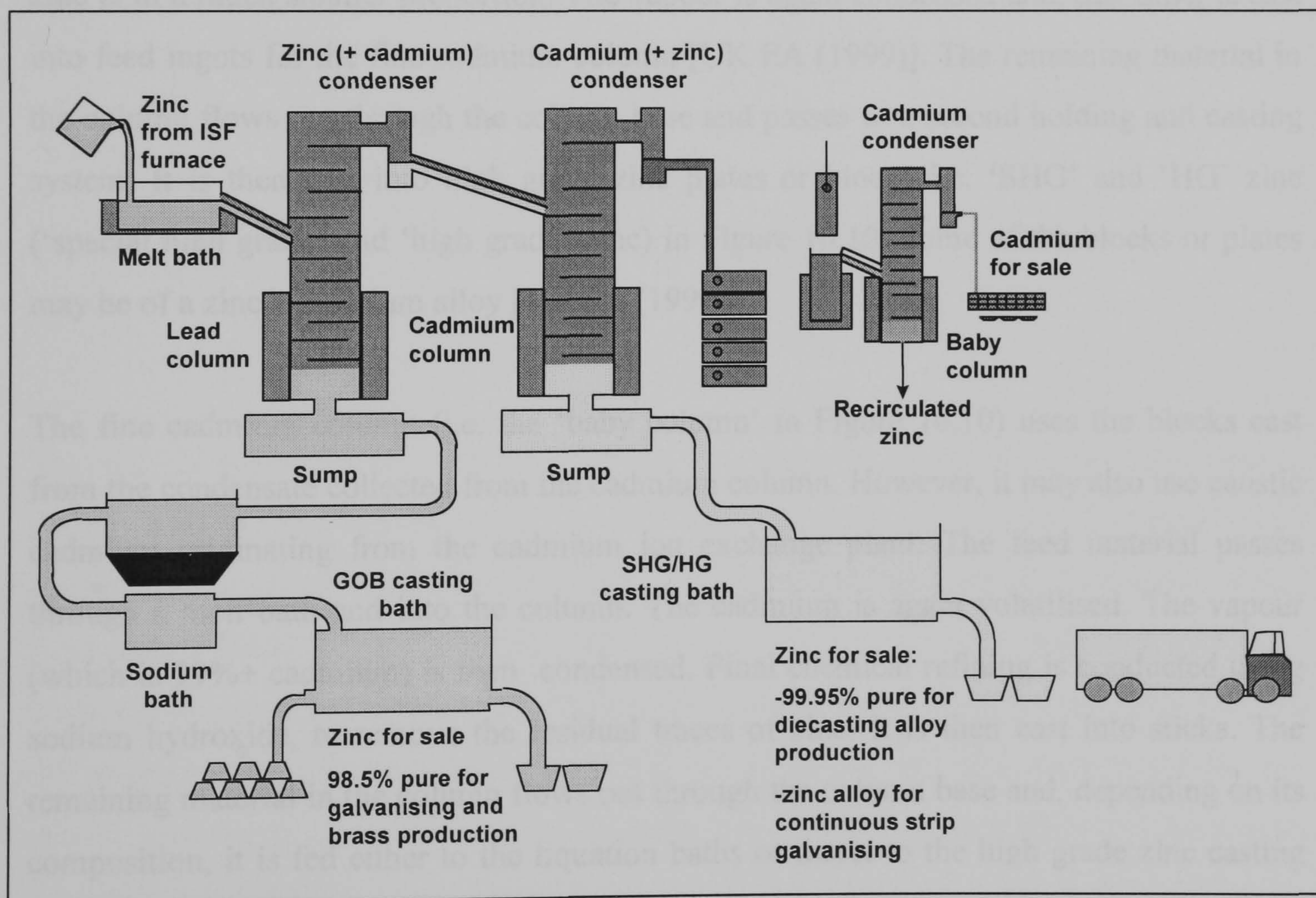


Figure 10.10: Schematic diagram of the zinc and cadmium refining process [BZL (2000)]

The principal feed material for the refinery is ISF zinc. This is generally still in the molten state from the Imperial smelting furnace. However, it will be solid blocks when the furnace is off-line. The ISF zinc (which also contains some cadmium) is fed through an oil fired melt bath and into trayed lead columns [UK EA (1999)]. The lower parts of the columns are heated by natural gas burners but the top part of the columns are not [HMIP (1993)]. Hence, within the columns, the temperature is such that the cadmium (plus some zinc) is volatilised and exits by the top of the column. Being cooler here, the volatilised cadmium and zinc are condensed and then pass to the cadmium columns. The remaining material in the lead column (which is principally zinc but still has some impurities) flows out from the column base to liquation baths, where impurities such as lead and arsenic are separated by cooling. Residual arsenic is then removed by sodium treatment and the zinc is finally sent to a holding system, from where it is cast into blocks or plates of general grade zinc [UK EA (1999)] i.e. 'GOB' zinc ('good ordinary brand' zinc) in Figure 10.10.

In the cadmium columns, the cadmium is again vaporised, but, this time, the associated zinc is in a much smaller proportion. The vapour is again condensed and, this time, is cast into feed ingots for the fine cadmium column [UK EA (1999)]. The remaining material in the column flows out through the column base and passes to a second holding and casting system. It is then cast into high grade zinc plates or blocks i.e. 'SHG' and 'HG' zinc ('special high grade' and 'high grade' zinc) in Figure 10.10. Some of the blocks or plates may be of a zinc/aluminium alloy [UK EA (1999)].

The fine cadmium column (i.e. the 'baby column' in Figure 10.10) uses the blocks cast from the condensate collected from the cadmium column. However, it may also use caustic cadmium originating from the cadmium ion exchange plant. The feed material passes through a melt bath and into the column. The cadmium is again volatilised. The vapour (which is 99%+ cadmium) is then condensed. Final chemical refining is conducted using sodium hydroxide, to remove the residual traces of zinc. It is then cast into sticks. The remaining material in the column flows out through the column base and, depending on its composition, it is fed either to the liquation baths or direct to the high grade zinc casting system [UK EA (1999)].

g) Boiler house:

In the boiler house, the heat energy from natural gas is used both to raise steam and to generate hot water. The former is used in the cadmium and zinc refinery, whilst the latter is used in office and workshop heating, the showering facilities etc.

h) Plant overheads:

The overheads, which have been modelled separately in the LCA, are towns water, grid electricity and natural gas consumption and effluent and office waste production.

i) Ancillary transports:

Natural gas is transported to BZL by pipeline. All other ancillary transports are either by road exclusively or involve a combination of road and sea transport legs.

All ancillary transports have been modelled as separate atoms.

10.3.3. Hilton/Mt. Isa stream

The main output from Hilton/Mt. Isa stream operations is Isa crude lead bullion, with a typical assay of Pb: 99.16%, S: 0.50% and Ag: 0.24%, and Sb: 0.10% by mass.⁸⁸ The entire lead bullion output from Mt. Isa is shipped, via the port of Townsville, Qld., Australia to BRM, Northfleet, UK. The ore, from which the Isa crude lead bullion is obtained, is mined underground at Mt. Isa, Qld. and at Hilton, Qld. Concentration of the ore to produce a zinc and a lead concentrate is conducted, on the surface, at the Mt. Isa central processing site. The zinc concentrate, thus produced, is transported by rail to Townsville and sold on, whilst the lead concentrate is smelted at Mt. Isa, to produce the Isa

⁸⁸ Average for the calendar year 1998. Calculated by the author from BRM data records. However, the lead concentration is not measured routinely by BRM. Therefore, it has been assumed to comprise the remainder, after deducting the contributions to the total of the other materials.

crude lead bullion. This is then transported, principally by rail, to the port of Townsville, from where it is shipped to the UK. Transport of the Isa crude lead bullion to the UK is considered in section 10.3.3.4.

Figure 10.11 indicates the locations of the Hilton/Mt. Isa stream Australian operations.

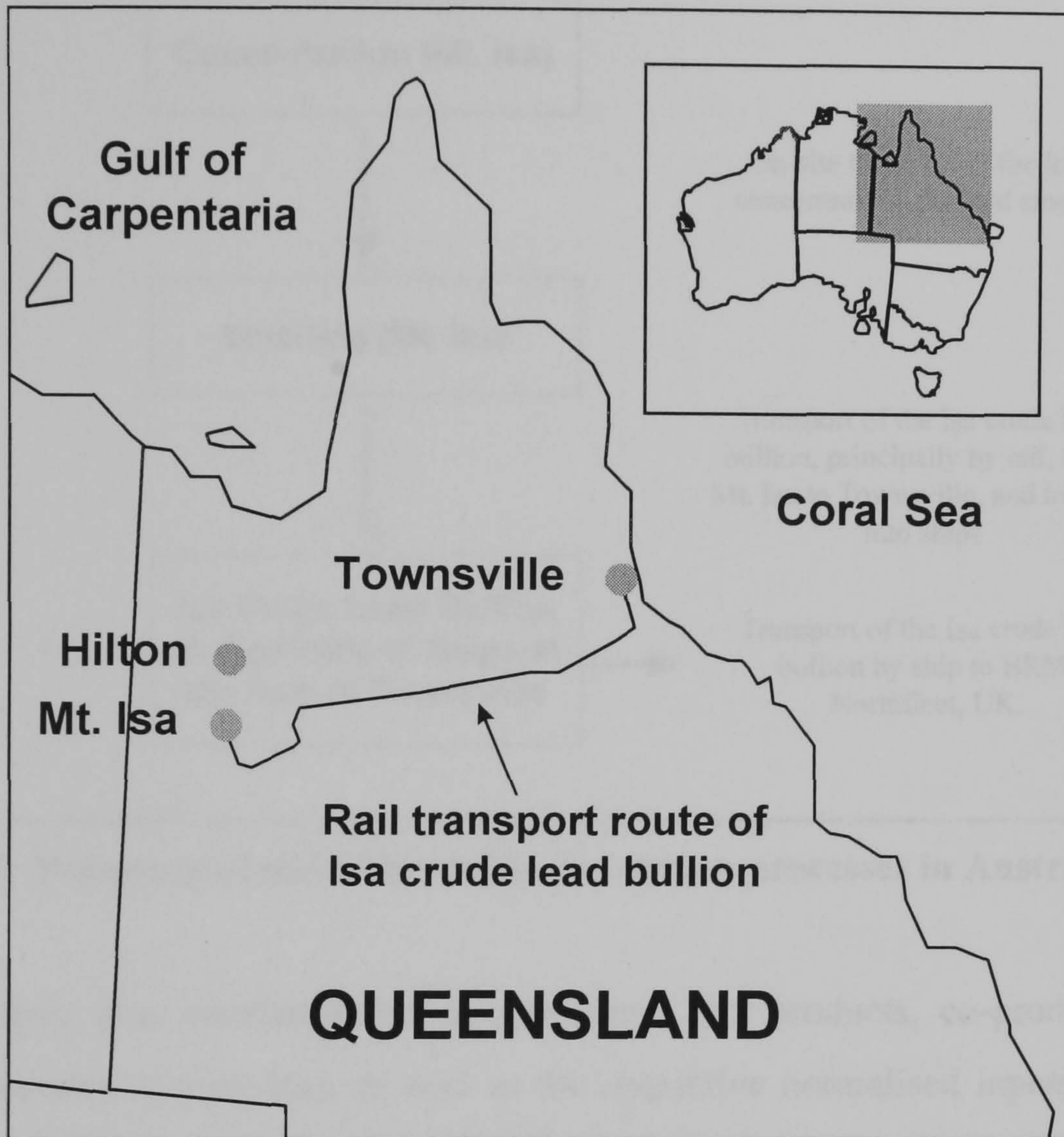


Figure 10.11: Hilton/Mt. Isa stream operations in Queensland, Australia

The overall processing sequence may be summarised as in Figure 10.12.

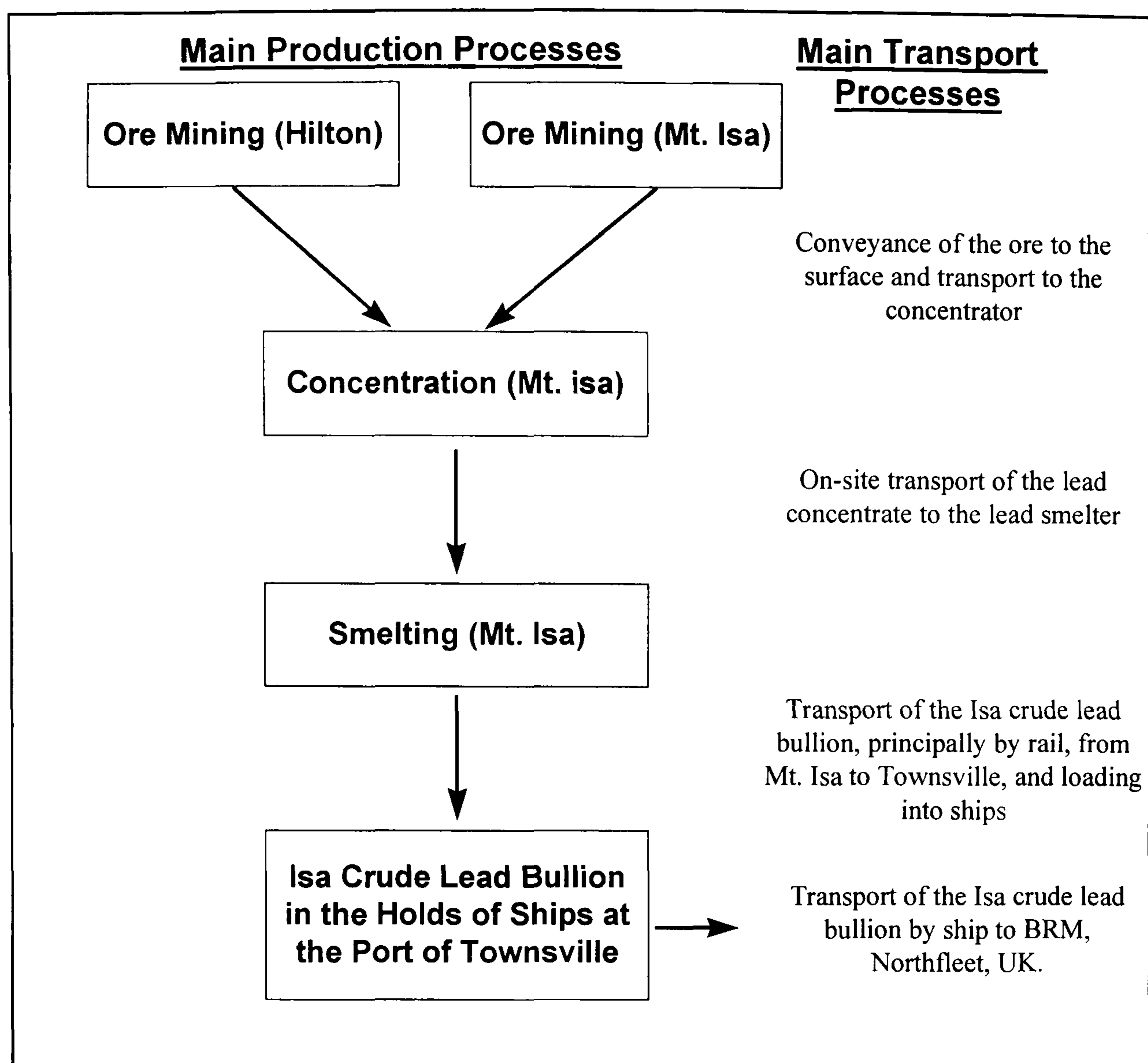


Figure 10.12: Summary of main Hilton/Mt. Isa stream processes in Australia

The gross inputs (i.e. consumptions) and outputs (i.e. products, co-products and by-products, emissions and wastes), as well as the respective normalised inputs and outputs per tonne of functional output, of the processes shown above, are given in the input/output Excel files. These contain the data used in the life-cycle modelling. They are also enclosed in the input/output data volume accompanying this thesis (volume 2). The functional outputs are different for each modelled process, as indicated in Tables 10.4 to 10.8. These Tables consider, respectively, the processes associated with the Hilton site, the Mt. Isa site, electricity production for both sites, the port of Townsville and miscellaneous other processes which have been modelled using site-specific data.

With the exception of many of the transports, which operate over considerable distances, the processes in Tables 10.4, 10.5 and 10.6 all occur within the vicinity (i.e. within about 20 km) of the Mt. Isa central processing site.

Process description	Excel file name (s)	Functional unit description
Zn-Pb-Ag ore mining at the Hilton, Qld. site	MIM, Hilton -Zn-Pb-Ag ore mining	1 kg of mined ore (Hilton)
Transport of mined ore from the Hilton to the Mt. Isa site	Detailed within: MIM, Mt Isa - Transport data	1 kg of mined Hilton ore transported ¹
Ancillary transports associated with the Hilton site processes	All are detailed within: MIM, Mt Isa - Transport data	1 kg of each material transported ¹
Note: 1 These include both the transports for materials required by each major process, and the return of the empty transport containers, where applicable.		

Table 10.4: Excel file names and the functional outputs used in the modelling of each of the foreground processes associated with the Hilton site

Process description	Excel file name (s)	Functional unit description
Bulk oxygen production at the Mt. Isa site	MIM, Mt Isa -Mines Power Station -oxygen production	1 kg of bulk oxygen
Various transports associated with oxygen production at the Mt. Isa site	All are detailed within: MCPS & MIM, Mica Creek and Mines Power Stations Transport data	1 kg of each material transported ¹
Zn-Pb-Ag ore mining at the Mt. Isa site	MIM, Mt Isa -Zn-Pb-Ag ore mining	1 kg of mined ore (Mt. Isa)
Pb and Zn concentrate production from the Hilton and Mt. Isa mine ores are the Mt. Isa site.	MIM, Mt Isa -Zn and Pb concentration	1 kg of Isa Pb concentrate
Smelting of the Pb concentrate at the Mt. Isa site.	MIM, Mt Isa -Pb smelting	1 kg of Isa crude Pb bullion
On-site transports associated with the Mt. Isa Pb smelter	MIM, Mining & Smelting -On-site transports	1 kg of materials (all types) delivered to the Mt. Isa Pb smelter
Note: 1 These include both the transports for materials required by each major process, and the return of the empty transport containers, where applicable.		

Table 10.5: Excel file names and the functional outputs used to model each of the foreground processes associated with the Mt. Isa processing site

Process description	Excel file name (s)	Functional unit description
Electricity generation by the Mica Creek Power Station (MCPS), Qld., Australia	MCPS, Mica Creek power Station - Electricity production (post conv)	1 MJ of electricity (from the Mica Creek Power Station)
Various transports associated with the MCPS	All are detailed within: MCPS & MIM, Mica Creek and Mines Power Stations Transport data	For natural gas transport: 1 MJ of energy from natural gas. For all other transports: 1 kg of each material transported ¹
On-site generation of electricity at Mt. Isa, Qld. by the Mines Power Station (MPS)	MIM, Mt Isa -Mines Power Station -electricity production	1 MJ of electricity (from the Mines Power Station)
Note: 1 These include both the transports for materials required by each major process, and the return of the empty transport containers, where applicable.		

Table 10.6: Excel file names and the functional outputs used in the modelling of the electricity production processes associated with the Mt. Isa and Hilton sites

Process description	Excel file name (s)	Functional unit description
Isa crude Pb bullion rail and road transport from the Mt. Isa processing site to the port of Townsville	MIM Isa Pb Crude Bullion to Townsville -Transport Data	1 kg of Isa Pb bullion transported
Isa crude Pb bullion shipping from Townsville, Qld., Australia to BRM, Northfleet, Kent, UK	MIM Isa Pb Crude Bullion Shipping to BRM -Transport Data	1 kg of Isa Pb bullion transported

Table 10.7: Excel file names and the functional outputs used in the modelling each of the foreground processes associated with the port of Townsville

Process description	Excel file name (s)	Functional unit description
Metallurgical and nut coke production by Bowen Coke Ltd. (BCL), at Bowen, Qld., Australia	BCL, Bowen -Coke Production	1 kg of metallurgical coke
Transport of metallurgical coke produced by BCL to the Mt. Isa processing site.	Detailed within: CCL, Collinsville and BCL, Bowen -Transport data	1 kg of metallurgical coke
Various ancillary transports associated with BCL processes	All are detailed within: CCL, Collinsville and BCL, Bowen -Transport data	1 kg of each material transported ¹
Production of coal, for use by the MCPS, by Collinsville Coal Pty. Ltd. (CCL) at Collinsville, Qld., Australia	CCL, Collinsville -Coal mining (Coal for MCPS)	1 kg of mined coal
Production of coal, for use by BCL, by Collinsville Coal Pty. Ltd. (CCL) at Collinsville, Qld., Australia	CCL, Collinsville -Coal mining (Coal for BCL)	1 kg of mined coal
Transport of coal produced by CCL to Mica Creek Power Station.	Detailed within: CCL, Collinsville and BCL, Bowen -Transport data	1 kg of mined coal
Transport of coal produced by CCL to BCL.	Detailed within: CCL, Collinsville and BCL, Bowen -Transport data	1 kg of each material transported ¹
Various ancillary transports associated with CCL processes	All are detailed within: CCL, Collinsville and BCL, Bowen -Transport data	1 kg of each material transported ¹
<p>Note:</p> <p>1 These include both the transports for materials required by each major process, and the return of the empty transport containers, where applicable.</p>		

Table 10.8: Excel file names and the functional outputs of each of the miscellaneous additional processes modelled using site-specific data

The location of the Mt. Isa central processing complex, the Hilton mine and the town of Mt. Isa are shown in Figure 10.13. The location of the new George Fisher mine is also indicated. However, it was noted in section 10.2, that at the time when the case study was conducted, production from the mine had not yet commenced. Hence, it has not been included in the life-cycle modelling. However, since the mining of Zn-Pb-Ag ore at George Fisher has now begun, it will need to be included within future iterations.

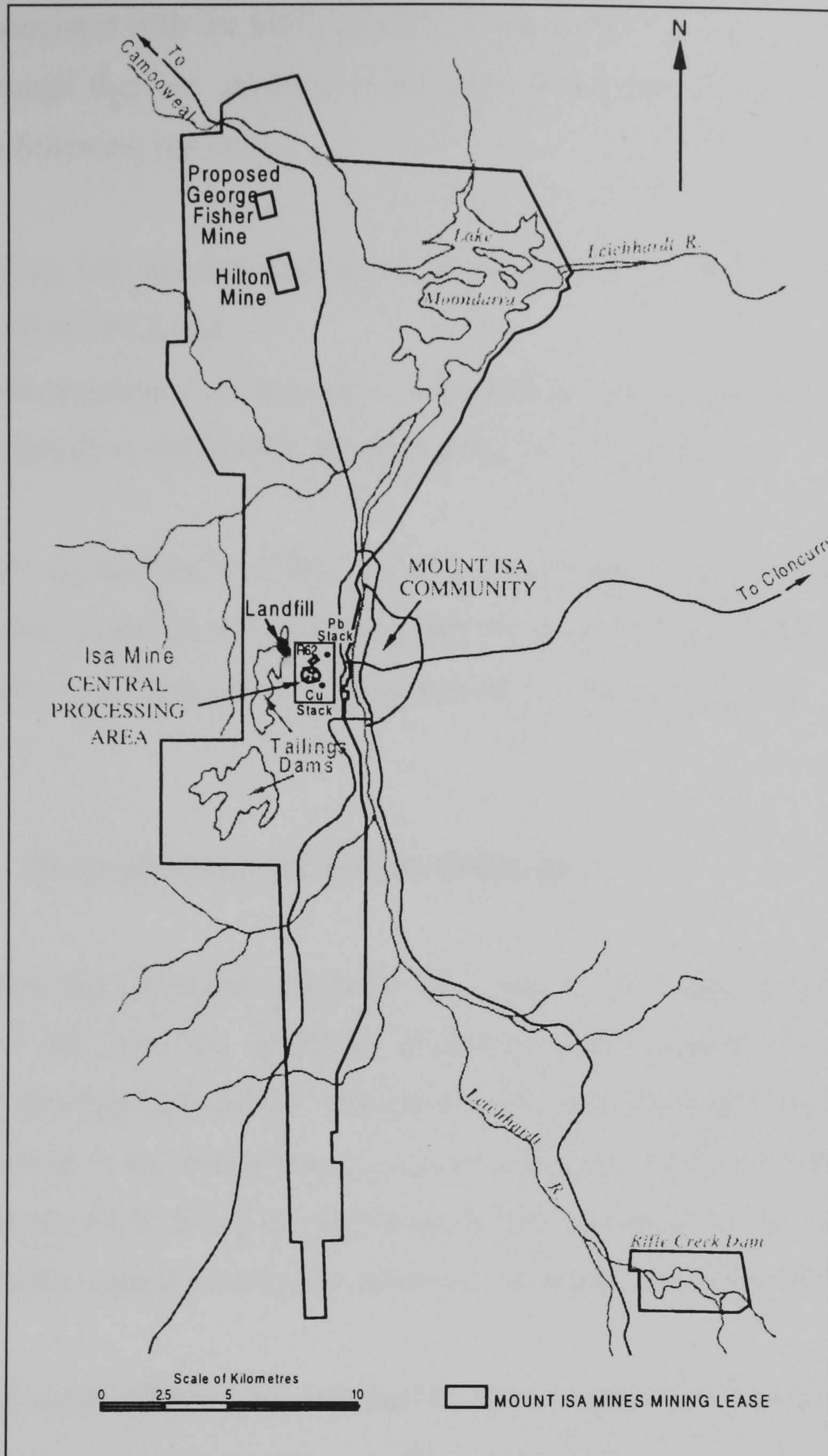


Figure 10.13: The location of the Mt. Isa central processing complex, within mining lease ML 8085, plus other operations in the vicinity [modified from MIM (1999)]

Operations associated with the MPS, MCPS, CCL and BCL have been modelled using site data, even though they are ancillary to the main production sequence shown in Figure 10.12, for the following reasons:

- MIM Holdings Ltd. have the majority of shares in CCL, and BCL is owned by them (as noted in section 10.2), and
- a significant proportion of the product outputs from these operations are consumed by processes directly involved with the main production sequence.

The processes summarised in Tables 10.4 to 10.8 constitute the foreground processes, modelled in the Australian component of the life-cycle of MIM's primary Pb products. These processes, as disaggregated in the modelling, are reviewed below.

10.3.3.1. Processes associated with the Hilton site

The Hilton mine site (indicated in Figures 10.11 and 10.13) is approximately 18 km north of the city of Mt. Isa. The orebodies at Hilton were discovered in 1947. However, underground development did not commence until late-1982 and the first cut-and-fill production (which is the current means) did not commence until mid-1987. The J53 shaft was sunk between 1970 and 1973, and the main P49 shaft between 1973 and 1975 [Leahy (1993)]. Currently, mined ore from the Hilton site is processed within the Mt. Isa complex.

Electric power for the Hilton site is supplied by Mica Creek Power Station (MCPS).

a) Ore mining at the Hilton site:

The Zn-Pb-Ag ore deposit at Hilton is composed of tabular nodes, six of which are being mined [Perkins and Bell (1998)]. The deposit is in a similar structural position to the Mt. Isa ore bodies and lies in the same stratigraphic sequence [Perkins and Bell (1998), Leahy (1993)]. However, the number of orebodies is greater, they are more deformed and the faulting has resulted in some redistribution of the ore minerals [Leahy (1993)]. The major Pb-bearing mineral is galena (PbS), and the major Zn-bearing mineral is sphalerite (ZnS), at both the Hilton and Mt. Isa Pb mines. The current production block consists of six narrowly separated discrete orebodies, between 10 and 12 levels. The thickness, separation grade and mineralogy all vary significantly throughout the orebodies [MIM (1999)].

Hilton mining and subsequent handling operations are summarised diagrammatically in Figure 10.14.

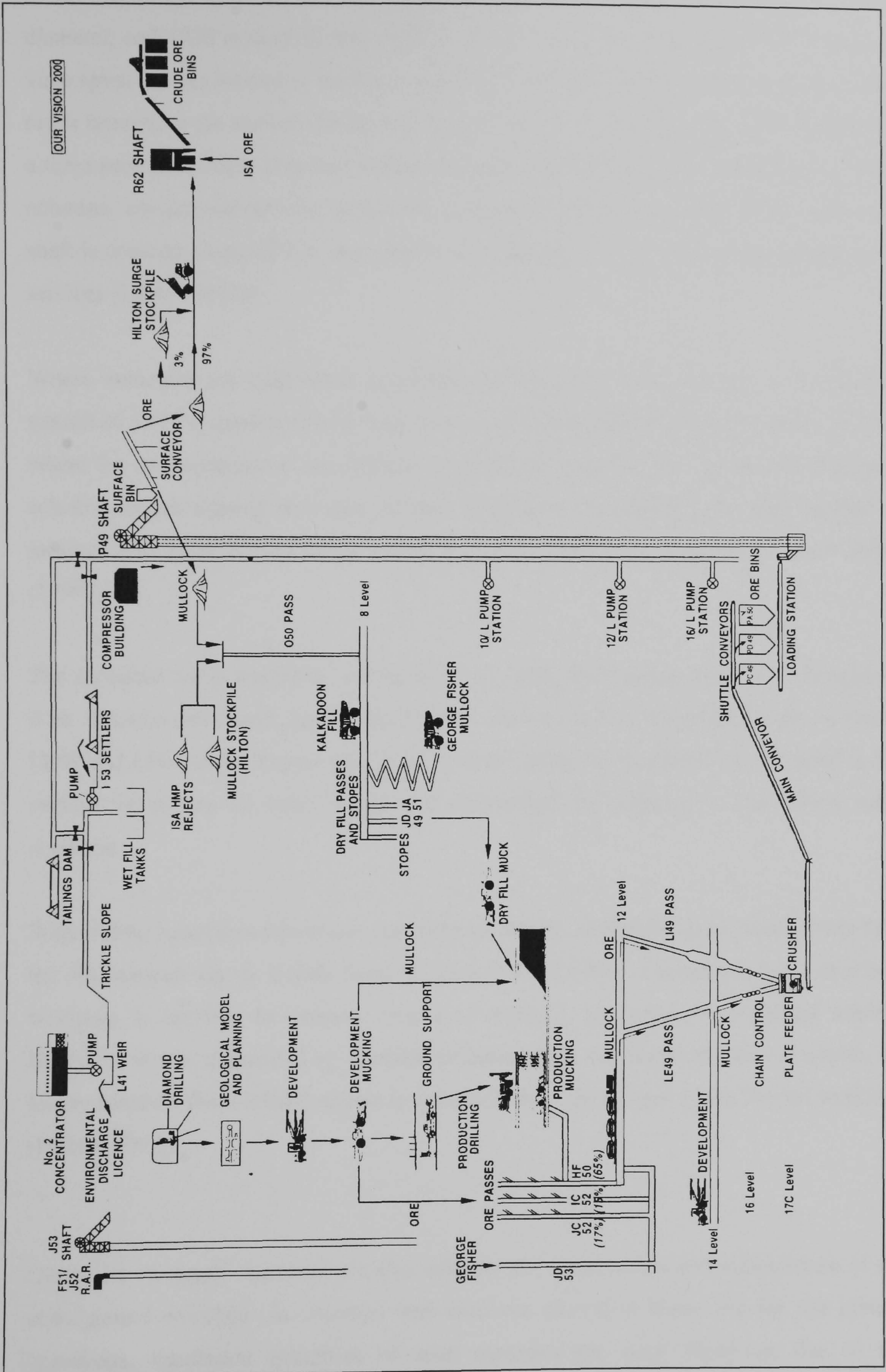


Figure 10.14: Process flow diagram of Hilton Zn-Pb-Ag ore mining and subsequent handling operations

The principal access to underground operations is via the P49 shaft, from which the main levels branch off at 60 m intervals [MIM (1999)]. The shaft is concrete lined, 8 m in diameter, and 1040 m deep [Leahy (1993)]. Access to the orebodies on 10 to 12 levels is via a spiral incline located to the foot wall of the orebodies [MIM (1999)]. Mined crushed ore is brought to the surface via the P49 shaft in two 12 tonne skips. The shaft also houses a three person auxiliary cage and various services including, electricity, fresh water, pump columns, compressed air and pre-mixed concrete [Leahy (1993)]. The slightly older J53 shaft is concrete lined, 630 m deep, and with a diameter of 4.3 m. It is used primarily for services [Leahy (1993)].

Where orebodies are sufficiently consistent, mining is by open stoping, with sub-level spaced 24 to 28 m apart and with blast holes drilled both up and down. However, in areas where the ore continuity is insufficient, or where the orebodies are too narrow, the more selective bench stoping technique is used. Currently, the latter is the main method of mining, with open stoping being limited to some of the lower areas of the mine [MIM (1999)].

The extracted ore is hauled by rail on level 12, using 1067 gauge diesel rail locomotives with 10 tonne side-dump cars [Leahy (1993)]. The ore is then dumped through ore passes LE49 and LI49 to the crusher station on 17 level. After being crushed, it is hoisted to the surface using two 12 tonne skips, and transported by conveyor to the Hilton surge stockpile.

Stope filling operations take place, currently, on 8 level, with diesel haul trucks distributing the fill material via an incline from 10 level [MIM (1999)]. Currently, all fill of mined workings is dry-fill. Its primary source is mullock, generated from current mining. However, this is augmented by material reclaimed from the Hilton mullock stockpile, Isa Heavy Medium Plant (HMP) rejects and mullock from the George Fisher Project workings [MIM (1999)].

Quantities of supply materials are also used for the construction and maintenance of the underground workings. In common with both the McArthur River and Mt. Isa mining operations, significant quantities of such materials are used. However, due to the

heterogeneous nature of their composition and mass, it has not been possible to model them in this case study. Nevertheless, they are a significant concern.

Ventilation of the workings is provided by atmospheric air being drawn down through the P49 shaft, the J53 shaft, and also the new L72 shaft. This airflow, and that through the rest of the workings, is induced by three 650 kW centrifugal exhaust fans, each of which is capable of moving 220 m³/s of air. These draw air from the workings via upcast shafts. Principally, these are the J52 shaft and two smaller shafts (the O50 in the P49 area, and the F51 West). Monitoring data on emissions contained within the vented exhaust air were not obtained. However, the emissions from the use of diesel fuel have been modelled using the DEAM 'Diesel Oil (used as fuel)' data module. Whether or not there are any other significant emissions is not known.

Approximately 1,370 M litres of water are collected on 8 and 10 levels, and pumped to the surface each each year. Currently, all mine water from underground workings is pumped to the Hilton Tailings dam for evaporation [MIM (1999)]. The various stockpile areas on the surface at the Hilton site are segregated by bunds from their surrounds to minimise the amount of storm run-off and to contain potentially contaminating materials [MIM (1999)].

Fresh water used at the site is supplied from Lake Moondarra and Lake Julius by pipeline.

b) Transport of the mined Hilton ore to the Mt. Isa central processing complex:

The crushed ore is transported by haul trucks along a dedicated ahul road from the surge stockpile at the Hilton site, to a receiving area at the top of the R62 shaft in the Mt. Isa central processing complex. The journey distance is 18 km approximately. Kalkadoon Mining are the main operators of these transports. However, periodically some transports are also conducted by MIM Ltd. The transports conducted by Kalkadoon Mining carry up to 180 tonnes, whilst those by MIM Ltd. range from 35 to 100 tonnes.

c) Ancillary transports associated with Hilton site operations:

The delivery of explosives and distillate to the site by truck have been modelled, and as separate atoms.

10.3.3.2. *Processes associated with the Mt. Isa central processing complex*

The mining of Zn-Pb-Ag ore, ore concentration, Pb concentrate smelting and various other activities at the Mt. Isa central processing complex are conducted by Mount Isa Mines Ltd. (MIM Ltd.), who are a wholly owned subsidiary of MIM Holdings Ltd. The complex, which is situated on mining lease number 8058 at Mt. Isa, covers an area of 320 km² approximately and extends for nearly 52 km from its northern to its southern ends. Operations at the complex are authorised by the Australian Mount Isa Mines Limited Agreement Act 1985 [MIM (1999)].

First mining began at the site in 1924, the first concentrator began operations in May 1931, and the smelting of Ag-bearing Pb concentrate began in June 1931 [MIM (1999)]. The presence of mining and processing activities have caused the development and growth of the town of Mt. Isa, which currently has a population of over 21,000. The majority of the population of Mt. Isa, either work directly for MIM Ltd. or for concerns directly dependant upon its activities.

a) Bulk oxygen production:

The three bulk oxygen manufacturing plants in the Mt. Isa complex, are powered by the MPS. They consist of two Linde L525 plants, each of which is rated at 525 tonnes of oxygen per day, and one Union Carbide U80 plant, rated at 71.5 tonnes per day. Oxygen is extracted from atmospheric air by being passed through filters and sieves to remove atmospheric dust, water vapour, carbon dioxide and hydrocarbons [MIM (1999)].

Input and output data for the MPS, for the period of the case study, have not been obtained. Hence, they have been estimated. The method used is described in the Excel file 'Mines

Power Station and Oxygen Production', sheets from which have been enclosed in volume 2, and precede the input/output modelling data for this process.

b) Transports associated with oxygen production:

All transports have been modelled as separate atoms.

c) Ore mining:

As with the Hilton mine, the principal Pb and Zn-bearing minerals are galena (PbS) and sphalerite (ZnS). Significant Ag mineralisation is also associated with them. 28 orebodies have been exploited in the Mt. Isa Lead Mine. These orebodies are divided into three groups, namely:

- 'Black Star',
- 'Racecourse' and
- 'Rio Grande'.

The 'Black Star' orebodies range from 10 m to 40 m thick, they tend to be lower grade than the 'Racecourse' orebodies and contain significant amounts of pyrite (FeS₂). The 'Racecourse' footwall orebodies are 3 m to 25 m thick, contain less pyrite and are higher grade [Hall (1993)]. Extraction from all three groups occurs. However, production is expected to decrease significantly over the coming period, though it is expected that ore extracted from the George Fisher mine will supplement this decreasing production [MIM (1999)].

Mining and subsequent handling operations, associated with the Lead Mine at Mt. Isa, are summarised diagrammatically in Figure 10.15.

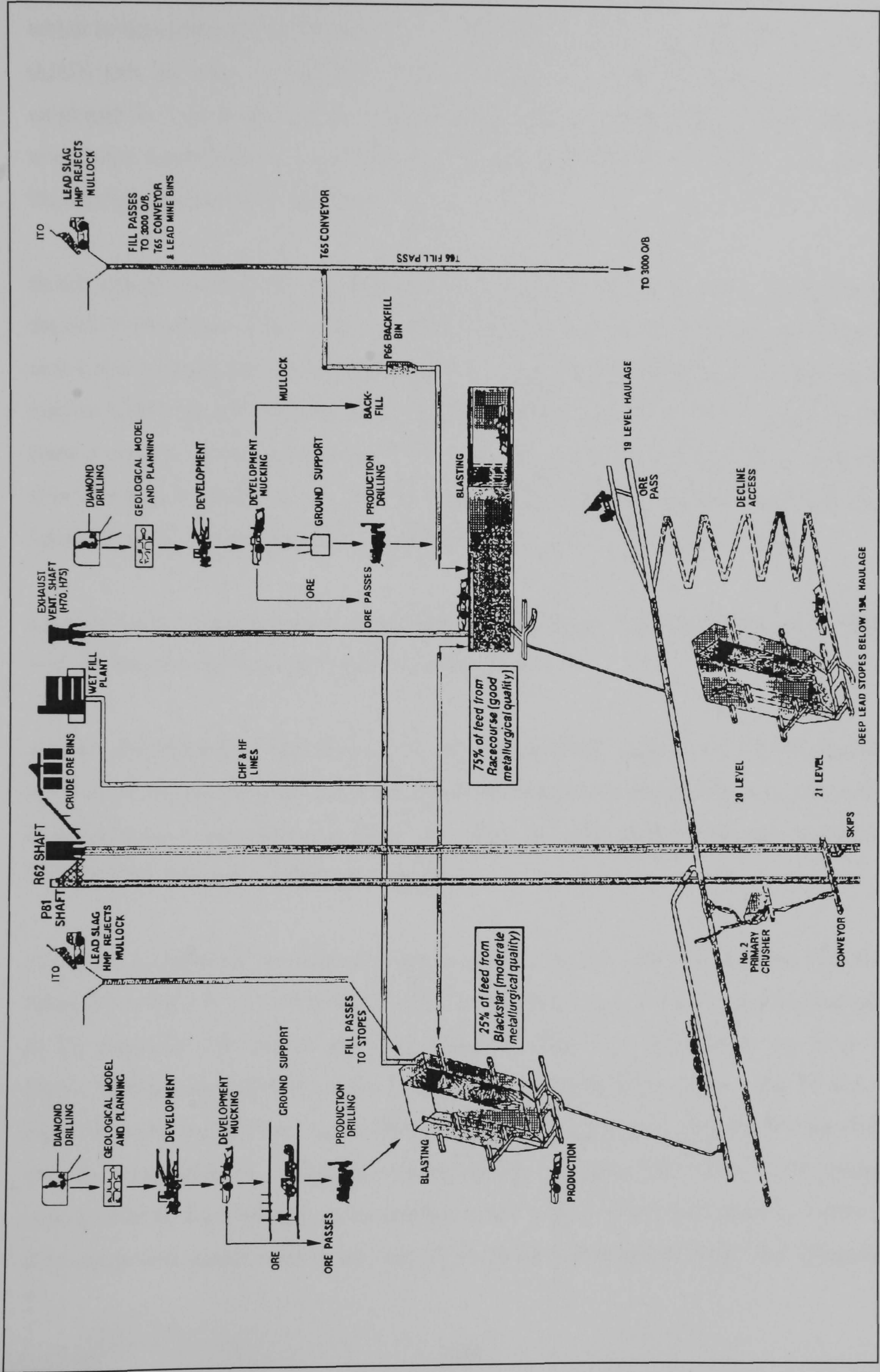


Figure 10.15: Process flow diagram of Zn-Pb-Ag ore mining at the Mt. Isa Lead Mine and subsequent handling operations

Two mining methods are employed, sub-level open stoping and bench stoping. Currently, sub-level open stoping methods account for 40 to 50% of total production [MIM (1999)]. Sub-level stoping involves extraction from stopes with a dimension of 40 m², with a height which is dependent upon the dimensions of the orebody. Diesel powered load-haul-dump (LHD) units are used for mucking, with tele-operated remote controlled vehicles being employed for final stope clearance [MIM (1999)]. The ore is transported by the LHD units to declines, from where it is tipped down ore passes onto 19 level. From here it is hauled to the crusher pass, and then crushed.

Bench stoping involves the development of a long open stope, with a top and bottom sill the full width of the ore body. Ore removal involves parallel holes being drilled into the ore and several of these being fired with explosive simultaneously. Both conventional and tele-remote LHD units are used for mucking [MIM (1999), Hall (1993)]. Once the stope has been completely blasted and cleared of ore, it is filled back to the floor level of the next sill. This then becomes the bottom sill for the next bench stope [MIM (1999)]. The ore is hauled from the workings by electric rail haulage to 19 level, where it is crushed.

Crushed ore from all sources is conveyed to the R62 shaft, hoisted to the surface in skips, and conveyed to the Pb-Zn concentrator crude ore bins.

As with the Hilton and McArthur River mines, significant quantities of supply materials are used for the construction and maintenance of the mine workings. However, due to their heterogeneous composition and mass, they have not been modelled in this case study. Nevertheless, they are a significant concern.

A variety of different materials are mixed as fill materials. The Mt. Isa Wet Fill Plant (situated on the surface within the Mt. Isa central processing complex) mixes various types of fill materials with cement and water. These include heavy medium rejects (from the Heavy Medium Plant (HMP) of the Pb-Zn concentrator), mullock, and Cu and Pb smelter slag. They also include the coarser fraction of the tailings streams from the Mt. Isa Pb-Zn and Cu concentrators, which are extracted by cyclones. The wet fill is pumped underground to the workings, in the various mines within the Mt. Isa complex. A network of underground passes convey the wet fill to its final destination. Some dry filling also

takes place in the Lead Mine, and these materials may be delivered underground by fill passes on the surface.

Ventilation in the mine is provided by a series of down-draft and upcast fans. However, information on the composition of the ventilation system of the Lead Mine has not been obtained.

Water is pumped underground for drinking, cooling, drilling, dust control and hygiene (i.e. washing and cleaning). In addition, aquifer water has to be pumped away to prevent it from flooding mine workings. Most is pumped to the surface, after first being sent to underground ponds, to allow the settling out of gross solids. However, some of the water is re-used in the mine. Water pumped to the surface, is collected in the Mine Head Water Tanks and re-distributed within the Mt. Isa central processing complex [MIM(1999)].

d) Concentrate production:

The Mt. Isa Pb-Zn concentrator is located east of the R62 shaft. Crushed ore from the Mt. Isa lead Mine and from the Hilton Mine is deposited, by conveyor, into the concentrator's crude ore bins [MIM (1999)]. Concentrate production involves three sequential processes, conducted by different plant within the concentrator. These are:

- crushing,
- heavy medium separation, and
- Pb/Zn grinding and flotation.

These processes are summarised diagrammatically in Figures 10.16, 10.17 and 10.18, respectively.

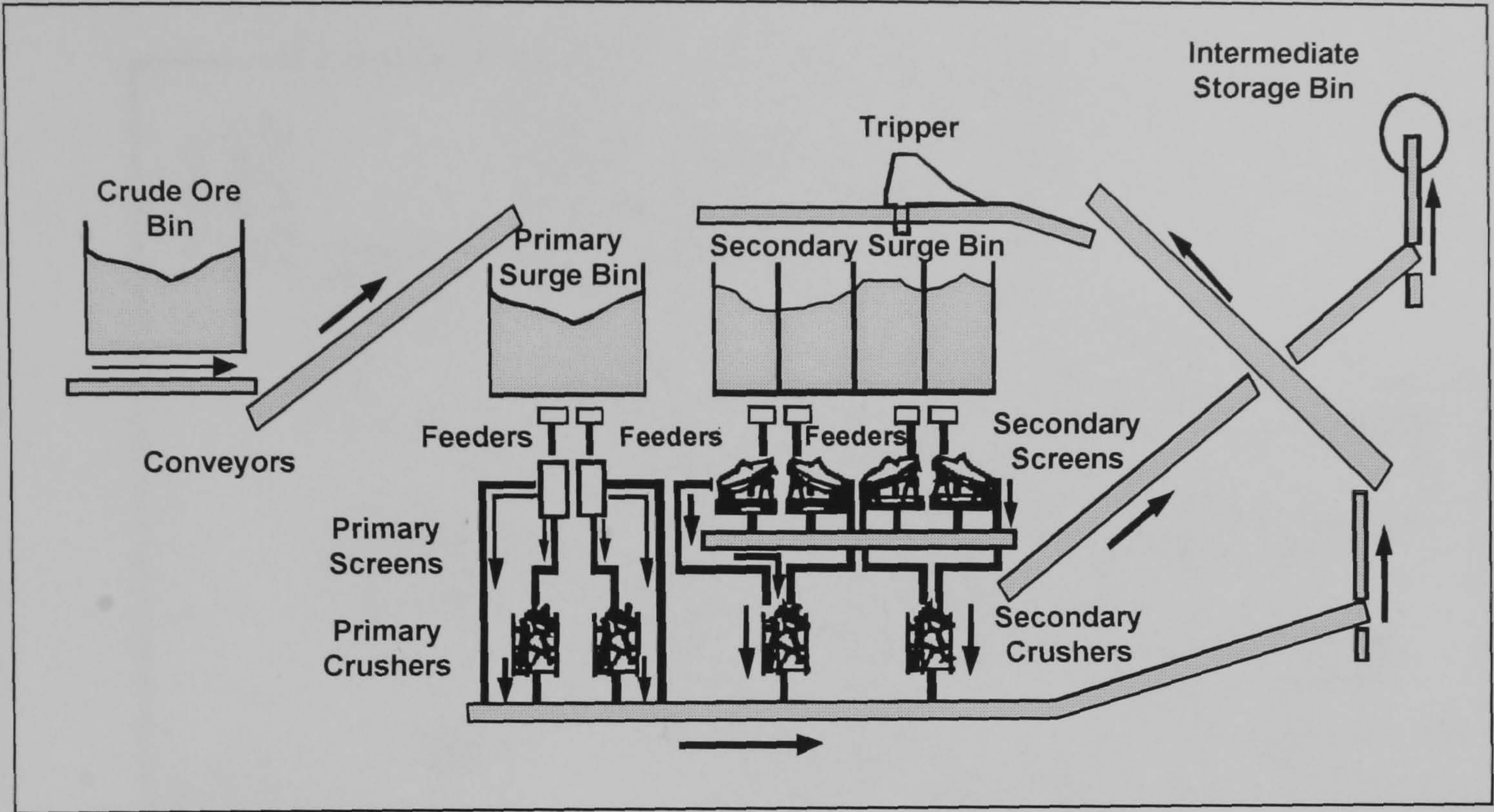


Figure 10.16: Crushing plant flowsheet [MIM (1999), Munro (1993)]

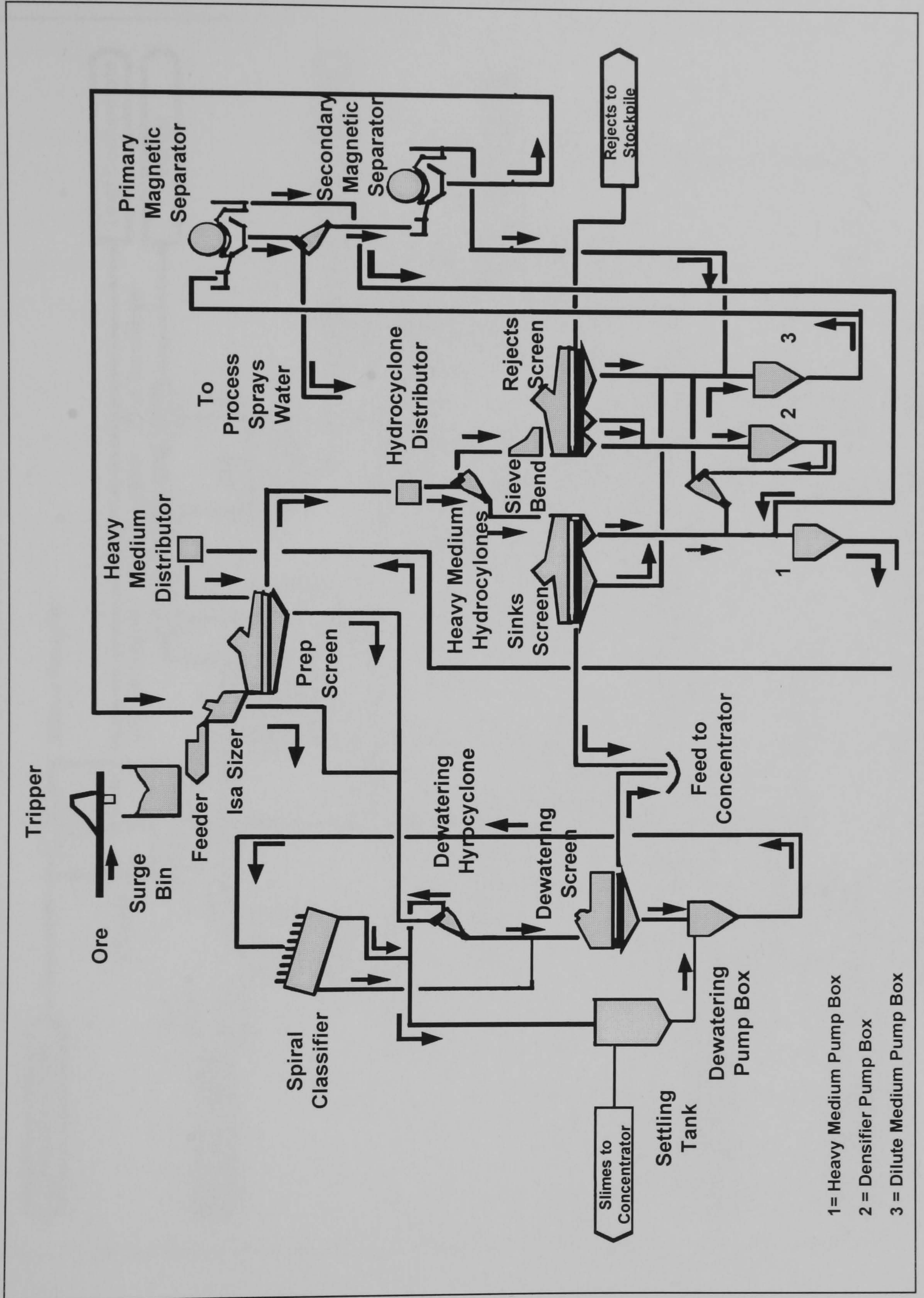


Figure 10.17: Heavy medium plant flowsheet [MIM (1999), Munro (1993)]

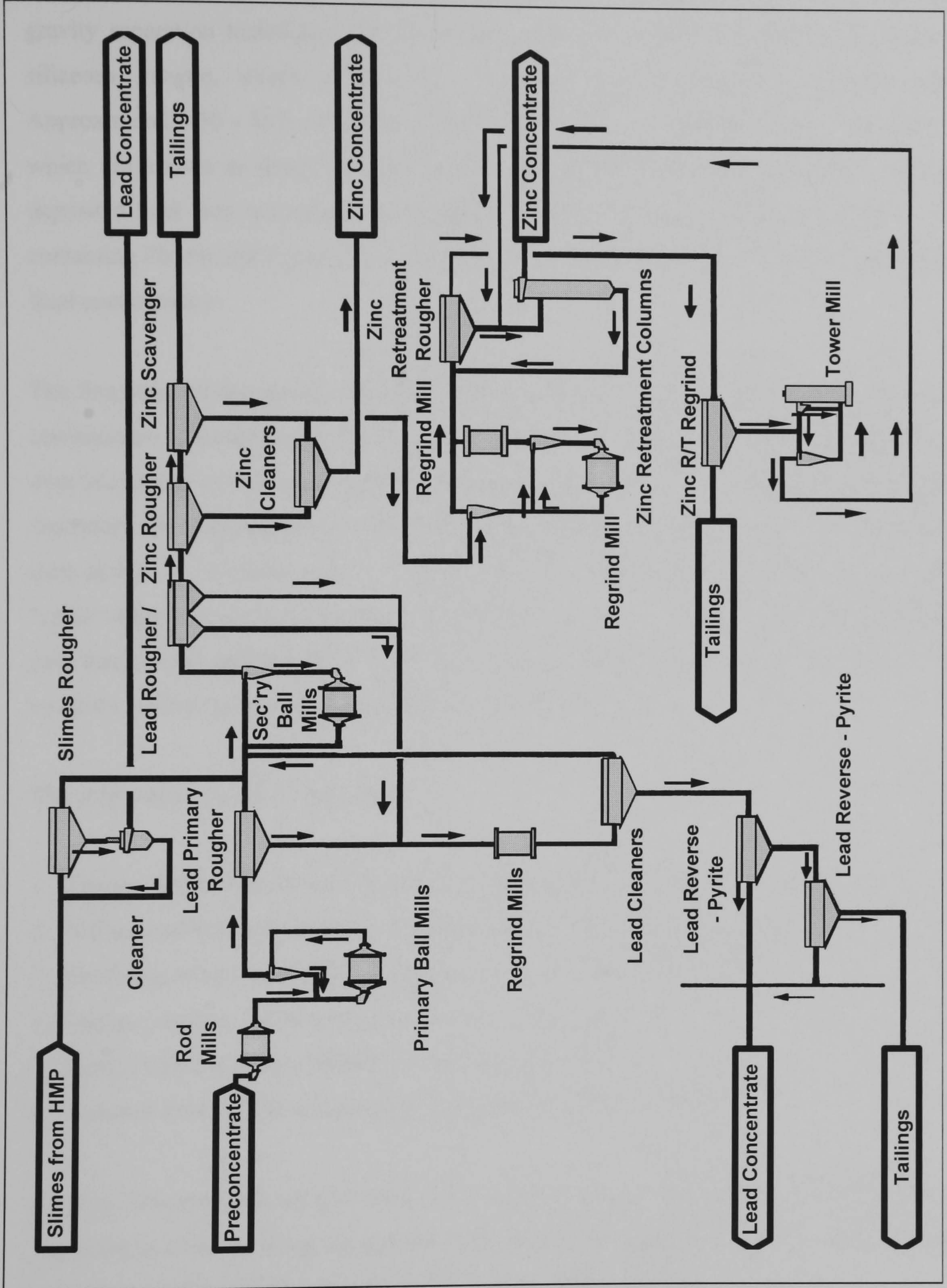


Figure 10.18: Pb/Zn grinding and flotation flowsheet [MIM (1999)]

In the crushing plant, two stages of cone crushing reduce the particle size from around 200 mm to 14 mm. The ore is then conveyed to an intermediate storage bin. In the Heavy Medium plant, the next stage, the ore is subjected to a variety of wet screening, sizing and gravity separation techniques. The principal purpose of these, is to remove the lighter siliceous gangue, which floats, from the more valuable material, which sinks. Approximately, 30 - 35% of the ore is rejected by this means [MIM (2000)]. The rejects, which are known as heavy medium rejects, are conveyed to a stockpile, prior to being deposited back into the mines as fill [MIM 91999)]. The 'value' containing slimes (i.e. containing Zb, Pb and Ag) are then subject to grinding and flotation circuits to produce the final concentrates.

The first stage of this process consists of wet grinding in rod mills, which operate using a combination of tumbling and steel rods to further reduce the particle size. Further grinding then takes place in ball mills. Various reagents are added, and the ore then passes through a secondary fine grinding circuit. Further reagents are added to the grinding slurry, which is then aerated in flotation cells. As a result of the reagents which have been added, the 'value' materials are wetted selectively and attach themselves to the air bubbles, which pass through the agitated slurry. The 'value' containing materials are then collected in the roughers, whilst the non-value materials remain in the water column.

The main reagent used in flotation are:

1. Dextrin, which acts for the depression of carbonaceous pyrite.
2. Sodium cyanide, which acts for the depression of sphalerite and eudrapyrite.
3. Xanthates, which act for Pb scavenging and as the sphalerite collector.
4. Copper sulphate, which acts as an activator for the sphalerite.
5. Methyl isobutyl carbinol (MIBC), which acts as a frother.
6. Hydrated lime, which is used for pH adjustment [Munro (1993)].

Vertical Jameson Cells are also used in the flotation circuits and with the Isa mills to help maximise recoveries of Ag, Pb and Zn. They have also helped to reduce the quantities of materials which need to be recycled in the circuits [MIM (1999)].

The Pb concentrate, thus produced, is thickened in a 45.7 m diameter thickener, prior to being pumped to storage tanks ahead of the Pb smelter. The Zn concentrate is thickened in 30 m diameter thickener and is then pumped to storage tanks where it is de-watered [Munro (1993)]. Further de-watering occurs via open air evaporation. It is then loaded into rail wagons and sold on to customers [MIM (1999)]. The tailings gravitate to the Wet Fill Plant, where they are cycloned to produce a 'sand', for the sand and cement wet fill, which is used underground in the mines. The fines are then combined with chalcopyrite fines (from the Cu concentrator tailings stream), and are pumped to three 61 m diameter thickeners [Munro (1999)]. About 75% of the water in the tailings stream is removed by this process, which is then re-used in the circuit water systems in the Mt. Isa complex [MIM (1999)]. The thickened tailings are then pumped to the Number 7 Tailings Dam on the mining lease. From here, they meander into the Number 8 Tailings Dam [MIM (1999)] where they settle out and the water evaporates to atmosphere.

The concentration process requires significant quantities of water. However, extensive water recycling is conducted. Indeed, water is reclaimed not only from the tailings stream in the thickeners, but also from the Pb and Zn concentrate thickeners, from the Number 8 Tailings Dam and from the wet fill.

e) Smelting:

The products from the Pb smelter, which is within the Mt. Isa central processing complex, are Isa crude Pb bullion, plus a small quantity of high grade dross. The Isa crude Pb bullion is transported to Britannia Refined Metals Ltd. (BRM), at Northfleet, Kent, UK, where it undergoes final refining. The high grade dross is sold to external customers overseas.

The purpose of smelting is to remove the majority of the impurities from the Pb and Ag. It involves three pyrometallurgical processes, which are conducted in sequence. These are:

1. sintering,
2. blast furnacing, and
3. dedrossing.

All three processes operate at high temperatures. Other ancillary processes manage the feed materials, products, co-products and waste streams associated with these three processes. These ancillary processes are, principally,

- the storage, mixing and conditioning of feed materials,
- hygiene ventilation,
- gas cooling and dust removal from the sinter machine and blast furnace exhaust streams,
and
- the casting of the 4 tonne crude bullion blocks.

Figure 10.19 summarises the interrelationships between the principal and ancillary processes diagrammatically.

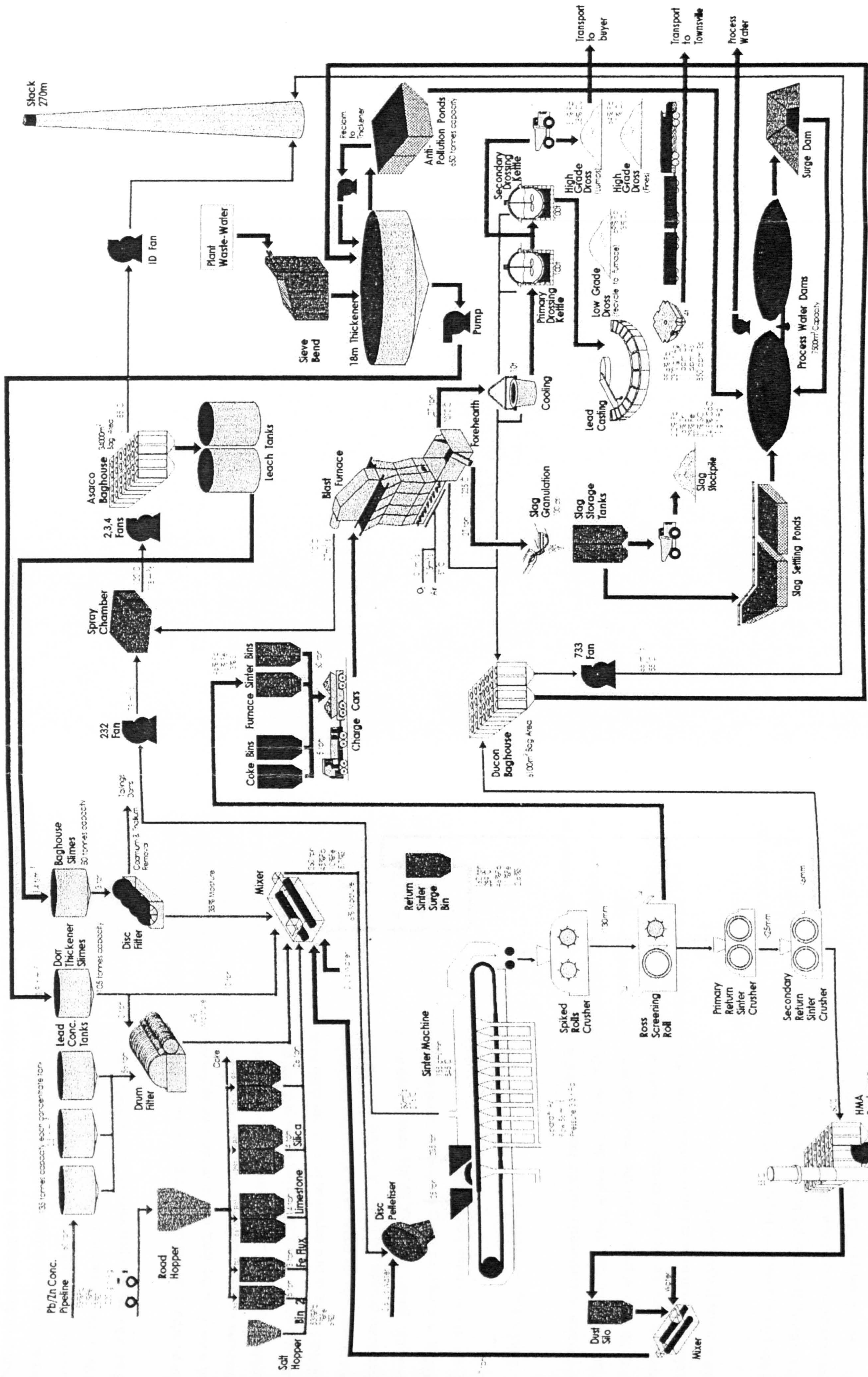
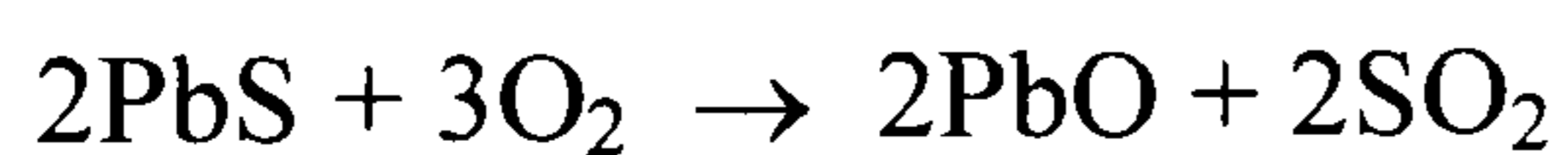


Figure 10.19: Pb smelter process flowsheet

The Pb concentrate is first de-watered, to 14% moisture approximately, in the filter plant. Then, prior to sintering, the Pb concentrate, fluxes, baghouse slime, hot return sinter and recycle dross are mixed using a twin-shaft paddle type unit [Ramus and Clift (1993)]. The fluxes (limestone and silica) are added to aid in the removal mainly of Fe impurities [MIM 91999)]. The mixture is then fed into a pelletiser. This converts the feed into disks, a form which enhances their permeability [MIM (1999), Ramus and Clift (1993)].

The principal purposes of sintering are to remove sulphur (principally in the form of PbS) and water from the feed, and to produce an agglomerate (sinter) that allows for effective ventilation and heat transfer in the blast furnace [MIM (1999)]. The design of the sinter machine, and its operation, are indicated in Figure 10.19. It shows that the sinter machine contains a conveyor belt of moving grates and that there are two sinter feed hoppers. The pelletised sinter is first deposited in a 40 mm thick layer on the moving grates from one of these hoppers. As the grates move along, this layer is ignited by an oil fired stove operating under down-draught conditions. A second 450 mm layer of material is then laid down on top of the ignited first layer by the second hopper. The air flow is now reversed, and sintering is completed using up-draught conditions [Ramus and Clift (1993)]. The sinter process may be summarised as follows:



The reaction is exothermic and the heat generated is sufficient to cause the material to partially melt and fuse. The sulphur dioxide gas (SO₂) is exhausted to atmosphere via the 270 m Pb smelter stack, whilst the sinter agglomerates are crushed, to make them of a manageable size for the blast furnace. The crushing process also produces fines. Since these are too small to be fed into the blast furnace, they are recycled by adding them to the sinter feed mix [MIM (1999)].

The blast furnace removes impurities, Fe, Zn, CaCO₃ and silicates, through heat separation [MIM (1999)]. It is charged in a layered manner with sinter, coke and a small amount of miscellaneous process scrap [Ramus and Clift (1993)]. Typical charge ratios are; sinter 89%, coke 9% and process scrap 2%. Molten material is tapped continuously from the furnace base into the forehearth well. Gravity causes it to separate into Pb and slag layers, due to the fact the molten slag is less dense than the molten Pb. The crude Pb is tapped

from the forehearth well into 10 tonne ladles, whilst the slag, which floats on the top, is allowed to overflow the forehearth into a 1.1 m³ settler. It is then ready for final removal of entrained Pb [Ramus and Clift (1993)]. This is conducted by recycling the Pb-rich slag underneath to the top of the blast furnace, whilst the discard slag (the overflow) is granulated by passing it through a stream of high pressure water. It is then placed in two large storage tanks prior to being transported to the slag dump.

Drossing is conducted on the molten crude Pb. Its purpose is to remove the majority of remaining impurities, which are Cu, As and Sb [MIM (1999)]. It is a four stage process. These are as follows.

1. Dirt drossing, where the temperature is lowered to 480°C. This causes the molten Cu to solidify. It then rises to the top of the molten Pb, from where it is skimmed off.
2. Caustic drossing, where caustic is added. This causes a dross to be formed containing Cu, As and Sb, which is skimmed off.
3. Sulphur drossing, where sulphur is added to the molten Pb. This causes a dross to be formed, which is skimmed off.
4. Second sulphur dross, where a series of cooling, sulphur addition, heating and stirring processes cause a further Cu-containing dross to be formed, which is skimmed off [MIM (1999)].

Once drossing has been completed, the crude Pb is pumped to the casting machine where it is formed into 4 tonne blocks.

The wearing of respiratory protective equipment is compulsory in most areas of the Pb smelter. Hygiene extraction is also provided to most areas, by means of exhaust fans, its purpose being to control dust in the air in workplace areas. The air thus removed, is passed through the HMA and Ducon baghouses, which filter it, prior to discharge into the atmosphere. This takes place via the 40 m HMA and 270 m Pb smelter stacks respectively [MIM (1999)]. Exhaust gases from the sinter machine and blast furnace are also filtered prior to discharge to atmosphere. This is conducted by passing them through the Asarco baghouse before emitting them via the 270 m Pb smelter stack. In addition, some areas of the Pb smelter, not ventilated to any of the baghouses, have their own dedicated stacks. For

example, the feed mixer has a wet scrubbing system, which collects particulates before discharging the air to atmosphere via the 446 Hydrofilter stack [MIM (1999)].

Dusts collected from the HMA and Ducon baghouses are recycled through the sinter plant, whilst dusts from the Asarco baghouse are collected in pooling tanks to produce baghouse slimes [MIM (1999)]. These may either be recycled in the sinter plant, or leached to remove Tl and Cd (depending on their concentration). The leach liquor is then pumped to the No. 8 Tailings dam for final disposal [MIM (1999)].

Process and storm water, from the Pb smelter, are collected by gravity in two lined earth dams. Pumps then feed it back into the Pb smelter recycled water system. Excess water, is pumped to the mine head water tanks [MIM 91999)]. In addition, anti-pollution ponds collect storm water from areas not connected to the lined earth dams. This water may either be combined with process water for re-use in the plant, or pumped to the Cu concentrator, where it is disposed of via the tailings system [MIM (1999)].

f) On-site transports:

Three groups of transports at the Mt. Isa complex have been modelled as separate atoms. These are:

1. miscellaneous transports of Hilton ore,
2. transports of mullock associated with Mt. Isa ore production, and
3. transports of various materials associated with the Mt. Isa Pb smelter.

Group 1 and 2 have been modelled from individual data entries in the transport movement records of MIM Ltd., at Mt. Isa, whilst group 3 transports have been amalgamated from 15 individual movement records.

All transports are conducted using 50 tonne dump trucks, except for the transports of coke breeze from the stockpile at Mt. Isa to the stockpile at the Mica Creek Power Station (MCPS), which is one of the movements comprising the group 3 transports. This is conducted using 35 tonne trucks.

g) Transport of ancillary materials:

The transports of ancillary materials to the Mt. Isa central processing complex are by a variety of means. Some transports are by rail or truck exclusively, whilst others undergo multi-stage journeys involving rail, truck (and for some substances) ship transport legs.

All ancillary transports have been modelled as separate atoms.

10.3.3.3. *Processes associated with the production of electricity consumed by the Hilton site and Mt. Isa complex*

Electric power for both the Mt. Isa central processing complex and for the Hilton site is supplied by the Mica Creek Power Station (MCPS). The MCPS facility is approximately 5 km south of the complex. Some additional electric power is provided within the Mt. Isa complex by the Mines Power Station (MPS). However, the principal activities of the MPS are the supply of high and low pressure air for the Pb and Cu smelters. In addition, it is linked to bulk oxygen generators which also supply the smelters.

a) Electricity generation by the Mica Creek Power Station (MCPS):

Currently, the MCPS is owned by a joint venture between MIM Ltd. (20%) and North West Energy Pty. Ltd. (80%), and is operated by North West Operations Pty. Ltd. [MIM (1999)]. The plant is authorised to generate up to 5000 MW per year of electricity by either a combination of coal, distillate and gas, or gas alone [MIM (1999)].

Prior to 1 October 1997, the fuel source of the MCPS was coal exclusively. However, from that date, a proportion of the electric power supplied to customers has been derived from the combustion of natural gas. Fly ash, from the combustion of the coal, is collected by scrubbers from boilers 1 and 2, and boilers 3 and 4 have electrostatic precipitators installed. Fly ash is disposed of as a slurry at the Number 8 Tailings Dam. Clinker, also

from coal combustion, is disposed of as landfill. Both disposal areas are on the Mt. Isa lease [MIM (1999)].

The sources of the raw water, used by the MCPS, are the Rifle Creek Dam and the Mt. Isa Terminal Reservoir. Waste water arises from cooling tower discharges, general site run-off, the coal and coke yard run-off, and the treated effluent from the MCPS sewage plant. Cooling tower waste water is also mixed with the fly ash to create the slurry, which is pumped to the Number 8 Tailings Dam.

Electricity is transmitted from MCPS to its consumers by overhead lines.

b) Transports associated with the MCPS:

Coal and coke yards are situated within the MCPS complex. The source of the coal, used by the MCPS, is the Collinsville coal mine (i.e. CCL). It is transported by rail directly from the Collinsville mine site to the MCPS. The transport route is from Collinsville, Qld. to Bowen, Qld., and then to the MCPS. Coke from Bowen coke works (i.e. BCL) is also transported by rail to the MCPS coal and coke yard. Here it is unloaded by a side-tipler onto trucks, which then transport it to the Mt. Isa central processing complex. Dust, arising from coke and coal handling operations in the yards, is suppressed by means of an irrigation system [MIM (1999)].

The distillate used by the MCP, is also transported by rail to MCPS, and is then pumped to on-site storage tanks. The natural gas is supplied to the MCPS by AGL (the Australian Gas Light Company), from the Ballera field, via a pipeline of approximately 890 km in length. The Ballera gas field covers an area traversing southern Queensland (i.e. Qld.) and northern New South Wales.

c) Electricity production by the Mines Power Station (MPS):

The MPS is located between the Cu and Pb smelters within the Mt. Isa central processing complex. Steam from the Cu Isasmelt waste heat boilers (and the Pb Isasmelt boilers, when

in operation) is fed by steam lines to the MPS. Here, it is used to drive turbines. During the period covered by the case study, however, the Pb Isasmelt was not in operation. Hence, the sole supply source of steam for the MPS was from the Cu Isasmelt. After use, the steam is condensed and re-used in the boilers [MIM (1999)]. The MPS has a capacity to generate up to 32.5 MW [MIM (1999)].

Water used at the MPS, is drawn from Lake Moondarra or Lake Julius [MIM (1999)], which are also the principal and secondary water sources, respectively, for the town of Mt. Isa.

Data for electricity production by the MPS were not obtained, and insufficient data were available to enable modelling of the process. However, the Excel file 'Mines Power Station and Oxygen Production' demonstrates that the contribution compared with that of the MCPS is minor. The sheets from this file have been enclosed in volume 2. They precede the input/output modelling data for oxygen production at the Mt. Isa complex.

d) Bulk oxygen production on the Mt. Isa site:

The three bulk oxygen manufacturing plants in the Mt. Isa complex, are powered by the MPS. They consist of two Linde L525 plants, each of which is rated at 525 tonnes of oxygen per day, and one Union Carbide U80 plant, rated at 71.5 tonnes per day. Oxygen is extracted from atmospheric air by being passed through filters and sieves to remove atmospheric dust, water vapour, carbon dioxide and hydrocarbons [MIM (1999)].

Input and output data for the MPS, for the period of the case study, have not been obtained. Hence, they have been estimated. The method used is described in the Excel file 'Mines Power Station and Oxygen Production', sheets from which have been enclosed in volume 2, and precede the input/output modelling data for this process.

e) Transports associated with oxygen production at the Mt. Isa complex:

All transports have been modelled as separate atoms.

10.3.3.4 *Transport of Isa crude bullion to BRM, Northfleet, UK*

The journey of the Isa crude Pb bullion from Mt. Isa to BRM is in two legs. The first is from Mt. Isa to the port of Townsville, Qld., and the second from Townsville to BRM.

a) Transport from Mt. Isa to Townsville:

The majority of the bullion blocks are loaded onto rail cars at the Mt. Isa central processing complex. They are then transported by rail to the port of Townsville. However, some blocks are used to back load transport containers to Townsville, which were used to bring ancillary materials to the complex on their outward journeys. Most of these back loads are by rail, though a small proportion are by road.

All of the rail and truck transports to Townsville have been amalgamated into one atom in the modelling.

b) Transport from Townsville to BRM:

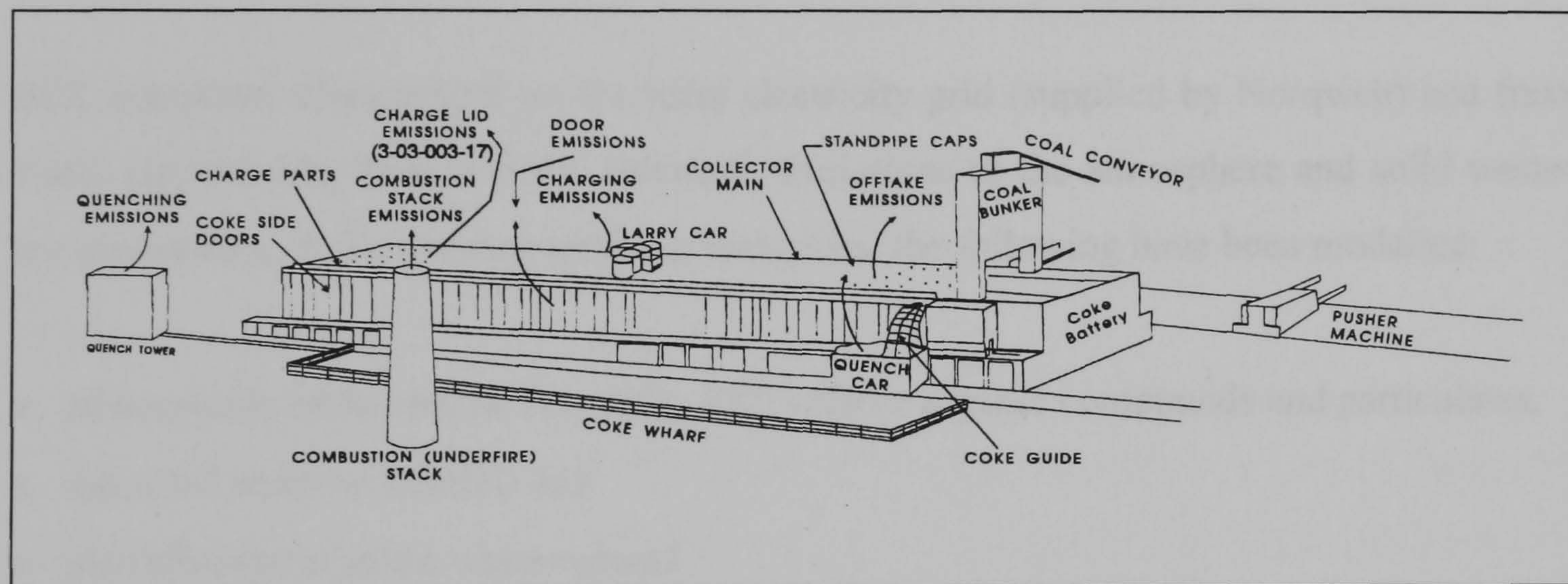
This journey is by ship. The ships pass through the Suez Canal, and are of the Panama type. Data regarding the tonnages transported have been used in the modelling. However, information regarding the actual route and distance have not been obtained. Therefore, they have been calculated on the assumption the ships follow recognised major shipping lanes, wherever possible.

10.3.3.5. Additional processes associated with the Hilton and Mt. Isa sites

The production of coal by Collinsville Coal Co. Pty. Ltd (CCL), Collinsville, Qld., and of coke by Bowen Coke Pty. Ltd. (BCL), Bowen, Qld., have been modelled. The transport of coal from CCL to BCL and to the MCPS, and of metallurgical coke from BCL to Mt. Isa, plus the transport of ancillary materials associated with all of the processes, have also been modelled.

a) Coke production by BCL:

Coke production at BCL is managed by MIM Townsville Operations, who also manage the MIM associated port operations at Townsville. Production at BCL is from a coke oven battery similar to the type illustrated in Figure 10.20.



[Note: Some details may differ slightly from BCL.]

Figure 10.20: A typical coke oven battery showing major emission sources

[US EPA (1995)]

The source of the coal, used to produce the coke, is the CCL coal mine at Collinsville. Coal from CCL is unloaded from rail cars, crushed and stored in bins.

Coke is produced using refractory brick lined bee hive type ovens. Currently, BCL has 54 such ovens in operation. Each oven is charged with coal for 72 hours approximately, before being emptied. After charging, the entry port to the oven is sealed using luting (pasted on

wet mud) to control the ingress of air. The coal in the ovens is carbonised and various gaseous products are given off. For this to occur, the temperature needs to be held above 900°C [US EPA (1995)]. The presence of other hot ovens immediately adjacent to newly charged ovens usually provide sufficient heat to start the process. However, some additional pre-heating of ovens may be required. Wood and diesel oil is used for this. No data were obtained for these consumptions, though they are believed to be relatively small. Since the process is exothermic, once the ovens have reached a sufficient temperature, the process becomes self-sustaining. On completion of the process, the oven is emptied by pushing the contents onto a receiving car, running on the BCL rail system. The car then transports the coke and ash to the quench facility, which cools the coke using water and prevents it from igniting. After quenching, the coke is pushed off onto conveyors, which transport it to crushers. It is then screened. The nut coke (smaller coke particles) and coke breeze (the fine product) are deposited into separate bins, whilst the metallurgical coke (the larger sized particles) is loaded into rail cars. The nut coke and coke breeze are stockpiled and sold on to external customers.

BCL consumes electricity from the local electricity grid (supplied by Norqweb) and fresh water (supplied by Bowen Shire Council). Emissions to the atmosphere and solid wastes are also produced. To account for these emissions, the following have been modelled:

- atmospheric emissions of SO₂, CO₂, CO, volatile organic compounds and particulates,
- ash solid waste to landfill, and
- the sediment in storm water run-off.

b) Transport of metallurgical coke from BCL to the Mt. Isa complex:

This is conducted in two legs. The first, is the rail transport from BCL to the MCPS coal and coke yard. The second, is the transport, by truck, from here to the Mt. Isa processing complex.

These two transport legs have been modelled as separate atoms.

c) Ancillary transports associated with BCL processes:

The transport to landfill of the ash, which collects in the quench pond, has been modelled.

d) Coal production by BCL:

The CCL mine is located 80 km south-west of Bowen, Qld., and produces steaming coal products using open cut techniques for both the domestic (Australian) and overseas markets [MIM (2000b)]. Mining operations are conducted by Thiess Contractors Pty. Ltd.

Coking coal is produced from seams in the western areas of the mining leases. Mining operations involve the overburden first being removed, using a combination of cast blasting, bull dozing and truck excavator removal [MIM (2000b)]. Then, continuous high wall miner (CHM) and strip mining techniques are used to remove the coal. The coal is loaded, using excavators and front-end loaders into rear-dump coal haulers, which transport it to the coal preparation plant. Here, it is blended and washed according to customer specifications [MIM (2000b)]. Steaming coal is mined using selective mining techniques, which involve discrete production passes being made. Steaming coal is crushed but is not washed.

Following mining and coal preparation, the coal is loaded into rail cars, which transport it various destinations including Abbott Point, Qld. (for export to external customers), the MCPS, and BCL.

CCL have made, and continue to make, substantial efforts to rehabilitate land disturbed by mining activities. Thus topsoil overburden, removed to obtain access to the coal, is stockpiled. In the rehabilitation process, mined waste is shaped to contours designed to minimise both erosion problems due to storm water run-off and water infiltration. The waste is then capped with an impermeable layer using an inert material and covered with topsoil. Finally, fertilisers and native plant seeds are added. CCL are committed to complete the backlog of all rehabilitation work by the year 2000.

The extent to which such rehabilitation was conducted during the modelled year (i.e. the calendar year 1998) is identified using the category 'Land rehabilitated'. This has been developed specifically to identify the extent of such work. CCL are also committed to fully rehabilitate currently existing infrastructure such as roads etc [MIM (2000b)].

The production of coal for use by BCL and by the MCPS, have been modelled using separate atoms.

e) Transport of CCL coal to the MCPS and to BCL:

These journeys, which are by rail, have been modelled as two separate atoms.

f) Ancillary transports associated with CCL processes:

All ancillary transports have been modelled as separate atoms.

10.3.4. Final refining (both streams) at BRM, Northfleet, Kent, UK

Final refining is conducted at BRM to produce the refined lead and lead alloy products from the Isa crude Pb bullion and the BZL crude bullion. The processing of the former is conducted by the Isa stream throughput through BRM, whilst the processing of the latter is conducted by the BRM stream throughput through BRM. The data and modelling in this case study have been extracted from that used in the BRM case study (chapter 9).

Since the modelling of these processes in this case study is exactly the same as in the BRM case study, the modelling and process descriptions for the Isa stream and BRM floor throughputs through BRM are applicable in their entirety here. Hence, the reader is directed to refer to section 9.3.1 of chapter 9 for this information.

10.3.5. Environmental emissions sources, concerns and abatement procedures

Emissions to the three environmental media (i.e. air, water and the land) occur through both controlled, as well as uncontrolled (i.e. fugitive) means, to varying extents, from all industrial processes. The types of such emissions, typically associated with primary refined Pb production, are identified in section 6.1 of chapter 6. Reviews of their potential human health and environmental effects have also been conducted in chapters 7 and 8.

For the processes associated with the life-cycle of the refined primary Pb products of MIM companies (modelled in this case study), some or all of these emissions may be more or less significant (or even negligible), depending the specific characteristics of the process concerned. This is because, for any given material being processed, the emission levels per functional unit of output, depend not only upon the technologies but also on the techniques used. For example, the atmospheric emissions of particulates and SO₂ from a specific pyrometallurgical process, will depend not only upon whether or not they are abated (using e.g. baghouse filtration and wet scrubbing technologies), but also upon the manner in which the materials giving rise to the emissions are handled and the efficiency of these abatement techniques. The latter will themselves depend not only upon factors such as process design, but also upon how they are managed (i.e. the maintenance techniques). Similarly, the extent of actual contamination of local water courses and aquifers by storm water run-off, from sites containing materials with the potential to pollute them, will depend not only upon whether anti-pollution ponds are established to catch the water emissions and their design, but also upon whether they are maintained properly and the manner in which the run-off is subsequently processed. Some technologies are also inherently cleaner environmentally than others. For example pyrometallurgical techniques, tend to give rise to greater emissions to the environment than do non-pyrometallurgical techniques.

The emission concerns will vary, therefore, from process to process and are ongoing. The foreground processes of the MIM primary refined Pb life-cycle are restricted to the UK and Australia (apart from the ship transport of MRM bulk concentrate and Isa crude bullion between the two). In both countries, the activities of industry are tightly regulated. Thus, where there are concerns regarding certain emissions from specific processes, these are

monitored and companies operating these processes are required to abate them to levels, considered by the national, regional and local industry regulators to be acceptable. However, it was explained in chapter 6 (section 6.1) that concerns regarding which types emissions and what quantities are significant are normative in nature (i.e. they are a reflection of the current concerns). They will, therefore, change with time. The developing pressures on the lead industry, such as demands for more sustainable forms of industrial development, and the threats to the future of the industry (identified in chapter 2) are indicative of these changes.

Partly in response to these changes, but also due to its desire to be a responsible organisation, MIM has adopted a corporate environmental policy (Table 10.9 overleaf) which goes well beyond the legal requirements placed itself or its subsidiary companies.

There is substantial evidence that these commitments by MIM and its companies are real and ongoing. This is provided, not only by the publication of annual reports by MIM, which report environmental performance and progress, but also by, amongst others:

- the active efforts and progress being made to develop environmental management systems for their operations,
- the site-level environmental audits which have been conducted,
- the risk assessment which are conducted on all major projects,
- the efforts being made to develop site level environmental performance standards,
- the setting of specific environmental performance targets for various activities, and the concerted efforts being made to ensure these targets are met,
- the openness with which MIM and its companies report their environmental performance,
- MIM's signatory to (and leading role in the development of) the Australian Minerals Industry Code for Environmental Management [Minerals Council of Australia (1996)] and
- the ongoing monitoring of the progress of MIM companies in meeting environmental objectives, at MIM board level, via review and compliance committees.

MIM Holdings Limited
Environmental Management Policy

As a fundamental policy, MIM group companies are committed to conducting their businesses responsibly and in a manner designed to protect their employees, the community's health and the environment.

In implementing the policy, the following goals will be pursued, namely we will:

- Design, develop and operate our facilities with a view to reducing the impact of our operations; ensuring efficient use of energy, water and other resources; minimising waste generation and disposal; and where waste must be disposed of, doing so responsibly.
- Assess the potential environmental effects of our activities and integrate environmental considerations into all aspects of our planning, operational decisions and processes.
- Strive for continuous improvement in our environmental performance and continually monitor and audit that performance.
- Advise and train our employees and contractors as necessary to meet our environmental undertakings.
- Ensure all our employees, and especially managers, are accountable for their environmental performance.
- Progressively rehabilitate areas no longer required for efficient operation using the most practical methods.
- Communicate with our employees, the community, regulators and other stakeholders in relation to environmental and heritage (and associated cultural and social) issues.
- Work with the community and governments in the formulation of environmental policy and regulation which affect us.
- Comply with legal requirements as a minimum and go beyond those requirements where necessary to comply with our fundamental policy.

Table 10.9: MIM Environmental Management Policy [MIM (1998)]

The author considers the sponsoring of this research project by MIM exemplifies the proactive and forward looking attitude of the company to environmental concerns.

10.3.6. The process of regulation, voluntary initiatives, and the contributions of this case study

Whilst regulations controlling the activities of industrial processes differ from country to country, the foreground processes of concern in this case study are restricted to the UK and Australia.

In the UK, the two principal companies where production processes relevant to the case study occur are:

- BRM, at Northfleet, Kent, and
- BZL, at Avonmouth.

Both BRM and BZL are authorised to operate their processes, under the regime of Integrated Pollution Control (IPC), under Section 6 of the UK Environmental Protection Act (EPA, 1990). As defined in EPA (1990), and its subsidiary regulations, both BRM and BZL operate Part A Prescribed Processes, under the category “non-ferrous metals”, which are best described by Section 2.2 of SI No. 472 Environmental Protection (Prescribed Processes and Substances) Regulations 1995. Therefore, BRM and BZL are required to meet the environmental protection requirements provided for by EPA (1990) and its subsidiary regulations.

In Australia, the principal companies where production processes relevant to the case study occur are:

- MRM, at McArthur River, N.T.,
- CMS at Bing Bong, N.T., and
- MIM Ltd., at Mt. Isa, Qld.

MRM and CMS are required to meet the various Australian environmental protection requirements “provided for in:

- the McArthur River Project Agreement Ratification Act 1999, as amended,
- the McArthur River Project Agreement,
- Mineral Leases N1121 - N1126 (inclusive),
- the Mine Management Act, and
- applicable laws of the Northern Territory and Commonwealth of Australia” [MRM (1998)].

The activities of MIM Ltd., at Mt. Isa and Hilton in Queensland, Australia, “to the extent to which they have or may have an environmental impact, are regulated by:

- the Environmental Protection Act 1994,
- the Mount Isa Mines Limited Agreement Act 1985, and
- the Mineral Resources Act 1989” [MIM (1999)].

MIM Ltd. also operate under the following control documents:

- two separate licences issued under the Environmental Protection Act 1994,
- an Environmental Management Overview Strategy (EMOS), under the Mineral Resources Act 1989, and
- a Mining Plan, under the Mount Isa Mines Limited Agreement Act 1985 [MIM (1999)].

Whilst the regulatory regimes under which these companies in the UK and Australia operate differ, they are based on the general assumption that decisions may be made on the basis of weighing up the relative pros and cons of different options. Hence, they are essentially pragmatic in nature. In the UK, specific approaches such as BATNEEC (best available techniques not entailing excessive costs) and BPEO (best practicable environmental option) have been developed to help regulators in this pragmatic ordering process.

In addition to regulatory requirements, MIM are a leading signatory to the Australian Minerals Industry Code for Environmental Management [Minerals Council of Australia (1996)]. This voluntary agreement, developed proactively by Australian mining companies, commits signatories to several key obligations indicated in Table 10.10.

Key obligations of signatories to the Code include:

- developing and implementing comprehensive environmental management systems;
- committing to continual improvement, while recognising that environmental management technology and community standards change;
- identifying stakeholders and providing them with information on proposals and operations;
- applying risk management techniques in planning and selecting options for operations and activities;
- requiring contractors to comply with company environmental policies and practices whenever they operate on the company's behalf or on company sites;
- prepare publicly available annual environmental reports that demonstrate performance against code principles and indicators;
- committing to evaluation of Code conformance at least every three years by a qualified externally-accredited internal auditors or by appointed external auditors

All signatories will take reasonable steps to implement the Code. A signatory conforms with the Code once it has systems and processes in place to implement Code principles.

Table 10.10: The Australian Minerals Industry Code for Environmental Management -Key obligations [Minerals Council of Australia (1996)]

In the UK, BRM and BZL operate environmental management systems, accredited to the ISO 14000 standard, which place additional environmental performance commitments on these companies.

It should be noted, however, that legislative frameworks, their subsidiary regulations, and voluntary agreements and commitments are normative. This is because they aim to reflect current concerns. They are, therefore, subject to periodic adjustment and replacement. For example, in the UK, the regime of IPC is to be replaced by Integrated Pollution Prevention and Control (IPPC), whose emphasis is likely to be more on prevention than on end-of-pipe (i.e. abatement) solutions. It may be argued that this change in emphasis is a reflection of the increasing strength of the demands for more sustainable and efficient means of industrial production.

Therefore, the approaches developed in this case study, and in the BRM case study (chapter 9), provide crucial data and assessments, aimed at facilitating the development of adaptive approaches, which will:

- enable the lead industry to meet legislative and regulatory changes occurring both nationally and internationally, and
- help guide legislators in their drafting.

They are also intended to contribute to the development and articulation of the lead industry's response to the environmental challenges which lie ahead, at different scales ranging from the global to the site specific. Part of this response is likely to include voluntary commitments such as those in the Australian Minerals Industry Code for Environmental Management.

10.4. MIM primary lead products: Inventories, assessments of potential human health and environmental effects, and comparisons

10.4.1. Background and derivation of the modelling and assessment approaches

The overriding purpose of this study is to provide MIM and its subsidiary companies with a cradle-to-gate scale, and individual product stream scale approaches, which will act as a practical foundation for the company for dealing with current and future environmental challenges. Though applicable on their own, they are part of a wider strategy designed to function multi-dimensionally i.e. at different scales. The structure of these approaches have, therefore, been designed to be pre-adapted for full integration into other approaches, which will be developed to operate at other scales. Indeed, the means by which such integration is to be achieved is demonstrated by the way in which appropriate elements of the modelling in this case study have been extracted and used within the BRM case study. This study, which is principally a whole site scale assessment, developed by the author for BRM, is included within this thesis, in chapter 9.

For the approaches in this case study to be fully commensurate with other scale approaches, similar framing assumptions and compatible system boundaries are required. However, the approaches also still need to be able need to take full account of the fact that the emphasis for environmental and human health effects assessments tends to differ significantly when they are required at different scales. Thus, whilst individual MIM companies are part of the MIM group and so share common interests, each tends to have its

own foci. These are on its own site(s), its own throughputs, and its own specific emission sources, since they may be directly attributed to its own activities. MIM, on the other hand, is more concerned with the strategic planning and management of environmental and human health effects across its whole group of companies. Therefore, whilst it would still have some interest in individual site concerns, the primary focus of its interests tends to be directed towards more holistic (i.e. life-cycle type) concerns such as:

- comparing the environmental performance of different processes and stages in the life-cycle of a specific product,
- the environmental performance between products and
- competing systems providing an equivalent service, either as a single snapshot or as trends over time.

Thus, approaches developed to operate at these different scales need to be able to reflect these differences, whilst, at the same time, appropriate elements of them also need to be readily extractable and able to be incorporated into approaches developed for other specific scales of focus.

These requirements are met by the use of a nested node type of structure, where individual nodes are derived from selected data modules and appropriately adjusted to fit the purpose to which they are put within the tool. Thus, the system boundaries become defined by the number and type of modules, which have been derived and linked together. The fundamental framing assumptions also tend to be similar, as regardless of the scale at which the approach has been developed, the approach is based on aggregated nodes derived from similarly constructed modules and in some cases some of the modules selected for use in different approaches may actually be the same.

The sheets entitled 'MIM Pb LCA TEAMTM Model Structure', which are enclosed as Document A2 (in the Appendix), demonstrate that the modelling has been conducted in a hierarchical manner, with the lower levels (the higher level numbers) being subsumed fully into the higher levels (the lower level numbers). The sheets also indicate that the MIM Pb LCA contains up to 8 levels at its greatest depth, and that there are two types of data atoms:

- system nodes, which represent operations (and are composed of aggregates of lower order nodes), and
- atomic nodes, which represent the individual modelled processes (and are not subdivided further).

In the sheets entitled 'MIM Pb LCA TEAM™ Model Structure' system nodes are denoted by the symbol 'S' and atomic nodes by the symbol 'A'.

The atomic nodes are derived from modules, which have been given the same name and contain the data collected from the various processes which have been modelled. Atomic nodes and modules differ from each other, in that the latter contain the actual site data, normalised to the functional output for that process only, whilst the former contain data normalised appropriately to the functional unit of output for the whole system being modelled. The quantity and nature of the functional units of output used in this case study are identified and discussed in section 10.4.2.2.

The modules and inventories for primary Pb refining processes at BRM are also directly compatible with the overall site scale and individual throughputs through the site scale modelling developed by the author in the BRM case study. This is because, they use two of the same modules; the 'No. 1 Refinery' and the 'BZL Throughput' modules, to derive atomic nodes, which are used to develop the inventories and assessments provided in that case study.

This type of approach has been possible through the adaptation of the TEAM™ LCA modelling software to a site-specific mode. The advantages and disadvantages of the use of the TEAM™ software for this purpose are discussed in section 9.6.4 (chapter 9) of the BRM study, and in the Overall Conclusions and Recommendations (in chapter 11).

10.4.2. Scopes of the Inventories and Assessments

There is now an international standard, ISO 14040:1997, which considers the general framework of LCAs and which defines their "key features". There is also an ISO standard, ISO 141041:1998, defining the characteristics of the LCA phases of goal and scope

definition, and inventory analysis. Those ISO key features for LCA which are applicable for the LCA modelling, inventories and assessments provided in this case study, are reviewed below.

10.4.2.1. System boundaries

The foreground system boundary has been placed around what are considered, currently, to be the major concerns of MIM, and its subsidiary companies, associated with the life-cycle of MIM's Pb products. These are the potential environmental and human health effects attributable to its primary refined Pb production and ancillary processes, which are under the direct control of its companies. Background activities (i.e. ancillary material productions and transports, fuel production and transports, and waste disposal operations and transports) have also been considered, but have been characterised using databases which model the average or typical conditions. Thus, the foreground part of the system has been modelled using site specific data, whilst the background part has been modelled using generalised data. This approach, has been adopted, since it is peoples' concerns regarding the human health and environmental effects of its metal refining operations (i.e. its foreground system operations) which threaten, most directly, the future of MIM and the Pb industry in general. Therefore, detailed knowledge of the site specific effects, is necessary to provide the material basis for making decisions at this crucial scale. For the background activities, however, the environmental challenges tend to be similar to those for the rest of industry in general. Hence, it is considered appropriate, currently, to model these using such generalised data. However, since the framework is inherently flexible, the foreground system boundary could be easily modified, in the future, to incorporate one or more of these background processes within the foreground, as and when it might be deemed necessary.

Transports flows, of raw material and fuel inputs and waste material outputs, have been treated as crossing between the foreground and background systems.

The foreground inflows and outflows involved in the life-cycle of MIM's primary refined Pb products (illustrated in Figure 10.2), are detailed in the input/output sheets for each process, in volume 3 of the Portfolio.

10.4.2.2. *Functional Units of Output*

ISO 14040:1997, notes the scope of an LCA study should state clearly the functions of the system being studied, and that the functional unit should be a measure of the functional outputs of this system. Hence, it is arguing that the functional output should be based upon the units of service which the product(s) provide. This definition for the functional unit is necessary to ensure a common basis for comparison of results between LCAs, which have different material outputs but have similar functional outputs.

However, the assessments conducted in this case study all have functional outputs based on mass (a material output). This is considered to be acceptable, for these assessments even though the approach is not fully compliant with the ISO standard, for the following reasons:

1. All comparisons which are made, are between outputs similar both materially and functionally. Therefore, the use of functional outputs based on units of service would make no effective difference to any of these comparisons.
2. The assessments have been designed to meet, most effectively, the needs of MIM and the personnel within its subsidiary companies, who normally think in terms of mass rather than functionality.
3. Future iterations of the modelling may be adapted, with relative ease, to have a functional output based units of service.

In each assessment, the functional unit of output is 1000 kg of the material in question for solid materials, and 1 litre for liquid outputs.

10.4.2.3. *Allocated and Unallocated Systems*

The processes involved in the cradle-to-gate life-cycle of MIM's primary refined Pb and Pb alloy products, give rise to several co-products and by products. The modelling of such multiple outputs may be achieved in two possible ways. Either, the contributions to the inflows and outflows in the inventories associated with the co-products and/or by-products may be excluded, with the result that the inventories represent only that fraction of the total which is associated with the Pb and Pb alloys. Or, the contributions of the co-products and by-products are included. In the former case, the product outputs are 1000 kg of refined Pb and Pb alloys only. In the latter case, the products are 1000 kg of the refined Pb and Pb alloys, plus the appropriate quantities of the other co-products and by-products. In the latter case, data normalised to the functional unit of output, but not otherwise manipulated, are used. However, in the latter case, some form of allocation (i.e. manipulation) is required.

Both approaches are valid as means of modelling systems, certainly at the life-cycle scale. Therefore, the modelling has been duplicated in its entirety for both allocated and unallocated approaches. The usefulness and disadvantages of each approach, are discussed in section 10.6 of this chapter, and in the Overall Conclusions and Recommendations (chapter 11).

10.4.2.4. *General Characteristics of the Data Used*

The foreground system data, used to develop the input/output data sheets (in volume 3 of the Portfolio), have been produced from data provided by site personnel involved in the management of the processes being modelled, and cover one calendar year. Therefore, they are actual production and consumption data. A data coverage of one calendar year, has been selected, to try to ensure that short term fluctuations, and those associated with seasonal variations, are taken into account. In some cases, it has been necessary to partition data between different throughputs. Where this has been necessary, the means by which it has been achieved is indicated clearly in the notes at the bottom of the relevant input/output sheet. In addition, its potential influence upon the overall findings of the assessments is assessed by sensitivity analysis, and in the discussion and conclusions to the case study (section 9.6.4). The likely precision, completeness and representativeness of the data are

also characterised on the input/output sheets by the use of a scoring system for each characteristic considered. A description and a key to this scoring system prefaces the MIM case study input/output data sheet set in volume 3 of the Portfolio.

Transport data (which cross between the foreground and background systems) have been provided by site personnel, though DEAMTM transport data modules have been used to derive the transport inventory data sheets, which are also enclosed in volume 3 of the Portfolio. Data characterisation columns, similar to those for the other material and fuel input/output data sheets, have been provided on these sheets.

Since it is not practical to model every single input or output, however trivial, only those which are considered 'significant' should be modelled. The criteria which the author considers should be used for identifying whether an input or output is 'significant' or not, and hence is to be monitored, is possession of one or more of the following:

- it is already monitored by site personnel of the MIM company whose process is being modelled,
- its consumption or production is a concern to the general public on environmental, human health or resource depletion grounds, or
- it is tracked in the BRM case study, and so should be tracked in the MIM inventories, if total compatibility with them is to be achieved.

The author has not been able to obtain all possible data pertaining to all of these categories. For example, no data have been obtained for lubricant consumption, even though it is a 'significant' concern on the grounds that its production and transport to the site of use consumes significant quantities of raw materials and fuels. However, since the expectation is that the inventories and assessments developed herein will continue to be developed, any such omissions will be overcome in future iterations

The uncertainty associated with every modelled input and output flow, is considered qualitatively in the TEAMTM module and node flow information boxes, which may be accessed by pressing the <INFO> buttons.

Further discussion of the overall uncertainty associated with the findings of the assessments is provided in the overall discussion and conclusions to this chapter (in section 10.6.4).

10.4.3. Inventories, Assessments and Comparisons

10.4.3.1. Introduction

The data input/output sheets provided in the Portfolio, show two types of data, namely:

1. The actual annual input and output data for the process in question. (Most of these data, are as supplied by the site personnel of the MIM company whose process is being modelled. However, as noted in section 10.4.2.4, in some cases it has been necessary to estimate certain flows using partitioning parameters.)
2. Annual input and output data, normalised to the functional unit of output for the process being modelled. (These data have been calculated directly from the actual annual input/output data.)

The input/output data are of two types: terminal exchanges and non-terminal exchanges. Terminal exchanges, are those which either input into the process in question directly from the environment, without additional processing, or output directly into it, and undergo no further processing. Non-terminal exchanges, are those which input into the process in question within the foreground system, from other processes within the background system (such as ancillary material manufacturing operations), or output from the process in question within the foreground system, to other processes within the background system (such as waste disposal operations).

Wherever possible, the normalised non-terminal input/output exchanges have been linked to background system DEAMTM data modules using the TEAMTM software. The DEAMTM modules provide cradle-to-gate life cycle inventories (LCI) for each the raw material and fuel inputs, and gate-to-grave inventories for each of the outputs. The TEAMTM software, adjusts the values in these database inventories so they are representative for the quantity of the material or energy they are being used to model (i.e. the functional output).

The inventories associated with each of the DEAMTM data modules, plus any terminal inputs and outputs for the process in question, are compiled into overall inventories, which include both the background and foreground parts of the system, for the process in question. (These inventories are provided in volume 4 of the Portfolio.) In some instances, however, suitable DEAMTM or other LCI data to model certain types non-terminal exchanges are not currently available. In most cases it has been possible to model the LCI data for the exchange using a close equivalent. For example, steel banding has been modelled using steel coil. In a very few cases, however, no suitable data are available. Where this has occurred, it has not been possible to account for the full inventories associated with these exchanges. Where such approximations or omissions have been necessary for a process, this is clearly recorded, both within the TEAMTM information box for the flow, and in the notes in the input/output data sheets in the Portfolio for the flow. They are also summarised in section 10.6.4, where their potential influences on the overall findings of the case study are assessed.

Environmental impact assessments have been generated using the TEAMTM software from these inventories. In accordance with common practice in LCAs, the categories used for these impacts are similar to those in Table 5.1. Hence, these environmental impact assessments also assess human health impacts as they are accounted for in the impact category of Human Toxicity. This approach, called the 'Problem Oriented Approach', was developed by the Centre of Environmental Science (CML), of the University of Leiden, in The Netherlands. In the CML approach, environmental impacts are calculated by multiplying individual types of terminal exchanges (i.e. inventory flows) by a weighting factor. This weighting factor is assigned relative to a reference burden. Thus, for example, for the impact category of Global Warming, carbon dioxide (CO₂) is assigned a weighting factor of 1. Other emissions are assigned values greater and lesser than 1 depending on their own global warming potentials (GWP) relative to CO₂. The individual contributions from each of the exchanges are then summed to produce the total contribution for that impact category.⁸⁹

⁸⁹ Explanations of the process of impact assessment within an LCA context, of the Problem Oriented and other approaches, and of the exact method of calculation of impacts, have been provided in the elective module assignment, which has been enclosed as Document 15, in volume 2 of the Portfolio. This document has not been provided with this copy of the thesis.

A complete set of inventories are provided in the Portfolio for the systems which have been studied. This has been conducted, as they are intended to form the basis of a database for MIM, its subsidiary companies and other interested parties, which, it is hoped, will be updated on a regular basis (e.g. annually). However, the inventory graphs provided at the end of this chapter in section 10.7, are merely a selection of the more 'significant' inflows and outflows. (The criteria for deciding which flows are deemed 'significant', are provided in section 10.4.3.2.2.) Similarly, the impact assessment graphs and the graphs comparing the inventories and impacts of different systems (also in section 10.7), show only the most 'significant' inventories and impacts. They are not intended to provide an exhaustive analysis. However, should BRM, or any other parties, need to examine any other of the inventory flows or impacts in the future, this would be relatively easy task using either the inventory tables in the Portfolio alone, or in conjunction with the TEAM™ LCA software.

Finally, it should also be noted, the environmental impacts calculated in the impact assessments are in fact potential impacts i.e. the types and quantities of the flows in the inventories for the systems concerned, have the potential to give rise to impacts in each of the categories to the extent indicated. Whether or not they occur, in reality, depends on the actual fate in the environment of the inventory flows concerned. This question is not addressed in these case studies. To address it, site impact pathway assessment (IPA) approaches, as described in section 5.3 of chapter 5 would be required. To give a complete picture, these IPA approaches would also need to be conducted for both the foreground and background systems.⁹⁰

10.4.3.2. Inventories

10.4.3.2.1. Introduction

Table 10.11 indicates the complete set of Excel file based inventory tables which have been collated for the 'MIM Pb LCA (unallocated)' TEAM model, and which have been also enclosed as sheets in the Portfolio. A similar set of Excel files and sheets, have also been created for the 'MIM Pb LCA (allocated)' model. These sheets have also been enclosed in the Portfolio.

Excel file name	Sheet name (where applicable)	Comprising nodes	Level	Code
ecobalunalloc2(1)		MIM Pb (all operations)	1	unalloc/-
		BRM stream (all operations)	2	unalloc/A
		BRM Stream (UK operations)	3	unalloc/A1
		McArthur River Stream (Australian Operations)	3	unalloc/A2
		Isa Stream (all operations)	2	unalloc/C
		Isa Stream (Australian operations)	3	unalloc/C1
		Isa Stream (UK operations)	3	unalloc/C2
ecobalunalloc2(2)		BRM stream (all operations)	2	unalloc/A
		BRM Stream (UK operations)	3	unalloc/A1
		BRM: Lead Refining Operations (BRM floor throughput)	4	unalloc/A1,1
		BRM: On-site Electricity Generation Operations (BRM floor throughput)	4	unalloc/A1.2
		BRM: Overheads to BZL Input to BRM Floor Throughput Operations	4	unalloc/A1,3
		BRM: Overheads to MHD Input to BRM Floor Throughput Operations	4	unalloc/A1,4
ecobalunalloc2(3)	Section 1 of 5	BRM Stream (UK operations)	3	unalloc/A1
		BZL: Mixed Concentrate Processing Operations at Avonmouth	4	unalloc/A1,5
		BZL: Effluent Treatment Operations	5	unalloc/A1,5,1
		BZL: Materials Handling, Sintering, Smelting, Acid Production and Cd and Zn Processing Operations	5	unalloc/A1.,5,2
		BZL: Cadmium and Zinc Refining Operations	6	unalloc/A1,5,2,1
ecobalunalloc2(3)	Section 2 of 5	BZL: Mixed Concentrate Processing Operations at Avonmouth	4	unalloc/A1,5
		BZL: Cadmium and Zinc Refining	7	unalloc/A1,5,2,1,1
		BZL: Overheads (refined Cd production)	7	unalloc/A1,5,2,1,2
		BZL: Overheads (refined Zn production)	7	unalloc/A1,5,2,1,3
		BZL: Cadmium Ion Exchange Operations	6	unalloc/A1,5,2,2

⁹⁰ This represents an area for further research.

ecobalunalloc2(3)	Section 3 of 5	BZL: Mixed Concentrate Processing Operations at Avonmouth	4	unalloc/A1,5
		BZL: Lead Bullion Production Operations -Imperial Smelting Furnace	6	unalloc/A1,5,2,3
		BZL: Lead Bullion Production - Imperial Smelting Furnace	7	unalloc/A1,5,2,3,1
		BZL: Overheads (Pb bullion production)	7	unalloc/A1,5,2,3,2
		BZL: Materials Handling Operations	6	unalloc/A1,5,2,4
ecobalunalloc2(3)	Section 4 of 5	BZL: Mixed Concentrate Processing Operations at Avonmouth	4	unalloc/A1,5
		BZL: Sinter Process Operations	6	unalloc/A15,2,5
		BZL: Sulphuric Acid Production Operations	6	unalloc/ A1,5,2,6
		BZL: Overheads (sulphuric acid production)	7	unalloc/A1,5,2,6,1
		BZL: Sulphuric Acid Production	7	unalloc/A15,2,6,2
ecobalunalloc2(3)	Section 5 of 5	BZL: Mixed Concentrate Processing Operations at Avonmouth	4	unalloc/A1,5
		BZL: Steam Production Operations	5	unalloc/A1,5,3
		BZL: Office Waste Disposal Operations	4	unalloc/A1,6
		Truck Transport Operations for Lead Bullion (BZL to BRM)	4	unalloc/A1,7
ecobalunalloc2(4)	Section 1 of 3	McArthur River Stream (Australian Operations)	3	unalloc/A2
		CMS: Bing Bong operations	4	unalloc/A2,1
		CMS: Bing Bong Concentrate Handling Operations	5	unalloc/A2,1,1
		CMS: Overheads Associated with Bing Bong Activities	5	unalloc/A2,1,2
		CMS: Sea Barge Transport Operations	5	unalloc/A2,1,3
ecobalunalloc2(4)	Section 2 of 3	McArthur River Stream (Australian Operations)	3	unalloc/A2
		CMS: Electricity Production Operations at Bing Bong	4	unalloc/A2,2
		MRM: Electricity Production Operations at McArthur River	4	unalloc/A2,3
		MRM: McArthur River operations	4	unalloc/A2,4
		HTS: Operations Associated with Transport of Mixed Concentrate to Bing Bong	5	unalloc/A2,4,1

ecobalunalloc2(4)	Section 3 of 3	McArthur River Stream (Australian Operations)	3	unalloc/A2
		MRM: Mixed Concentrate Production Operations at McArthur River	5	unalloc/A2,4,2
		MRM: Ore Mining Operations at McArthur River	5	unalloc/A2,4,4
		Ship Transport Operations for McArthur River Mixed Concentrate	4	unalloc/A2,5
ecobalunalloc2(5)		Isa Stream (all operations)	2	unalloc/C
		Isa Stream (UK operations)	3	unalloc/C2
		BRM: Lead Refining Operations (Isa stream)	4	unalloc/C2,1
		BRM: On-site Electricity Generation Operations (Isa floor throughput)	4	unallocC2,2
		BRM: Overheads (Isa stream operations)	4	unalloc/C2,3
ecobalunalloc2(6)	Section 1 of 7	Isa Stream (all operations)	2	unalloc/C
		Isa Stream (Australian operations)	3	unalloc/C1
		Isa Lead Bullion Shipping Operations to BRM (UK)	4	unalloc/C1,1
		Operations Associated with Mt. Isa Site	4	unalloc/C1,2
		Bowen Coke Works (met. coke production operations)	5	unalloc/C1,2,1
ecobalunalloc2(6)	Section 2 of 7	Isa Stream (Australian operations)	3	unalloc/C1
		BCL: Coke Production Operations at Bowen	6	unalloc/C1,2,1,1
		Operations Associated with Transport of Met. Coke to Isa	6	unalloc/C1,2,1,2
		Bowen Met. Coke: Rail Transport Operations (BCL to MCPS)	7	unalloc/C1,2,1,2,1
		Bowen Met. Coke: Truck Transport Operations (MCPS to Mt. Isa)	7	unalloc/C1,2,1,2,2
ecobalunalloc2(6)	Section 3 of 7	Isa Stream (Australian operations)	3	unalloc/C1
		Collinsville Operations (coal for coke production)	5	unalloc/C1,2,2
		CCL: Coal Mining Operations at Collinsville (coal for coke production)	6	unalloc/C1,2,2,1
		Rail Transport Operations (coal to BCL)	6	unalloc/C1,2,2,2
		Collinsville Operations (coal for Mica Creek Power Station)	5	unalloc/C1,2,3

ecobalunalloc2(6)	Section 4 of 7	Isa Stream (Australian operations)	3	unalloc/C1
		CCL: Coal Mining Operations at Collinsville (coal for Mica Creek Power Station)	6	unalloc/C1,2,3,1
		Rail Transport of Coal to Mica Creek Power Station	6	unalloc/C1,2,3,2
		Hilton Operations	5	unalloc/C1,2,4
		Hilton Mined Ore Transport Operations	6	unalloc/C1,2,4,1
ecobalunalloc2(6)	Section 5 of 7	Isa Stream (Australian operations)	3	unalloc/C1
		Hilton Mining Operations	6	unalloc/C1,2,4,2
		MCPS: Electricity Production Operations (Mica Creek Power Station)	5	unalloc/C1,2,5
		Mount Isa Lead Stream Processing Operations	5	unalloc/C1,2,6
		MIM: Lead Smelting On-site Transport Processes	6	unalloc/C1,2,6,1
ecobalunalloc2(6)	Section 6 of 7	Isa Stream (Australian operations)	3	unalloc/C1
		MIM: Lead Smelting Processes at Mt. Isa	6	unalloc/C1,2,6,2
		MIM: Lead Smelting at Mount Isa	7	unalloc/C1,2,6,2,1
		MIM: Zinc-Lead-Silver Ore Concentration Processes at Mt. Isa	6	unalloc/C1,2,6,3
		MIM: Zinc-Lead-Silver Ore Mining Processes at Mt. Isa	6	unalloc/C1,2,6,4
ecobalunalloc2(6)	Section 7 of 7	Isa Stream (Australian operations)	3	unalloc/C1
		MIM: Processes Associated with Transport of Isa Lead Bullion to Townsville	6	unalloc/C1,2,6,6
		MPS: Bulk Oxygen Production Operations	5	unalloc/C1,2,7

Table 10.11: Complete list of nodes for which inventories have been developed in this case study, using the ‘MIM Pb LCA (unallocated)’ TEAMTM model, and collated in the Portfolio

Each of the files listed in Table 10.11 contains inventories for the nodes indicated. The levels and codes identify their position according to the modelling structure shown in the sheets entitled: ‘MIM Pb LCA TEAMTM Model Structure’ (which preface the collated inventory sheets in the Portfolio, and which have been enclosed as Document A2). The collated inventory sheets have been designed, so the data in the lower levels (i.e. higher level numbers) are subsumed into the higher levels. For example, in Excel file:

'ecobalunalloc2(2)', the level 4 data atoms are subsumed within the higher level (level 3) data atom which is: 'BRM stream (UK operations)'.

The collated inventories (in volume 4 of the Portfolio) are all of systems nodes, even at the lowest levels. For example, even data atom: 'BZL: Sulphuric Acid Production' code: A1.5,2,6,2, which is at the lowest level at which inventory data have been collated, is a system node. This approach has been adopted, since atomic nodes contain input and output data only in the categories originally entered by the author. Hence, they have been collated, and are enclosed as separate sets of sheets in volume 4 of the Portfolio.

The categories of the inventory articles in the collated inventory sheets, are the same as those provided for the BRM case study. Hence, they are as indicated in Table 9.2. Each set of sheets contains over 400 different data articles.

The principal aim of the research has been to create a database which MIM, its subsidiary companies, and industry in general may use for their own comparisons and assessments. The sheets enclosed in the Portfolio provide this database. However, as an indication of its usefulness for helping to develop environmental performance indicators and, hence, for aiding environmental decision making, some simple comparisons of some of the more 'significant' inventory articles have been conducted and enclosed in this thesis. Any of the other inventory inflows and outflows may also be compared relatively easily, at a later date, should someone wish to do so.⁹¹

⁹¹ This is an area for further research.

10.4.3.2.2. Identifying 'significant' flows in the inventories

The criteria for identifying inventory flows as being 'significant', are to be included in one or more of the following categories.

1. To be in the TEAM PlusTM list of automatic charts, which are part of the software package provided by Ecobilan, for the analysis of inventory data generated using their TEAMTM modelling tool. [See Ecobilan (1995).]
2. Specific flows considered significant by MIM, its subsidiary companies, and its regulators. For example emissions reported by BRM to the UK EA, or monitored by MIM in its annual environmental reports. [See BRM (1995) and MIM Holdings Ltd. (1998) respectively.]
3. Flows which are closely associated with the flows selected under any of the other criteria. For example, emissions of '(a) Hydrocarbons (except methane)' are significant because they are reported on an annual basis to the UK EA. Closely associated with these are emissions of '(a) Hydrocarbons (unspecified)'. Hence, these also need to be considered.
4. For the quantity of the flow at the highest system level, in the unallocated model, when normalised to the functional unit of 1000 kg of final lead product, to be:
 - a) $\geq 5.00E+01$ kg for resource consumptions,
 - b) $\geq 1.00E+04$ mg, kg or litre for ancillary materials (secondary),
 - c) $\geq 1.00E+04$ g for air, water and ground emissions, and
 - d) $\geq 1.00E+01$ kg for wastes.

Criteria 1 and 2 are normative rather than arbitrary, since these flows would be expected to reflect, broadly speaking, current concerns. Hence, the flows thus selected as 'significant', reflect societal concerns. However, it has also been necessary to adopt two additional non-normative criteria. The aim of the first (criterion 3) is to ensure that flows allied to the identified criteria are also tracked. The aim of the second (criterion 4), is to try to ensure other terminal exchanges are identified, which occur in relatively large quantities but which are not currently identified by any of the other criteria. In future iterations of the modelling, the two latter criteria should be replaced by more normatively based approaches.⁹²

The flows in Table 10.12 have been identified as 'significant' using the four criteria.

Flow	Units
<i>Resource consumptions</i>	
(r) Calcium Sulphate (CaSO ₄ , ore)	kg
(r) Clay (in ground)	kg
(r) Coal (in ground)	kg
(r) Iron (Fe, ore)	kg
(r) Lead (Pb, ore)	kg
(r) Lignite (in ground)	kg
(r) Limestone (CaCO ₃ , in ground)	kg
(r) Natural Gas (in ground)	kg
(r) Oil (in ground)	kg
(r) Silver (Ag, ore)	kg
(r) Sodium Chloride (in ground)	kg
(r) Sulphur (bonded)	kg
(r) Sulphur (S, in ground)	kg
(r) Zinc (Zn, ore)	kg
(r) Uranium (U, ore)	kg
<i>Ancillary materials (secondary)</i>	
Raw materials (unspecified)	kg
Water Used (total)	litre
Water: Ground	litre
Water: Unspecified Origin	litre
<i>Reminders</i>	
E Total Primary Energy	MJ
Electricity	MJ elec
E Fuel Energy	MJ
E Feedstock Energy	MJ
E Renewable Energy	MJ
E Non Renewable Energy	MJ
<i>Emissions to air</i>	
(a) Carbon Dioxide (CO ₂ , fossil)	g
(a) Carbon Dioxide (CO ₂ , biomass)	g
(a) Carbon Monoxide (CO)	g
(a) Hydrocarbons (except methane)	g
(a) Hydrocarbons (unspecified)	g
(a) Methane (CH ₄)	g
(a) Nitrogen Oxides (NO _x as NO ₂)	g
(a) Nitrous Oxide (N ₂ O)	g
(a) Sulphur Oxides (SO _x as SO ₂)	g
(a) Hydrogen Chloride (HCl)	g
(a) Particulates (unspecified)	g
(a) Arsenic (As)	g
(a) Cadmium (Cd)	g
(a) Lead (Pb)	g
(a) Zinc (Zn)	g
(a) Metals (unspecified)	g

⁹² This is an area for further research.

<i>Emissions to water</i>	
(w) Suspended Matter (unspecified)	g
(w) COD (Chemical Oxygen Demand)	g
(w) BOD5 (Biochemical Oxygen Demand)	g
(w) Water (unspecified)	litre
(w) Water: Chemically Polluted	litre
(w) Arsenic (As ³⁺ , As ⁵⁺)	g
(w) Cadmium (Cd ⁺⁺)	g
(w) Copper (Cu ⁺ , Cu ²⁺)	g
(w) Lead (Pb ⁺⁺ , Pb ⁴⁺)	g
(w) Sodium (Na ⁺)	g
(w) Zinc (Zn ⁺⁺)	g
(w) Metals (unspecified)	g
(w) Ammonia (NH ₄ ⁺ , NH ₃ , as N)	g
(w) Fluorides (F ⁻)	g
(w) Chlorides (Cl ⁻)	g
(w) Nitrates (NO ₃ ⁻)	g
(w) Sulphate (SO ₄ ⁻⁻)	g
(w) Sulphates (SO ₄ ⁻⁻)	g
(w) Phosphates (PO ₄ ³⁻ , HPO ₄ ⁻⁻ , H ₂ PO ₄ ⁻ , H ₃ PO ₄ , as P)	g
<i>Ancillary material outputs (wastes)</i>	
Waste (total)	kg
Waste (hazardous)	kg
Waste: Non Mineral (inert)	kg
Waste (municipal and industrial)	kg
Waste: Mineral (inert)	kg
Waste (industrial, miscellaneous)	kg
Waste: Mining	kg
Waste: Slags and Ash (unspecified)	kg
Hydrochloric Acid (HCl, 100%)	kg
Water Used (total)	litre

Table 10.12: ‘Significant’ inventory flows

Note, ‘significant’ flows are distinct from ‘dominant’ flows, identified by dominance analysis in section 10.5.4.1. This is because, ‘significant’ flows are simply those which are considered likely to be of the most direct interest for MIM, its subsidiary companies, and other stakeholders. The ‘dominant’ flows, however, are used to assess the influence of variability and other uncertainties in the input/output data (entered by the author), on the findings from inventory analyses and effect assessments (section 10.5.4.1). Whilst there may be considerable overlap between the two, many of the ‘dominant’ flows may result from specific processes not under the direct control of BRM or other stakeholders. Hence, they would not be directly ‘significant’ for them. Conversely, some ‘significant’ flows

may not be dominating, in terms of their ability to give rise to the specific impacts which have been considered in this case study.

10.4.3.2.3. Graphs of selected flows of interest, and comparisons of contributions

It is impractical within the confines of this thesis, to plot graphs for all of the flows identified in Table 10.12, either at the whole system level or to examine how the nodes listed in Table 10.11 contribute to these total flows.⁹³ Indeed, since the aim of the research has been create a database, to be used into the future as an aid to decision making, these are tasks which should be conducted only as and when the need arises. However, as an illustration of the capabilities of the modelling approach, graphs for some of the more important current concerns are provided at the end of the chapter (section 10.6).

The ‘significant’ inventory flows which have been selected for graphing, their graph numbers, and the categories of information which they depict are summarised in Table 10.13.

Inventory flow	Graph number			
	Allocated model		Unallocated model	
	Category 1	Category 2	Category 1	Category 2
(r) Natural gas (in ground)	10.1	10.15	10.29	10.43
(r) Oil (in ground)	10.2	10.16	10.30	10.44
(a) Arsenic (As)	10.3	10.17	10.31	10.45
(a) Cadmium (Cd)	10.4	10.18	10.32	10.46
(a) Lead (Pb)	10.5	10.19	10.33	10.47
(a) Carbon Dioxide (CO ₂ , fossil)	10.6	10.20	10.34	10.48
(a) Sulphur Oxides (SO _x as SO ₂)	10.7	10.21	10.35	10.49
(w) Arsenic (As ³⁺ , As ⁵⁺)	10.8	10.22	10.36	10.5
(w) Cadmium (Cd ⁺⁺)	10.9	10.23	10.37	10.51
(w) Copper (Cu ⁺ , Cu ⁺⁺)	10.10	10.24	10.38	10.52
(w) Lead (Pb ⁺⁺ , Pb ⁴⁺)	10.11	10.25	10.39	10.53
(w) Zinc (Zn ⁺⁺)	10.12	10.26	10.4	10.54
E Total Primary Energy	10.13	10.27	10.41	10.55
Total Electricity	10.14	10.28	10.42	10.56

Table 10.13: Flows considered and categories depicted in the MIM Pb LCA inventory graphs

The two graph categories, indicated in Table 10.13, illustrate the following:

Category 1 graphs:

The left hand single wide bar (in black) depicts the overall total for the flow in question. The pair of bars immediately to the right, depict and compare the separate overall contributions from all operations for the McArthur/BZL and the Hilton/Mt. Isa streams. The pairs of bars to the left of these depict and compare the contributions to the overall totals of the McArthur/BZL and the Hilton/Mt. Isa streams for the operations shown. These operations are:

1. Lead Refining Operations,
2. Smelting Operations,
3. Concentration Operations,
4. Mining Operations, and
5. Transport Operations

Note: 'Transport Operations' considers the transport of the intermediate products only. The contributions from ancillary material transports have been excluded.

The data have been normalised to 1000 kg of MIM refined primary Pb and Pb products throughout (i.e. the data have been normalised to the functional output of the modelled life-cycle).

Category 2 graphs:

In these graphs, operations 1 to 5 (listed above) only have been considered. For each of the operations and for each stream, the data have been normalised to 1000 kg of functional output from the operation shown. The purpose of this normalisation is to enable direct comparisons to be made between the two streams for each operations, irrespective of the overall output from the whole life-cycle.

⁹³ This is an area for further work.

The means by which the data for both categories of graphs have been calculated from the inventory data, is indicated in the sheets entitled 'Calculation Method for Inventory and Assessment Graphs', which are enclosed as Document 4 in volume 5 of the Portfolio.

The graphs are discussed in section 10.4.4.4.

10.4.3.3. Assessments

10.4.3.3.1. Introduction

The inventory data from the 'MIM Pb LCA (allocated)' and 'MIM Pb LCA (unallocated)' TEAMTM models may also be used to conduct a variety of different assessments. In compliance with general current practice, the assessments in this case study, follow the guidelines for the impact assessment phase of LCA, devised by the Society for Environmental Toxicology and Chemistry (SETAC), and incorporated in the SETAC Code of Practice (Consoli et al. 1993)⁹⁴.

Consoli et al. (1993) and Lindfors et al. (1995), state that the following categories of impacts should be assessed if comprehensive assessments are to be conducted:

1. resource depletion,
2. human health effects, and
3. ecological effects.

However, it is not the aim in this thesis to provide a fully comprehensive assessment. As with the inventory analysis, conducted in section 10.4.3.2, the aim is to provide a database, which may then be used as a tool by interested parties to conduct their own assessments, as and when the need arises. The principal purpose of the assessments provided below, is, therefore, to demonstrate some of the capabilities of the approach as a decision support tool. Hence, the assessments of the potential impacts consider some of the impacts only, and only at some of the levels at which these assessments may be made.

⁹⁴ These are reviewed in the elective EngD module assignment, enclosed as Document 15, in volume 2 of the Portfolio. This document has not been enclosed with this copy of the thesis.

10.4.3.3.2. Graphs of selected potential impacts, and comparisons of contributions

The types of potential impacts (i.e. effects) which have been considered in the assessment graphs at the end of the chapter (section 10.7), and the categories of information which they depict are summarised in Table 10.14. Calculation of the impacts has been conducted using the TEAMTM Plus assessment database version 2.5.

Potential effect	Graph number			
	Allocated model		Unallocated model	
	Category 1	Category 2	Category 1	Category 2
Air Acidification -CML [Heijungs et al. (1995)]	10.57	10.71	10.85	10.99
Aquatic Eco-toxicity -CML [Heijungs (1995)]	10.58	10.72	10.86	10.100
Depletion of non-renewable resources -CML [Heijungs et al. (1995)]	10.59	10.73	10.87	10.101
Eutrophication -CML [Heijungs et al. (1995)]	10.60	10.74	10.88	10.102
Eutrophication (water) -CML [Heijungs et al. (1995)]	10.61	10.75	10.89	10.103
Human Toxicity -CML [Heijungs et al. (1995)]	10.62	10.76	10.90	10.104
Terrestrial Eco-toxicity -CML [Heijungs et al. (1995)]	10.63	10.77	10.91	10.105
Greenhouse effect (direct, 100 years) [IPCC (1994)]	10.64	10.78	10.92	10.106
Greenhouse effect (direct, 20 years) [IPCC (1994)]	10.65	10.79	10.93	10.107
Greenhouse effect (direct, 500 years) [IPCC (1994)]	10.66	10.80	10.94	10.108
Depletion of the ozone layer (high) [WMO (1991)]	10.67	10.81	10.95	10.109
Depletion of the ozone layer (low) [WMO (1991)]	10.68	10.82	10.96	10.110
Photochemical oxidant formation (high) [WMO (1991)]	10.69	10.83	10.97	10.111
Photochemical oxidant formation (low) [WMO (1991)]	10.70	10.84	10.98	10.112

Table 10.14: Flows considered and categories depicted in the MIM Pb LCA impact assessment graphs

Categories 1 and 2 in Table 10.14 are the same as those used with the inventory graphs (Table 10.13). Therefore, the descriptions of the categories in section 10.4.3.2.3 are applicable for these graphs too. The means by which the data for both categories of graphs have been calculated from the inventory data is indicated in the sheets entitled ‘Calculation Method for Inventory and Assessment Graphs’, which are enclosed as Document 4 (in volume 5 of the Portfolio).

These graphs are discussed in section 10.4.4.4.

10.4.4. Discussion and uncertainty analysis

10.4.4.1. The need for uncertainty analysis

It was noted in section 4.4.2.1 of chapter 4, that epistemological, methodological, and technical uncertainties exist, to varying degrees, in all scientific experimentation and measurements. It was explained that, within an LCA context, epistemological uncertainty corresponds to ignorance of the system (i.e. lack of understanding of system behaviour), methodological uncertainty with bias from the choice of model and the system boundary, and technical uncertainty with inexactness [Lindfors et al. (1995)]. It was also pointed out, that whilst the scientific method aims to keep such uncertainties to a level where they are so small they are negligible (within defined parameters), for large scale problems (such as those dealing with the environment) the uncertainties are likely to be high, and hence significant. However, decisions still have to be made, even at these large scales. In addition, as shown in Figure 4.2, the stakes of such decisions may be very high. For example, it was argued, in chapter 2, that there are potential threats to the future of the entire lead industry. Therefore, if the lead industry is to argue its environmental case effectively using data from such modelling, an effective assessment of the influence of uncertainties, on all findings is essential.

This need has also been recognised in ISO14141 (1998)E, the international standard for the “goal and scope definition and inventory analysis” phases of LCA. Hence, it states:

“the results of the LCI [life-cycle inventory] shall include a data quality assessment and sensitivity analysis of inputs, outputs and methodological choices in order to understand the uncertainty of the results” (p. 13).

It notes also, that the interpretation of an inventory analysis should consider:

1. whether the delineations of the functional unit are appropriate,
2. whether the definitions of the system boundaries are appropriate, and
3. the limitations identified by the data quality assessment in the sensitivity analysis.

However, it does recognise that uncertainty analysis is a technique still in its infancy, but states, nevertheless, that:

“it would help to characterise uncertainty in results using ranges and/or probability distributions”.

To meet the requirements of the standard, two forms of uncertainty analysis have been adopted for this case study, namely:

1. sensitivity analysis, involving simulations of the effects of manual changes to key variables (i.e. inputs and outputs), and
2. Monte Carlo simulations, an automatic sensitivity analysis approach, to derive uncertainty ranges for the flows.

The manner in which these have been conducted, and their findings are discussed sections 10.4.4.2 and 10.4.4.3 below. In the light of these analyses, the findings of the inventory, assessment and comparison graphs in sections 10.4.3.2 to 10.4.3.4 are then discussed in section 10.4.4.4.

10.4.4.2. Sources of uncertainty in the system models

For each of the three categories of uncertainty, relating to the MIM Pb LCA modelling, the major general contributing sources are first reviewed, and various specific aspects are then

discussed. However, all three categories are inter-linked and overlapping to varying degrees.

The likely influence of these uncertainties, on the findings of the inventory and potential environmental impact assessment graphs, is discussed and assessed in section 10.4.4.5. Additional uncertainties, associated with the calculation of potential environmental impacts from inventory flows, are also discussed and assessed in the section.

10.4.4.2.1 Epistemological uncertainties:

a) General sources:

1. It is not known whether or not all of the DEAM and other LCI data modules, used to provide background LCI inventories, really do provide industry representative data. This is partly a result of the lack of detailed source information for some modules, and partly due to the time constraints in the preparation of this thesis, which have meant that it has not been possible to cross check them all.⁹⁵
2. The actual effects of the use of substitute modules, to provide approximate background LCI inventories, where exact matches could not be obtained, are unknown. However, their relative contributions to the flows and potential environmental impacts, which have been graphed, are discussed in section 10.4.4.5. A list of the flows which have had to be thus treated is provided in part b), in Tables 10.15 to 10.17.
3. Insufficient data were available to model a few of the flows in the background part of the system. Whilst the overall effects on the modelling of these omissions are expected to be relatively minor (as only a very small number of flows have had to be treated thus), their actual effects are unknown. A list of the flows, where this has happened, is provided in part b), in Table 10.18.
4. In the foreground part of the system, only those flows considered 'significant' have been modelled. The exclusion of some other flows, implies they are not significant. This may not be the case. For example, significant flows may have been excluded from the modelling, due to ignorance of their existence.

5. Insufficient data were available to model one or two substances thought to warrant modelling. For example, there were insufficient data to model the consumption of lubricants for many processes. A list of inputs and outputs where this is known to have occurred is provided in part b), in Table 10.19.
6. The foreground system boundary has been set to include both the McArthur River/BZL stream and the Hilton/Mt. Isa stream, but not the production of the MHD crude lead bullion. (The reasons for adopting this approach have been given in section 10.3.1.) The assumption has been made that the inventory for the production of MHD bullion from its raw materials follows the industry average. This may not be the case.

b) Specific aspects:

The following are reviewed in Tables and discussed below:

1. Process material flows whose background LCI inventories have had to be modelled using substitutes.
2. Process material flows for which it has not been possible to model the background LCI inventories.
3. Process material flows where insufficient data were available to conduct modelling.

1. Process material flows whose background LCI inventories have had to be modelled using substitutes:

Table 10.15 lists the material inflows and outflows (excluding water and natural gas) which have had to be modelled using substitutes. Whilst Table 10.16 lists the inflows of 'mains water' and 'fresh water', which have had to be modelled using the substitute 'Water (Softened)', and Table 10.17 lists the inflows of 'Natural Gas' and 'Natural Gas (used as fuel)', derived from gas fields in Australia, which have had to be modelled using data for the North Sea gas fields. In all cases, the aim has been to use substitutes which are materially as close to the actual material as possible. However, some materials are more

⁹⁵ This represents an area for further research.

representative than others. For this reason the likely representativeness of each substitute material is indicated in the Tables using a scoring from 1 to 4.

Flow ID code*	Inflow or Outflow	Flow name	Modelled substitute	Representativeness of approximation (scale of 1 to 5)**
BRM: Lead Refining (Isa stream)				
Process code**: C2,1,1		Level: 5		
AU3	Inflow	Nitre	Ammonium Nitrate (NH ₄ NO ₃ as N)	4
AU16	Inflow	Calcium lignosulphonate	Pulp	4
AU22	Inflow	Calcium/aluminium	Magnesium (Mg)	4
AU23	Inflow	Calcium	Magnesium (Mg)	4
AU25	Inflow	Sodium	Aluminium (Al)	4
AU27	Inflow	Steel banding	Coil	2-3
BRM: Lead Refining (BRM floor throughput)				
Process code**: A1,1,1		Level: 5		
AU3 & 7	Inflow	Nitre	Ammonium Nitrate (NH ₄ NO ₃ as N)	4
AU5	Inflow	Calcium	Magnesium (Mg)	4
AU25	Inflow	Steel banding	Coil	2-3
MIM: Zinc-Lead-Silver Ore Concentration at Mount Isa				
Process code**: C1,2,6,3		Level: 6		
AU2	Inflow	Grinding media (steel rods)	Coil	3
AU3	Inflow	Grinding media (12.7 mm steel balls)	Coil	3
AU4	Inflow	Grinding media (50 mm steel balls)	Coil	3
AU6	Inflow	Flocculant	Cement	4
AU7	Inflow	Sodium ethyl xanthate	Ethanol (C ₂ H ₅ OH)	4
AU8	Inflow	Sodium propyl xanthate	Ethanol (C ₂ H ₅ OH)	4
AU9	Inflow	Dextrin	Starch	4
AU10	Inflow	Methyl isobutyl carbinol	Ethanol (C ₂ H ₅ OH)	3
AU12	Inflow	Copper sulphate	Sodium Sulphate (Na ₂ SO ₄)	4
AU15	Inflow	Zinc sulphate	Sodium Sulphate (Na ₂ SO ₄)	4
BZL: Cadmium and Zinc Refining Plant				
Process code**: A1,5,2,1,1,1		Level: 8		
AU1	Inflow	Master alloy	Aluminium (Al)	4
AU2	Inflow	Sodium metal	Aluminium (Al)	4
AU3	Inflow	Zincex flux	Ammonium Nitrate (NH ₄ NO ₃ as N)	4

BZL: Lead Bullion Production -Imperial Smelting Furnace				
Process code**:		A1,5,2,3,1,1		Level: 8
AU1	Inflow	Ammonium chloride	Potassium Chloride (KCl)	4
MIM: Mixed Concentrate Production				
Process code**:		A2,4,2,1		Level: 6
AU1	Inflow	Optimer 9975 flocculant	Cement	4
AU2	Inflow	Sodium isobutyl xanthate	Ethanol (C ₂ H ₅ OH)	4
AU3	Inflow	Copper sulphate	Sodium sulphate	4
AU4	Inflow	Baymin	Starch	2-3
AU%	Inflow	Methyl isobutyl carbinol	Ethanol (C ₂ H ₅ OH)	3
AU6	Inflow	Tanigan	Starch	2-3
AU9	Inflow	Grinding media	Coil	2-3
Notes:				
* The Flow ID Codes are those cited in the input/output data sheets for each modelled process. (These sheets have been provided for all processes in volume 3 of the Portfolio.)				
** Process Codes have been produced for all of the modelled processes. The modelling structure and codes are indicated in the sheets entitled: "MIM Pb LCA: TEAM™ Model Structure" (enclosed in the Appendix as Document A2).				
*** Scoring system for representativeness: 1 = exact match (i.e. not a substitution) 2 = good match 3 = fair match 4 = match quality uncertain				

Table 10.15: Process inflows and outflows (other than water) where the LCI data have had to be modelled using substitutes

Process name	Process code*	Level	Water Inflow	
			Flow ID**	Name
BRM: Lead refining (Isa stream)	C2,1,1	5	AU13	Towns water
BRM: Lead Refining (BRM floor throughput)	A1,1,1	5	AU16	Towns water
BRM: Overheads (Isa stream operations)	C2,3,1	5	AU1	Towns water
BRM: Overheads (BZL bullion processing)	A1,3,1	5	AU1	Towns water
BRM: Overheads (MHD bullion processing)	A1,4,1	5	AU1	Towns water
MCPS: Electricity Production (Mica Creek Power Station)	C1,2,5,1	6	AU1	Fresh water
MPS: Liquid Oxygen Production	C1,2,7,1	6	AU2 & 3	Cooling water
MIM: Lead Smelting at Mt. Isa	C1,2,6,2,1	7	AU5	Fresh water
MIM: Zinc-Lead-Silver Ore Concentration at Mount Isa	C1,2,6,3,1	7	AU16	Fresh water
MIM: Zinc-Lead-Silver Ore Mining at Mount Isa	C1,2,6,4,1	7	AU3	Fresh water
MIM: Zinc-Lead-Silver Ore Mining at Hilton	C1,2,4,2,1	7	AU2	Fresh water
BCL: Coke Production at Bowen	C1,2,1,1,1	7	AU1	Towns water
CCL: Mining at Collinsville	C1,2,2,1,1	7	AU4	Potable water
BZL: Materials Handling Plant	A1,5,2,4,1	7	AU2	Towns water
BZL: Sulphuric Acid Production	A1,5,2,6,2,1	8	AU2	Towns water
BZL: Steam Production (Boiler House)	A1,5,3,1	5	RM1	Towns water
BZL: Cadmium Ion Exchange	A1,5,2,2,1	7	AU3	Towns water
BZL: Cadmium and Zinc Refining Plant	A1,5,2,1,1,1	8	AU4	Towns water
BZL: Lead Bullion -Imperial Smelting Furnace	A1,5,2,3,1,1	8	AU4	Towns water
BZL: Overheads (Pb bullion production)	A1,5,2,3,2,1	8	AU1	Towns water
BZL: Overheads (sulphuric acid production)	A1,5,2,6,1,1	8	AU1	Towns water
BZL: Overheads (refined Cd production)	A1,5,2,1,2,1	8	AU1	Towns water
BZL: Overheads (refined Zn production)	A1,5,2,1,3,1	8	AU1	Towns water
Notes:				
* For explanation, see the 'Notes' panel in Table 10.15.				
** For explanation, see the 'Notes' panel in Table 10.15.				

Table 10.16: Water inflows which have had to be modelled using the DEAM 'Water (Softened): Production' LCI data module

Process name	Process code*	Level	Natural Gas Inflow	
			Flow ID**	Name
MRM: Electricity Production at McArthur River	A2,3,1	5	RM1	Natural Gas
MCPS: Electricity Production (Mica Creek Power Station)	C1,2,5,1	6	RM2	Natural Gas
MPS: Liquid Oxygen Production	C1,2,7,1	6	EN1	Natural gas (used as fuel)

Notes:
* For explanation, see the 'Notes' panel in Table 10.15.
** For explanation, see the 'Notes' panel in Table 10.15.

Table 10.17: Natural Gas inflows from Australian gas fields modelled using the DEAM 'Natural Gas (North Sea): Production and Transport to Shore' LCI data module

Process	Process code*	Level	Input or output lacking a background LCI inventory		
			Flow ID**	Input/Output	Name
BRM: Lead refining (Isa stream)	C2,1,1	5	AU9 AU19 AU26	Input Input Input	Calgon Antimony Tellurium
BRM: Lead Refining (BRM floor throughput)	A1,1,1	5	AU21	Input	Arsenic
BZL: Sinter Process Lead Production	A1,5,2,5,1	7	AU1	Input	TTE water***
BZL: Materials Handling Plant	A1,5,2,4,1	7	RM5 AU3	Input Input	Oxides TTE water***
BZL: Lead Bullion Production -Imperial smelting furnace	A1,5,2,3,1,1	8	RM2 AU5	Input Input	Furnace additions (oxides) TTE water***
BZL: Cadmium and Zinc Refining Plant	A1,5,2,1,1,1	8	AU5	Input	TTE water***
CCL: Coal Mining at Collinsville	C1,2,2,1,1 & C1,2,3,1,1	7	WA2	Output	Coal wasted (spontaneous combustion)
MIM: Zinc-Lead-Silver Ore Concentration at Mount Isa	C1,2,6,3,1	6	AU6	Input	Ferrosilicon

Notes:
* For explanation, see the 'Notes' panel in Table 10.15.
** For explanation, see the 'Notes' panel in Table 10.15.
***TTE water = Treated Trade Effluent

Table 10.18: Process inputs and outputs where suitable LCI data were not available

Process name	Process code*	Level	Flow not modelled		
			Flow ID**	Input/Output	Name
BRM: Lead refining (Isa stream)	C2,1,1	5	AU13 AU14 WA3	Input Input Output	Cooling water Lubricants Lubricants
BRM: Lead Refining (BRM floor throughput)	A1,1,1	5	AU17 AU18 AU13 WA4	Input Input Output Output	Cooling water Lubricants Slag from secondary rotary, dross dross handling) Lubricants
BRM: Overheads (Isa stream operations)	C2,3,1	5	WA1	Output	Office waste
BRM: Overheads (BZL bullion processing)	A1,3,1	5	WA1	Output	Office waste
BRM: Overheads (MHD bullion processing)	A1,4,1	5	WA1	Output	Office waste
MCPS: Electricity Production (Mica Creek Power Station)	C1,2,5,1	6	WA2	Output	Clinker
CMS: Bing Bong Overheads	A2,1,2,1	6	EN1	Input	Electricity
MRM: Electricity Production at McArthur River	A2,3,1	5	AU1 WA1	Input Output	Lubricants Lubricants
MRM: McArthur River Overheads	A2,4,5,1	6	AU1 WE1	Input Output	Fresh water Waste water
Notes: * For explanation, see the 'Notes' panel in Table 10.15. ** For explanation, see the 'Notes' panel in Table 10.15.					

Table 10.19: Process inputs and outputs where insufficient data were available to conduct modelling

Whilst the actual influence of the substitutions and omissions in Tables 10.15 to 10.19, on any inventory and/or effect assessments, which may be conducted are unknown, some have a much greater potential to influence than others. For the inventory and assessment graphs, enclosed with this thesis, the dominant contributing sources to the overall findings have first been identified by dominance analysis, and their potential to influence these findings, has then been assessed using sensitivity analysis. The methodology of these analyses is indicated in section 10.4.4.3.

In the discussion of the inventory and assessment graphs (section 10.4.4.5), where key flows are shown to be associated with substances modelled using substitutes, their potential

influence on any findings are considered and assessed. In the few cases where suitable LCI data for certain substances were not available, or where suitable data were not available to include certain substances associated with individual substances in the modelling (i.e. Tables 10.18 and 10.19 respectively), such assessment is not possible. However, the number of flows where this has occurred is relatively small and their mass contributions are relatively small. Whilst their individual influences are expected to be relatively minor, these omissions must be made explicit in any interpretations which may be made. This question is, therefore, considered further, in both the discussion of the inventory and effect graphs (section 10.4.4.5), and in the Overall Conclusions and Recommendations (chapter 11).⁹⁶

10.4.4.2.2 Methodological uncertainties:

a) General sources:

1. Partitioning (i.e. allocation) approaches, where adopted, may significantly under or over estimate.
2. The use of background LCI data to model MHD bullion may significantly over or under estimate.
3. The assumption has been made that linear (i.e. incremental) changes in the demand for materials and/or energy from the background system and/or of wastes sent to the background, may be met by similar incremental changes in inventory values. This may not be the case in practice. For example, increased electricity demand may result in additional plant being brought into operation, rather than simply by an increase in the output from existing plant.
4. The input or output of a measured material or energy type may actually be significantly higher or lower than that indicated by the data. This bias may be due to the data not being fully representative of the full production cycle or to systematic errors in the measurement and/or subsequent handling and reporting chain.
5. The use of the arithmetic mean (the approach adopted in the modelling this LCA), assumes the distribution of the data spread is not significantly skewed. This may not

⁹⁶ It also represents a key area needing further research.

be the case in practice. The data may, for example be log-normal. In such cases, the use of the geometric mean would give a less biased estimate of the ‘typical’ value.

6. The use of the nearest truck capacity equivalents to estimate the inventories associated with transports, when an exact match is unavailable, may create systematic bias.

b) Various specific aspects:

The input/output annual data sheets for each modelled process (in volume 3 of the Portfolio), include a group of columns entitled ‘Characterisation of Data’. The numbers entered into these columns characterise each input or output according to the scoring system indicated in Table 10.20.

Column number	Data descriptor
1	Data source type
2	Representativeness of the data for characterising the unit ‘process’
3	Representativeness of the unit ‘process’ for its purpose in modelling
4	Age of data
5	Reference
6	Strict confidentiality for specific data items

Table 10.20: The criteria considered in the ‘Characterisation of Data’ columns in the input/output annual data sheets for each modelled process

The scoring system for the criteria in columns 1 to 3, has been modified from Wenzel et al. (1997), and assesses these characteristics against various criteria. For each flow, the number inserted in each column is intended to give a rough indication of the nature of the data with respect to each of the three descriptors. They provide, therefore, not only an

indication of how representative the data which have been used are, but also an indication of the possibility of significant bias (i.e. methodological uncertainty). This is because, in general, the more representative the data are, the less likely they are to be biased. Therefore, the higher the numbers in columns 1 to 3, the greater the possibility of bias.

10.4.4.2.3 Technical uncertainties:

a) General sources:

1. Variability occurs in the inputs and outputs, relative to the functional output from the whole system.
2. Variability also occurs in the inputs and outputs, relative to the functional output from the processes with which they are directly associated.
3. Different flows may be independent variables. However, many are correlated either stepwise (i.e. between different processes in production sequences) and/or process wise (i.e. within specific processes).
4. Rounding up and rounding down errors occur inevitably when data from differing sources are aggregated in modelling such as this.

b) Various specific aspects:

The input/output annual data sheets for each modelled process (in volume 3 of the Portfolio), contain groups of columns entitled 'Variation of Data Per Period'.

For each input or output, these columns indicate the following:

- the minimum value per period,
- the maximum value per period,
- the arithmetic mean value per period,
- the coefficient of variation (i.e. standard deviation/arithmetic mean) for the data, and
- the statistical skew of the data.

Where insufficient data are available to calculate all of the statistics, the cells concerned are left blank. If one datum value only has been obtained, all of these cells are left blank. The ‘period’ which these data refer to, is the monthly company period. Since the data cover one year, the statistics contain at least 12 elements. However, in some cases that data set is composed of many more elements than this. To overcome possible bias which could be caused by there being differing numbers of days in the periods (because there are differing numbers of days in the months), the statistics have been calculated from normalised periods, all of which have a similar number of days.

To try to ensure the effects of rounding errors are minimised, data from original spreadsheet sources are used wherever possible, and are copied and pasted directly into calculations. In many cases, however, it has not been possible to obtain such direct data, and for some calculations, direct copying and pasting is impractical.

10.4.4.3. *Uncertainty analysis using manual simulations*

Two steps to uncertainty assessment in LCA may be identified. These are:

- dominance analysis, followed by
- sensitivity analysis.

Dominance analysis identifies

- firstly, the main impact categories contributing to the ‘valuation’ result,
- then, the most important contributing inventory flows giving rise to these impacts, and
- finally, the processes from which these burdens arise.

‘Valuation’ is identified by Consoli et al. (1993) as the final stage in impact assessment, and involves the relative importance of each of the different potential impacts being weighted against each other.⁹⁷ Valuation is normative in nature, since the weighting values are influenced by socio-economic rather than purely scientific considerations. It is a stage which will be applied, as and when the need arises, by those who choose to use the

⁹⁷ Valuation has been discussed further in the elective EngD module assignment, enclosed as Document 15, in volume 2 of the Portfolio. This document has not been provided with this copy of the thesis.

database. The aim of the assessments shown here is to illustrate the assessment capabilities of the database only. This stage has, therefore, not been included in this thesis. However, the need to develop effective and fair means of valuation, within an integrated strategy, is crucially important if the lead and associated industries are to meet the environmental challenge with optimal effectiveness. This question is considered further in the Overall Conclusions and Recommendations (chapter 11).

Dominance analysis has been conducted for the inventories and effects, which have been graphed, for both the allocated and unallocated models. Sensitivity analyses have been conducted for flows, from all processes (whether they are in the foreground or background), which have been shown by the dominance analysis to contribute 5% or more to any of the overall system inventories or effects. The sensitivity analyses have been conducted by altering each of the flows in question separately, by plus one standard deviation from the actual value, and then calculating its effects on the inventories and effects considered in the graphs.

This method of analysis is possible, because all of the inputs and outputs associated with the foreground processes have been treated as variables in the TEAMTM modelling. This means that any, or all, of them may be changed using externally driven control panels. A complete list of these variables is provided in Document 9 (in volume 5 of the Portfolio). It may be observed, that for each variable there are three columns under the heading 'statistics' and two columns under the heading 'test values'. The columns under the former are labelled 'actual mean', 'coefficient of variation', and 'standard deviation', whilst under the heading 'test values' they are labelled 'minimum' and 'maximum'. The standard deviation and the 'minimum' and 'maximum' suggested test values, have been calculated from the mean and CoV values, in all cases. The 'minimum' and 'maximum' test values, are the mean minus and plus one standard deviation respectively. Where there have been sufficient data to calculate them, the 'coefficient of variation' (CoV) values are those cited in the 'Variation of Data per Period' columns in the input/output sheets for each process. However, where there are insufficient data for this, the CoV values have been estimated. Therefore, where insufficient data are available to derive the actual standard deviations, estimated standard deviations, using estimated CoV values, have been calculated instead.

The criteria for deriving the estimated CoV values are indicated in Document 18 (of volume 5 of the Portfolio). Where estimated values have been used, the cells in the CoV column in the variables list (in Document 9, of volume 5 of the Portfolio) have been shaded.

It is the 'maximum' test values, which have been used in the sensitivity analysis for testing the key flow variables identified by dominance analysis. These key flows, and their influence on the inventories and potential effects, are indicated and assessed in the sensitivity analysis sheets enclosed in volume 5 of the Portfolio, in Documents 11 and 12 for the allocated model, and in Documents 14 and 15 for the unallocated model.

Interpretation of the inventory and potential effect graphs (in section 10.4.4.5), is conducted in conjunction with these sensitivity analyses, where appropriate.

Finally, it should be noted that, due to time constraints in the preparation of this thesis, dominance analyses, for both the allocated and unallocated models, have been conducted for the whole life cycle only. However, two types of graphs have been constructed (and are listed in Tables 10.13 and 10.14). These are 'Category 1' graphs, where data are relative 1000 kg of MIM refined lead products, and 'Category 2' graphs, where the data are normalised per 1000 kg of principal output from each operation. Currently, the dominance analyses are applicable for 'Category 1' graphs only.⁹⁸

10.4.4.4. *Uncertainty analysis using Monte Carlo simulations*

Monte Carlo simulations have been conducted to assess the relative ranges in variability of all of the inventory values. Whilst these simulations are needed for fully comprehensive assessments, the aim within this thesis is simply to illustrate some of the inventories and potential effects of interest. For the interpretation of such graphs, uncertainty analysis using Monte Carlo simulations is not necessary. Therefore, the findings from the Monte Carlo simulations, which have been conducted, have not been included within this thesis. However, they have been included as Documents 22 and 23 (in volume 5 of the Portfolio)

⁹⁸ Conducting further dominance analyses, for the data used the 'Category 2' graphs, are an area for further work.

for the allocated and unallocated models respectively, and will be supplied to MIM, who have sponsored this research.

10.4.4.5. Discussion of the inventory and assessment graphs

The inventory and potential effect graphs, enclosed in section 10.6, are listed in Tables 10.13 and 10.14 respectively. The Tables also show that for both sets of graphs:

- the allocated and unallocated models have been considered separately, and
- the graphs for each of the models, may be divided into ‘Category 1’ and ‘Category ‘ graphs.

A full description of the graphs, and of the two categories, has been provided in section 10.4.3.2.3 for the inventories, and in section 10.4.3.1.2 for the effects.

It should be noted, that in the ‘Category 1’ graphs for the Hilton/Mt. Isa stream, the bars for the individual contributions from lead refining, smelting, concentration and mining operations when totalled together are equal, approximately, to the ‘all operations’ bar. However, this is not the case for the McArthur River/BZL stream. This is because, the contributions from the LCI data atoms which model additional bulk material inputs into BZL (of mixed concentrates other than MRM, lead concentrates and zinc concentrate), and additional bulk material inputs into BRM (of MHD bullion), have been included in the ‘all operations’ bar. However, they have been excluded from the other bars. Similar exclusions have not occurred for the Hilton/Mt. Isa stream, because it is not subject to any additional bulk material inputs.

Finally, the following should be borne in mind by those reading the discussion which follows:

1. In all cases, the names used for the graphed inventories and effects are identical to those used in the modelling, which has been conducted using the TEAMTM software. Where inventory flows and atoms are in the foreground, they have been named by the author, and follow the conventions recommended by the software suppliers. However, for

atoms in the background, and for inventory flows associated with them, the names are entirely those provided with the software. In addition, the TEAM™ software does not support the use of either superscripts or subscripts for the naming of flows and atoms. For example the inventory flow for carbon dioxide (CO₂) emissions to the atmosphere, arising from fossil fuel combustion, has been quoted as ‘Carbon Dioxide (CO₂, fossil)’. Also, many of the charges on aqueous ions are named in a non-standard manner in the DEAM™ modules (which are the main source of background data). For example, emissions of aqueous cadmium (Cd) ions (i.e. Cd²⁺ ions), have been quoted as ‘(w) Cadmium (Cd++)’. In consequence, for many chemical compounds, the names used to identify them, do not comply fully with the conventional methodology.

2. The TEAM™ software calculates inventory and effect values to several decimal places. This is reflected in the discussion below. Therefore, the number of decimal places indicated in the discussion, are related to the output from the modelling, and do not indicate any particular level of accuracy.

10.4.4.5.1 Inventory graphs

a) (r) Natural Gas (in ground):

Relevant graphs:	Graph 10.1:	Category 1, Allocated model
	Graph 10.15:	Category 2, Allocated model
	Graph 10.29:	Category 1, Unallocated model
	Graph 10.43:	Category 2, Unallocated model

Category 1 graphs:

Both Graphs 10.1 and 10.29 show that, relative to the total output from the modelled system, the Hilton/Mt. Isa stream appears to have a substantially greater total demand for ‘(r) Natural Gas (in ground)’ than the McArthur River/BZL stream. Both models also indicate that the greatest demand in the Hilton/Mt. Isa stream is from concentration operations.

Dominance analysis for both models demonstrates that 87% and 79% of the inventory, by mass, is associated with system node: 'MCPS: Electricity Production Operations (Mica Creek Power Station)'. For both models, the consumption of '(r) Natural Gas (in ground)', within this system node, is associated, almost exclusively, with the atomic node: '241 Water (Softened): Production.1'. This is because, all of the other consumptions account for less than 5%, individually, of the total system consumption. In consequence, the overall system and individual operations consumptions of '(r) Natural Gas (in ground)' is expected to be relatively robust to potential inaccuracies and biases in any of the other atoms within the system node.

Since the major consumption of '(r) Natural Gas (in ground)' is associated with a background system process, it cannot be modified on its own in a sensitivity analysis. This is because the flows in and out the DEAMTM modules, which make up the background atoms, are not variables. Therefore, to modify the flows in the '241 Water (Softened): Production.1' node, the foreground node into which its main output flows has to be altered. This main output is 'Water (Softened)' and the foreground atomic node is 'MCPS: Electricity Production'. Manipulation of the 'Water (Softened)' inflow into the node by one standard deviation results in a change of 138.57 kg for the allocated model, and a change of 502.67 kg for the unallocated model.⁹⁹ (Data from Documents 11 and 14, of volume 5 of the Portfolio.) If it is assumed the likely possible deviation of the flow from its true value, is plus or minus one standard deviation, then the variation for the allocated model may range over 277.14 kg, and for the unallocated model may range over 1005.34 kg (i.e. twice the value calculated by the sensitivity analysis).

Graph 10.1 suggests a difference, at the overall system level, of $624.02 - 27.33 = 596.69$ kg between the Hilton/Mt. Isa and McArthur River/BZL streams for the allocated model, and Graph 10.29 a difference of $2188.22 - 419.81 = 1768.41$ kg for the unallocated model. Both are greater than the predicted variations, attributable to the dominant contributor, which are 277.14 kg and 1005.34 kg respectively. It may be concluded, therefore, that with both models, the Hilton/Mt. Isa stream has a significantly greater demand for '(r) Natural Gas (in ground)' than the McArthur River/BZL stream.

⁹⁹ Throughout the discussion, the number of decimal places reflects the number calculated by the TEAMTM software. It does not suggest a particular level of accuracy.

For both models, the differences in consumption between the mining, concentration and smelting operations at Mt. Isa are due, principally, to differences in the relative consumptions of electricity supplied to them by the MCPS. For both models, the relative order of consumptions, from the greatest to the least, are first concentration, then mining and finally smelting operations. Since there are no other dominant contributors to '(r) Natural Gas (in ground)' consumption for these operations, this relative order is considered reasonably robust.

The actual differences in the relative consumptions of electricity from the MCPS, by operations associated with the Hilton/Mt. Isa stream, during the period modelled, are shown in Table 10.21.

Operation	Fractional consumption
Smelting	0.1366931
Concentration	0.685286981
Mt. Isa Mining operations	0.071575015
Hilton Mining operations	0.106444894
Combined total for Hilton and Mt. Isa mining operations= 0.071575015 + 0.106444894 =	0.17801991

[Source: Calculated from data supplied by MIM, Mt. Isa]

Table 10.21: Relative consumptions of electricity from the MCPS, consumed by operations associated with the Hilton/Mt. Isa stream

When these scaling fractions are applied to the differences identified by the sensitivity analysis for the '(r) Natural Gas (in ground)' inflow associated with the '241 Water (Softened): Production.1' node (which is within the 'MCPS: Electricity Production Operations (Mica Creek Power Station)' system node), the predicted variations in consumptions by the Hilton/Mt. Isa stream mining, concentration and smelting operations are as shown in Table 10.22:

Operation	Change in fractional consumption of '(r) Natural Gas (in ground)'	Predicted variation range
Allocated model: (Change identified by sensitivity analysis = 277.14 kg)		
Smelting	$0.1366931 \times 277.14 = 37.88$ kg	$2 \times 37.88 = 75.76$ kg
Concentration	$0.685286981 \times 277.14 = 189.92$ kg	$2 \times 189.2 = 379.84$ kg
Hilton and Mt. Isa mining combined	$0.071575015 \times 277.14 = 49.34$ kg	$2 \times 49.34 = 98.68$ kg
Unallocated model (Change identified by sensitivity analysis = 1005.34 kg)		
Smelting	$0.1366931 \times 1005.34 = 137.42$ kg	$2 \times 137.42 = 274.84$ kg
Concentration	$0.685286981 \times 1005.34 = 688.95$ kg	$2 \times 688.95 = 1377.9$ kg
Hilton and Mt. Isa mining combined	$0.071575015 \times 1005.34 = 178.97$ kg	$2 \times 178.97 = 257.94$ kg

Table 10.22: Calculation of the variation ranges in consumption of '(r) Natural gas (in ground)', associated with the MCPS operations atom: '241 Water (Softened): Production.1'

For the allocated model, Graph 10.1 indicates, for mining operations, a difference between the Hilton/Mt. Isa and McArthur River/BZL streams of $108.13 - 1.03 = 107.1$ kg, and Graph 10.29 indicates a difference of $392.47 - 26.59 = 365.88$ kg, for the unallocated model. Since both are greater than the variation ranges attributable to the dominant contributor (predicted in Table 10.23), of 98.68 kg and 357.94 kg, it may be concluded that, for both models, Hilton/Mt. Isa stream mining operations have a significantly greater demand for '(r) Natural Gas (in ground)' than do the McArthur River/BZL stream mining operations.

For concentration operations, the difference between the two streams for the allocated model is $396.36 - 4.82 = 391.54$ kg, which is greater than the predicted variation range of 379.84 kg. For the unallocated model, however, the difference between the two streams is

$1438.02 - 124.28 = 1313.74$ kg, which is less than the potential variation range, of 1377.9 kg (predicted in Table 10.23). Similarly, for smelting operations, the difference between the two streams for the allocated model is $94.51 - 8.96 = 85.55$ kg, which is greater than the predicted variation of 75.76 kg. Whilst for the unallocated model, the difference between the two streams is $313.17 - 214.48 = 98.69$ kg, which is less than the potential variation, of 274.84 kg (predicted in Table 10.22).

Hence, whilst it may be concluded the Hilton/Mt. Isa stream accounts for a significantly greater relative consumption for mining operations, for both models. For smelting and concentration operations, this is only the case for the allocated model. This is because in the unallocated model, the situation for both the smelting and concentration operations is equivocal (i.e. the potential variations in key variables are such that it has not been possible to demonstrate a difference). This does not mean there is necessarily no difference, only that it has not been possible to demonstrate it here.

Category 2 graphs:

Graph 10.15 suggests that, for the allocated model, the dominant contributor to the consumption of '(r) Natural Gas (in ground)', per 1000 kg of production from each operation, is from Hilton/Mt. Isa stream concentration operations. However, for the unallocated model (Graph 10.43), the contribution from McArthur River/BZL stream smelting operations appears to be comparable with that from Hilton/Mt. Isa stream concentration operations. This greater relative consumption by McArthur River/BZL stream smelting operations, in the unallocated, compared with that in the Category 1 graph (Graph 10.29), occurs because the overall throughput through the Hilton/Mt. Isa stream is greater than that for the McArthur River/BZL stream. As a result, this form of normalisation tends to increase the size of the bars associated with the McArthur River/BZL stream relative to those for the Hilton/ Mt. Isa stream.

With this form of normalisation, the relative domination of the contributions from the comprising atoms differ from that of the 'Category 1' graphs. Since, dominance analyses have not been conducted for this form of normalisation, interpretation of the 'Category 2' graphs, currently, is limited. Hence, this represents an area for further research.

General comments:

The consumption of (r) Natural gas (in ground)' associated with the atomic node '241 Water (Softened): Production.1', within the 'MCPS: Electricity Production Operations (Mica Creek Power Station)' system node, dominates consumption. However, it must be stressed that this node was used, because it provides a functional output (of 'Water (Softened)') which is an approximation for the flow described as 'fresh water' in the data from which the modelling has been conducted. (See Table 10.15.) This substitution was conducted, because the aim was to provide background LCI data for all ancillary materials, which are consumed. Since suitable data for 'fresh water' production were not available, '241 Water (Softened): Production' was used instead as it was believed to provide the nearest equivalent. However, it is not known how closely the '241 Water (Softened): Production.1' node actually approximates the inventory for 'fresh water' production. Since the atom has been shown to be the key contributor to the consumption of '(r) Natural Gas (in ground)', actual LCI data for the production of such 'fresh water' need be collected as a matter of priority. Such data should then replace the '241 Water (Softened): Production.1' node in future iterations of the modelling.

b) (r) Oil (in ground):

Relevant graphs:	Graph 10.2:	Category 1, Allocated model
	Graph 10.16:	Category 2, Allocated model
	Graph 10.30:	Category 1, Unallocated model
	Graph 10.44:	Category 2, Unallocated model

Category 1 graphs:

Graph 10.2 shows that, relative to the total system output from the allocated model, the Hilton/Mt. Isa stream appears to have a substantially greater demand for '(r) Oil (in ground)' than the McArthur River/BZL stream. It also indicates that Hilton/Mt. Isa stream consumptions appear to be dominated, approximately equally, by concentration and

transport operations. However, Graph 10.30 shows that, relative to the total system output from the unallocated model, at the 'all operations' level, the two streams appear to be close to parity. It also indicates that, for the Hilton/Mt. Isa stream, concentration operations appear to be the dominant contributor, whilst for the McArthur River/BZL stream the dominant contributor appears to be from transport operations.

Dominance analysis for the allocated model demonstrates that the consumption of '(r) Oil (in ground)' may be attributed principally to:

1. '232 Diesel Oil: Production.5', which connects to '602 Road Transport (Truck, 40t, Diesel Oil, kg.1', and is within the system node: 'MIM: Zinc-Lead-Silver Ore Concentration Operations at Mt. Isa'.
2. '241 Water (Softened): Production.1', which connects to 'MCPS: Electricity Production (Mica Creek Power Station)', and is within the system node: 'MCPS: Electricity Production Operations (Mica Creek Power Station)'.
3. '611 Sea Transport (Freighter, kg.km)1' which connects to 'Ship Transport of Lead Bullion (Mt. Isa) to BRM (UK)' is within the system node: 'Isa Lead Bullion Shipping Operations'.
4. '232 Diesel Oil: Production.1' which connects to '602 Road Transport (Truck 40t, Diesel Oil, kg.km).1', and is within the system node: 'MIM: Lead Smelting Processes at Mt. Isa'.
5. '232 Diesel Oil: Production.1' which connects to '602 Road Transport (Truck 40t, Diesel Oil, kg.km).1'. The 'Transport Road (diesel oil, kg.km)' output from this is, in turn, connected to 'Hilton Mined Ore Truck transport by KMC & MIM to Mt. Isa'. All are within the system node: 'Hilton Operations'.

Sensitivity analyses have been conducted for these dominating atoms, as indicated in Document 11 (of volume 5 of the Portfolio).

For the unallocated model, dominance analysis demonstrates that the consumption of '(r) Oil (in ground)' may be attributed principally to:

1. 'Mixed Concentrates (other than MRM, purchased by BZL)', which is within the system node: 'BZL: Materials Handling Operations'.

2. 'Zinc Concentrates', which is within the system node: 'BZL: Materials Handling Operations'.
3. '232 Diesel Oil: Production.5', which connects to '602 Road Transport (Truck, 40t, Diesel Oil, kg.1', and is within the system node: 'MIM: Zinc-Lead-Silver Ore Concentration Operations at Mt. Isa'.
4. '241 Water (Softened): Production.1', which connects to 'MCPS: Electricity Production (Mica Creek Power Station)', and is within the system node: 'MCPS: Electricity Production Operations (Mica Creek Power Station)'.
5. '232 Diesel Oil: Production.1' which connects to '602 Road Transport (Truck 40t, Diesel Oil, kg.km).1'. The 'Transport Road (diesel oil, kg.km)' output from this is, in turn, connected to 'Hilton Mined Ore Truck transport by KMC & MIM to Mt. Isa'. All are within the system node: 'Hilton Operations'.
6. '232 Diesel Oil: Production.1' which connects to '602 Road Transport (Truck 40t, Diesel Oil, kg.km).1'. The 'Transport Road (diesel oil, kg.km)' output from this is, in turn, connected to 'HTS: Road Transport of Mixed Concentrate to Bing Bong'. All are within the system node: 'HTS: Operations Associated with Transport of Mixed Concentrate to Bing Bong'.
7. '611 Sea Transport (Freighter, kg.km)1' which connects to 'Ship Transport of Lead Bullion (Mt. Isa) to BRM (UK)', and is within the system node: : 'Isa Lead Bullion Shipping Operations'
8. '611 Sea Transport (Freighter, kg.km)1' which connects to 'Ship transport of McArthur River Mixed concentrate to BZL (UK) is within the system node: 'Ship Transport Operations for McArthur River Mixed Concentrate'.

Sensitivity analyses have also been conducted for these dominating atoms, as indicated in Document 14 (of volume 5 of the Portfolio).

These dominance analyses demonstrate that the '(r) Oil (in ground)' consumptions are attributable to the production of 'Water (Softened)' used by the Mica Creek power Station, to the transport by ship of intermediate bulk materials, and to the production of the diesel used in the transport by road (also of intermediate bulk materials). In addition, for both the allocated and unallocated models, the dominance analyses show that, individually, all other individual contributions to '(r) Oil (in ground)' consumption, account for less than 5%, by mass, of the total for the system. In consequence, in both models, the overall system

consumptions of '(r) Oil (in ground)' are expected to be relatively robust to potential inaccuracies and biases in any of the atoms, within any of the system nodes.

All of the dominating atoms, in both models, are in the background. Since the flows in and out of DEAMTM modules (which have been used to construct these atoms) are not variables, the '(r) Oil (in ground)' flow within these atoms, cannot be modified on their own. Therefore, they have been modified by altering the linked flow(s) in the foreground atomic node(s), to which they are connected. The linked foreground flows, and the paths by which they are linked, are indicated in Documents 11 and 14 (of volume 5 of the Portfolio).

Graph 10.2 suggests, for the allocated model, a difference at the overall system level of $174.91 - 35.17 = 139.74$ kg between the Hilton/Mt. Isa and McArthur River/BZL streams and Graph 10.30, for the unallocated model, a difference of $496.35 - 410.71 = 85.61$ kg. The quantity changes in '(r) Oil (in ground)' consumption resulting from sensitivity analyses, applied to both models, are indicated in Documents 11 and 14 (of volume 5 of the Portfolio). Assuming the potential variation ranges are twice the changes identified in the sensitivity analyses (for similar reasons to those given in part a)), the predicted variation ranges attributable to the dominant flows , in the allocated model are:

- $2 \times 0.153 = 0.31 \text{ kg}^{100}$,
- $2 \times 8.738 = 17.48 \text{ kg}$,
- $2 \times 5.273 = 10.55 \text{ kg}$. and
- $2 \times 4.666 = 9.33 \text{ kg}$.

¹⁰⁰ Throughout the discussion, the number of decimal places reflects the number calculated by the TEAMTM software. It does not suggest a particular level of accuracy.

For the unallocated model, they are:

- $2 \times 8.151 = 16.30$ kg,
- $2 \times 7.267 = 14.53$ kg,
- $2 \times 0.558 = 1.12$ kg,
- $2 \times 31.696 = 63.39$ kg,
- $2 \times 17.077 = 34.15$ kg,
- $2 \times 13.815 = 27.63$ kg,
- $2 \times 9.392 = 18.78$ kg, and
- $2 \times 16.853 = 33.71$ kg.

For both the allocated and unallocated models, all of the above variation ranges are less than the differences between the Hilton/Mt. Isa and McArthur River/BZL streams (identified by Graphs 10.2 and 10.30), when considered individually. It may be concluded, therefore, that with both models, the Hilton/Mt. Isa stream has a significantly greater demand for '(r) Oil (in ground)' than the McArthur River/BZL stream. However, it should be born in mind, this assertion has been made on the assumption that only one of the key contributors may be biased. For the allocated model, the difference between the two streams is so great that, even if all four dominant contributors were biased by their maximum predicted extent, the difference between the two streams would still be greater. However, for the unallocated model, if more than one of the larger key contributors were biased by their maximum predicted extent, the difference between the two streams could no longer be regarded a significant. It may be concluded, therefore, that for the allocated model, the assertion is robust. For the unallocated model, however, the assertion is not as robust. It is concluded, therefore, the difference is probable but not certain.

For both models, the differences in '(r) Oil (in ground)' consumption between the mining, concentration and smelting operations at Mt. Isa are due, principally, to differences in the relative consumptions of electricity supplied to them by the MCPS. The significant '(r) Oil (in ground)' consumptions associated with the MCPS, are from the '241 Water (Softened): Production.1' node, which has been identified above as being a dominant contributor for both the allocated and unallocated models. Therefore, the differences seen in the graphs are due largely to the varying consumptions of electricity by the different operations. Since

there are no other dominant contributors to '(r) Oil (in ground)' consumption for these operations, this relative order is considered reasonably robust.

Table 10.21 indicates the actual relative differences in the consumptions of electricity from the MCPS, by operations associated with the Hilton/Mt. Isa stream, during the period modelled. In Table 10.23, these data have been used to calculate scaling fractions, which may be applied to attribute the differences, identified by the sensitivity analysis for the '241 Water (Softened): Production.1' node, to the various Mt. Isa based Hilton/Mt. Isa stream operations.

Operation	Change in fractional consumption of '(r) Oil (in ground)'	Predicted variation range
<i>Allocated model: (Change identified by sensitivity analysis = 8.738 kg)</i>		
Smelting	$0.1366931 \times 8.738 = 1.194 \text{ kg}$	$2 \times 1.194 = 2.39 \text{ kg}$
Concentration	$0.685286981 \times 8.738 = 5.988 \text{ kg}$	$2 \times 5.988 = 11.98 \text{ kg}$
Hilton and Mt. Isa mining combined	$0.071575015 \times 8.738 = 0.625 \text{ kg}$	$2 \times 0.625 = 1.25 \text{ kg}$
<i>Unallocated model (Change identified by sensitivity analysis = 31.696 kg)</i>		
Smelting	$0.1366931 \times 31.696 = 4.33 \text{ kg}$	$2 \times 4.33 = 8.66 \text{ kg}$
Concentration	$0.685286981 \times 31.696 = 21.72 \text{ kg}$	$2 \times 21.72 = 43.44 \text{ kg}$
Hilton and Mt. Isa mining combined	$0.071575015 \times 31.696 = 2.27 \text{ kg}$	$2 \times 2.27 = 4.54 \text{ kg}$

Table 10.23: Calculation of the variation ranges in consumption of '(r) Oil (in ground)', associated with the MCPS operations atom: '241 Water (Softened): Production.1'

For the allocated model, Graph 10.2 indicates, for mining operations, a difference between the Hilton/Mt. Isa and McArthur River/BZL streams of $23.94 - 0.50 = 23.44 \text{ kg}$, and Graph 10.30 indicates a difference of $87.41 - 12.83 = 74.58 \text{ kg}$, for the unallocated model. Since both are greater than the variation ranges attributable to the dominant contributors (predicted in Table 10.23), of 1.25 kg and 4.54 kg, it may be concluded that, for both models,

Hilton/Mt. Isa stream mining operations have a significantly greater demand for '(r) Oil (in ground)' than do the McArthur River/BZL stream mining operations.

For concentration operations, the difference between the two streams, for the allocated model, is $69.51 - 1.04 = 68.47$ kg. This is greater than the predicted variation range of 11.98 kg (from Table 10.23). For the unallocated model, the difference between the two streams is $253.62 - 26.87 = 226.75$ kg. This is also greater than the potential variation range, of 43.44 kg. Similarly, for smelting operations, the difference between the two streams for the allocated model is $20.23 - 2.99 = 17.24$ kg, which is greater than the predicted variation of 2.39 kg. However, for the unallocated model, the difference between the two streams is $46.25 - 43.63 = 2.62$ kg, and this is less than the potential variation of 8.66 kg.

Hence, whilst it may be concluded that Hilton/Mt. Isa stream mining and concentration operations account for a significantly greater relative consumption of '(r) Oil (in ground)', for both models. For smelting operations, this is only the case for the allocated model. In the unallocated model, the situation is equivocal (i.e. the potential variations in key variables are such that it has not been possible to demonstrate a difference). This does not mean there is necessarily no difference, only that it has not been possible to demonstrate it here.

In the allocated model, the difference between the two streams, for transport operations is $59.12 - 9.24 = 49.88$ kg. All of the sensitivity analyses, apart from that for the '241 water (Softened): Production.1' node already discussed, are associated with such transport operations. The predicted variation ranges calculated from the changes, identified from these sensitivity analyses, are 0.31kg, 17.48 kg, 10.55 kg, and 9.33 kg. These are less, both individually and combined than the difference indicated in the graph. It may be concluded, therefore, that, for transport operations, the Hilton/Mt. Isa stream accounts for a significantly greater relative consumption. With regard to the relative contributions of the concentration and transport operations in the Hilton/Mt. Isa stream, Graph 10.2 indicates a contribution of 69.51 kg from concentration operations and a contribution of 59.12 kg from transport operations (i.e. a difference of 10.39 kg). The predicted variation range attributable to the key contributor, for concentration operations in the allocated model is 11.98 kg (Table 10.23), and for transport operations the ranges of the key contributors are

0.31 kg and 9.33 kg (as shown above). Hence, the potential variation is greater than the difference. Hence, it is concluded that, for the allocated model, the findings are equivocal (i.e. it has not been possible to demonstrate a significant difference).

In the unallocated model, the difference between the two streams, for transport operations is $129.81 - 105.31 = 24.50$ kg. All of the sensitivity analyses, apart from that for the '241 water (Softened): Production.1' node already discussed, are associated with such transport operations. The predicted variation ranges calculated from the changes identified from these sensitivity analyses are 16.30 kg, 14.53 kg, 1.12 kg, 34.15 kg, 27.63 kg, 18.78 kg, and 33.71 kg. Several of these variations are greater than the difference indicated in the graph. Therefore, it may be concluded that the findings are again equivocal. With regard to the relative contributions of the concentration and transport operations in the Hilton/Mt. Isa stream, Graph 10.30 indicates a contribution of 253.62 kg from concentration operations and a contribution of 105.31 kg from transport operations (i.e. a difference of 148.61 kg). The predicted variation range attributable to the key contributor, for concentration operations, is 43.44 kg (Table 10.23), and for transport operations the ranges of the key contributors are 16.30 kg, 14.53 kg, 1.12 kg, 34.15 kg, 27.63 kg, 18.78 kg, and 33.71 kg (as shown above). Only if all of the key contributors for both concentration and transport operations were biased by their maximum predicted potential extent, would the variation be greater than the difference between the operations. This is considered unlikely. It is highly probable, therefore, that, in the unallocated model, the consumption associated with concentration is significantly greater than that for transport operations.

Category 2 graphs:

Graph 10.16 suggests that, for the allocated model, the dominant contributor to the consumption of '(r) Oil (in ground)', per 1000 kg of production from each operation, is from Hilton/Mt. Isa stream concentration operations. However, for the unallocated model (Graph 10.44), the contribution from McArthur River/BZL stream smelting operations appears to be comparable with that from Hilton/Mt. Isa stream concentration operations. This greater relative consumption by McArthur River/BZL stream smelting operations, in the unallocated, compared with that in the Category 1 graph (Graph 10.30), occurs because the overall throughput through the Hilton/Mt. Isa stream is greater than that for the

McArthur River/BZL stream. As a result, this form of normalisation tends to increase the size of the bars associated with the McArthur River/BZL stream relative to those for the Hilton/ Mt. Isa stream.

For smelting operations, in both the allocated and unallocated models, Graphs 10.16 and 10.44 also appear to show that the McArthur River/BZL stream has a greater consumption, per 1000 kg of production from the operations than does the Hilton/Mt. Isa stream.

With this form of normalisation, the relative domination of the contributions from the comprising atoms differ from that of the 'Category 1' graphs. Since, dominance analyses have not been conducted for this form of normalisation, interpretation of the 'Category 2' graphs, currently, is limited. Hence, this represents an area for further research.

c) (a) Arsenic (As):

Relevant graphs:	Graph 10.3:	Category 1, Allocated model
	Graph 10.17:	Category 2, Allocated model
	Graph 10.31:	Category 1, Unallocated model
	Graph 10.45:	Category 2, Unallocated model

Category 1 graphs:

Both Graphs 10.3 and 10.31 show that, relative to the total output from the modelled system, the Hilton/Mt. Isa stream appears to give rise to substantially greater total emissions to atmosphere of '(a) Arsenic (As)' than the McArthur River/BZL stream. For the allocated model, this dominance appears to be almost total. Both models also indicate that the emissions, from both streams, originate, almost exclusively, from smelting operations.

Dominance analysis for both models demonstrates that 96.01% of emissions of '(a) Arsenic (As)' by mass, in the allocated model, and 87.43% of emissions by mass, in the unallocated model, are associated with one Hilton/Mt. Isa stream atomic node. This node is 'MIM: Lead Smelting at Mount Isa'. In the unallocated model 9.04% of emissions by mass

are also associated with McArthur River/BZL stream atomic node 'BZL: Lead Bullion Production -Imperial smelting furnace'.

These emission sources are both in the foreground, and are based on measured data which have been collected and processed on a regular basis by site personnel using techniques of current best practice. Therefore, the measurements are expected to be reasonably accurate. In consequence, the findings indicated above are considered to be robust. It has not been necessary, therefore, to resort to sensitivity analyses to arrive at these conclusions, due to the clear cut nature of the differences.

Category 2 graphs:

Both, Graph 10.17 (of the allocated model) and Graph 10.45 (of the unallocated model) indicate that, per 1000 kg of output from the operations shown, emissions of '(a) Arsenic (As)' from smelting operations are by far the largest. Indeed, emissions from the other operations appear to be relatively insignificant. The differences are so extreme that these findings are considered robust.

For both models, the Hilton/Mt. Isa stream emissions, per 1000 kg of principal output from smelting operations, are also considerably larger than those from the McArthur River/BZL stream. Since the measurements upon which these data are based are considered reasonably accurate, and since the differences are so large, this finding is also considered robust.

d) (a) Cadmium (Cd):

Relevant graphs:	Graph 10.4:	Category 1, Allocated model
	Graph 10.18:	Category 2, Allocated model
	Graph 10.32:	Category 1, Unallocated model
	Graph 10.46:	Category 2, Unallocated model

Category 1 graphs:

Both Graphs 10.4 and 10.32 show that, relative to the total output from the modelled system, the Hilton/Mt. Isa stream appears to give rise to substantially greater total emissions to atmosphere of '(a) Cadmium (Cd)' than the McArthur River/BZL stream. For the allocated model, this dominance appears to be almost total. Both models also indicate that the emissions, from both streams, originate, almost exclusively, from smelting operations.

Dominance analysis for both models demonstrates that 93.26% of emissions of '(a) Cadmium (Cd)' by mass, in the allocated model, and 72.07% of emissions by mass, in the unallocated model, are associated with one Hilton/Mt. Isa stream atomic node. This node is 'MIM: Lead Smelting at Mount Isa'. In the allocated model 5.67% of emissions by mass, and in the unallocated model 24.34% of emissions by mass are also associated with McArthur River/BZL stream atomic node 'BZL: Lead Bullion Production -Imperial smelting furnace'.

These emission sources are both in the foreground, and are based on measured data which have been collected and processed on a regular basis by site personnel using techniques of current best practice. Therefore, the measurements are expected to be reasonably accurate. In consequence, the findings indicated above are considered to be robust. It has not been necessary, therefore, to resort to sensitivity analyses to arrive at these conclusions, due to the clear cut nature of the differences.

Category 2 graphs:

Both, Graph 10.17 (of the allocated model) and Graph 10.45 (of the unallocated model) indicate that, per 1000 kg of output from the operations shown, emissions of '(a) Arsenic (As)' from smelting operations are by far the largest. Indeed, emissions from the other operations appear to be relatively insignificant. The differences are so extreme that these findings are considered robust.

In Graph 10.17 (of the allocated model) the Hilton/Mt. Isa stream emissions, per 1000 kg of principal output from smelting operations, appear to be larger than those from the McArthur River/BZL stream. If it is assumed the emissions data from the two streams are accurate to within plus or minus 20%, the actual emissions from the McArthur River/BZL stream smelting operations could be increased from the current level at 8.29 g to 9.85 g and the Hilton/Mt. Isa stream emissions could be reduced from the current level at 18.04 g to 14.43 g¹⁰¹. Even at this level of accuracy, there is still a significant difference between the emissions from the two streams. Therefore, it may be concluded that this finding is robust.

In Graph 10.45 (of the unallocated model), smelting operations emissions from the McArthur River/BZL stream appear to be slightly larger than those from the Hilton/Mt. Isa stream. If again it is assumed the emissions data from the two streams are accurate to within plus or minus 20%, the actual emissions from the McArthur River/BZL stream smelting operations could be reduced from the current level at 22.76 g to 18.21 g and the Hilton/Mt. Isa stream emissions could be increased from the current level at 18.67 g to 22.40 g. Under these conditions, the McArthur River/BZL stream would no longer have the larger graph bar. It may be concluded, therefore, that, if one assumes a potential 20% inaccuracy in the measurements, the data are insufficient to ascertain whether or not there is a significant difference between the two streams, in the unallocated model.

¹⁰¹ Throughout the discussion, the number of decimal places reflects the number calculated by the TEAMTM software. It does not suggest a particular level of accuracy.

e) (a) Lead (Pb):

Relevant graphs:	Graph 10.5:	Category 1, Allocated model
	Graph 10.19:	Category 2, Allocated model
	Graph 10.33:	Category 1, Unallocated model
	Graph 10.47:	Category 2, Unallocated model

Category 1 graphs:

Both Graphs 10.5 and 10.33 show that, relative to the total output from the modelled system, the Hilton/Mt. Isa stream appears to give rise to substantially greater total emissions to atmosphere of '(a) Lead (Pb)' than the McArthur River/BZL stream. For the allocated model, this dominance appears to be almost total. Both models also indicate that the emissions, from both streams, originate, almost exclusively, from smelting operations.

Dominance analysis for both models demonstrates that 84.81% of emissions of '(a) Lead (Pb)' by mass, in the allocated model, and 59.34% of emissions by mass, in the unallocated model, are associated with one Hilton/Mt. Isa stream atomic node. This node is 'MIM: Lead Smelting at Mount Isa'. In the allocated model 6.07 % of emissions by mass, and in the unallocated model 24.07 % of emissions by mass, are also associated with McArthur River/BZL stream atomic node 'BZL: Lead Bullion Production -Imperial smelting furnace'. In addition, in the unallocated model 6.20 % of emissions by mass are associated with the McArthur River/BZL stream atomic node 'BZL: Sinter Process Lead Production'.

All of these emission sources are in the foreground, and are based on measured data which have been collected and processed on a regular basis by site personnel using techniques of current best practice. Therefore, the measurements are expected to be reasonably accurate. In consequence, the findings indicated above are considered to be robust. It has not been necessary, therefore, to resort to sensitivity analyses to arrive at these conclusions, due to the clear cut nature of the differences.

Category 2 graphs:

Both, Graph 10.19 (of the allocated model) and Graph 10.47 (of the unallocated model) indicate that, per 1000 kg of output from the operations shown, emissions of '(a) Lead (Pb)' from smelting operations are by far the largest. Indeed, emissions from the other operations appear to be relatively insignificant. The differences are so extreme that these findings are considered robust.

For the allocated model (Graph 1.19), the Hilton/Mt. Isa stream emissions, per 1000 kg of principal output from smelting operations, appear to be larger than those from the McArthur River/BZL stream. If it is assumed the emissions data from the two streams are accurate to within plus or minus 20%, the actual emissions from the McArthur River/BZL stream smelting operations could be increased from the current level at 130.22 g to 156.26 g and the Hilton/Mt. Isa stream emissions could be reduced from the current level at 198.74 g to 158.99 g. Even at this level of accuracy, there is still a small difference between the emissions from the two streams. Therefore, it may be concluded that this finding is fairly robust.

For the unallocated model (Graph 10.47), smelting operations emissions from the McArthur River/BZL stream appear to be larger than those from the Hilton/Mt. Isa stream. If again it is assumed the emissions data from the two streams are accurate to within plus or minus 20%, the actual emissions from the McArthur River/BZL stream smelting operations could be reduced from the current level at 344.17 g to 275.34 g and the Hilton/Mt. Isa stream emissions could be increased from the current level at 205.76 g to 246.91 g. Even at this level of accuracy, there is still a significant difference between the emissions from the two streams. Therefore, it may be concluded that this finding is robust.

f) (a) Carbon Dioxide (CO₂, fossil)¹⁰²:

Relevant graphs:	Graph 10.6:	Category 1, Allocated model
	Graph 10.20:	Category 2, Allocated model
	Graph 10.34:	Category 1, Unallocated model
	Graph 10.48:	Category 2, Unallocated model

Category 1 graphs:

Both Graphs 10.6 and 10.34 show that, relative to the total output from the modelled system, the Hilton/Mt. Isa stream appears to give rise to substantially greater total emissions to the atmosphere of '(a) Carbon Dioxide (CO₂, fossil)' than the McArthur River/BZL stream. Both models also indicate that the greatest emissions in the Hilton/Mt. Isa stream are from concentration operations.

Dominance analysis shows that, in both the allocated and unallocated models, emissions of '(a) Carbon Dioxide (CO₂, fossil)' may be attributed principally to '241 Water (Softened): Production.1', which connects to 'MCPS: Electricity Production (Mica Creek Power Station)', and is within the system node: 'MCPS: Electricity Production Operations (Mica Creek Power Station)'. All of the other consumptions account for less than 5%, individually, of the total system consumption. In consequence, the overall system emission and the individual operations emissions of '(a) Carbon Dioxide (CO₂, fossil)' are expected to be relatively robust to potential inaccuracies and biases in any of the other atoms within the system node.

¹⁰² Throughout the discussion, the names of the inventory flows, and atoms, are those supplied the TEAMTM software. In consequence, names for many chemical compounds do not comply fully with conventional methodology. For further information, see section 10.4.4.5 of this chapter.

Since the major emissions of '(a) Carbon Dioxide (CO₂, fossil)' are associated with a background system process, they cannot be modified on their own in a sensitivity analysis. This is because the flows in and out the DEAM™ modules, which make up the background atoms, are not variables. Therefore, to modify the flows in the '241 Water (Softened): Production.1' node, the foreground node into which its main output flows has to be altered. This main output is 'Water (Softened)' and the foreground atomic node is 'MCPS: Electricity Production'. Manipulation of the 'Water (Softened)' inflow into the node by one standard deviation results in a change of 1,445,380 g for the allocated model, and a change of 5,227,300 g for the unallocated model¹⁰³. (Data from Documents 11 and 14, of volume 5 of the Portfolio.) This is considered equivalent to potential variation ranges of $2 \times 1,445,380 = 2,890,760$ g and $2 \times 5,227,300 = 10,454,600$ g respectively (for the reasons given in part a)).

Graph 10.6 suggests a difference, at the overall system level, of $7,799,300 - 335,321 = 7,463,979$ g between the Hilton/Mt. Isa and McArthur River/BZL streams for the allocated model, and Graph 10.29 a difference of $26,055,800 - 4,552,360 = 21,503,440$ g for the unallocated model. Both are greater than the predicted variations, attributable to the dominant contributor, which are 2,890,760 g and = 10,454,600 g respectively. It may be concluded, therefore, that with both models, the Hilton/Mt. Isa stream gives rise to significantly greater emissions to atmosphere of '(a) Carbon Dioxide (CO₂, fossil)' than the McArthur River/BZL stream.

For both models, the differences in '(a) Carbon Dioxide (CO₂, fossil)' emissions to atmosphere between the mining, concentration and smelting operations at Mt. Isa are due, principally, to differences in the relative consumptions of electricity supplied to them by the MCPS. The significant '(a) Carbon Dioxide (CO₂, fossil)' emissions to atmosphere associated with the MCPS, are from the '241 Water (Softened): Production.1' node, which has been identified above as being a dominant contributor for both the allocated and unallocated models. Therefore, the differences seen in the graphs are due largely to the varying consumptions of electricity by the different operations. In both the allocated model and in the unallocated model, the largest single source of emissions is from Hilton/Mt. Isa stream concentration operations. The second largest from smelting operations and the third

¹⁰³ Throughout the discussion, the number of significant figures reflects the number calculated by the TEAM™ software. It does not suggest a particular level of accuracy.

largest from mining operations. Since, these emissions are attributable largely to the differences in the amounts of electricity they consume from the MCPS, the relative sizes of the emissions are likely to be reasonably robust. For the unallocated model, Hilton/Mt. Isa stream concentration operations are also the largest single contributor. Then, Hilton/Mt. Isa stream smelting and mining operations are the second largest contributors. Both are similar in size, though smelting emissions appear to be slightly greater. The difference between the two is, however, only $(4,840,792 - 4,265,358 / 4,840,792) \times 100 = 11.88\%$. The dominance analysis has only identified contributors of 5% or more at the whole system level. At these lower operations levels the contributions from the same atoms could be significantly more or less. Since, there are many emission sources for '(a) Carbon Dioxide (CO₂, fossil)' within the MIM Pb LCA, it is possible that inaccuracies in one or more of these other sources could create changes which would cancel out this difference. Therefore, it is concluded, that is currently not possible, without further research, to ascertain whether or not there is any significant difference between mining and smelting operations in the unallocated model.

Table 10.21 indicates the actual relative differences in the consumptions of electricity from the MCPS, by operations associated with the Hilton/Mt. Isa stream, during the period modelled. In Table 10.24, these data have been used to calculate scaling fractions, which may be applied to attribute the differences, identified by the sensitivity analysis for the '241 Water (Softened): Production.1' node, to the various Hilton/Mt. Isa stream operations.

Operation	Change in fractional '(a) Carbon Dioxide (CO ₂ , fossil)' emissions to atmosphere	Predicted variation range
Allocated model: (Change identified by sensitivity analysis = 1,445,380 g)		
Smelting	$0.1366931 \times 1,445,380 = 197,573.5 \text{ g}$	$2 \times 197,573.5 = 395,147 \text{ g}$
Concentration	$0.685286981 \times 1,445,380 = 990,500.1 \text{ g}$	$2 \times 990,500.1 = 1,981,000 \text{ g}$
Hilton and Mt. Isa mining combined	$0.071575015 \times 1,445,380 = 103,453.1 \text{ g}$	$2 \times 103,453.1 = 206,906 \text{ g}$
Unallocated model (Change identified by sensitivity analysis = 5,227,300 g)		
Smelting	$0.1366931 \times 5,227,300 = 714,535.3 \text{ g}$	$2 \times 714,535.3 = 1,429,071 \text{ g}$
Concentration	$0.685286981 \times 5,227,300 = 3,582,201 \text{ g}$	$2 \times 3,582,201 = 7,164,401 \text{ g}$
Hilton and Mt. Isa mining combined	$0.071575015 \times 5,227,300 = 374,144.1 \text{ g}$	$2 \times 374,144.1 = 748,288 \text{ g}$

Table 10.24: Calculation of the variation ranges of '(a) Carbon Dioxide (CO₂, fossil)' emissions to atmosphere, associated with the MCPS operations atom: '241 Water (Softened): Production.1'

For the allocated model, Graph 10.6 indicates, for mining operations, a difference between the Hilton/Mt. Isa and McArthur River/BZL streams of $1,174,608 - 4,159 = 1,170,449 \text{ g}$, and Graph 10.34 indicates a difference of $4,265,358 - 107,219 = 4,158,139 \text{ g}$, for the unallocated model. Both are greater than the variation ranges attributable to the dominant contributor (predicted in Table 10.24), of 206,906 g and 748,288 g. For concentration operations, the difference between the two streams for the allocated model is $4,527,149 - 24,913 = 4,502,236 \text{ g}$, which is greater than the predicted potential variation range of 1,981,000 g (Table 10.25). For the unallocated model, the difference between the two streams is $16,439,605 - 642,220 = 15,797,385 \text{ g}$, which is also greater than the predicted potential variation range, of 7,164,401g (Table 10.25). Similarly, for smelting operations, the difference between the two streams for the allocated model is $1,811,192 - 215,035 =$

1,596,157 g, which is greater than the predicted variation of 395,147 g (Table 10.25). Whilst for the unallocated model, the difference between the two streams is $4,840,792 - 3,021,629 = 1,819,163$ g, which is greater than the potential variation, of 1,429,071 g (Table 10.25).

Hence, it may be concluded that, for both models, Hilton/Mt. Isa stream smelting, concentration and mining operations give rise to significantly greater emissions of '(a) Carbon Dioxide (CO₂, fossil)' to atmosphere than do the McArthur River/BZL stream mining operations.

Category 2 graphs:

Graph 10.20 suggests that, for the allocated model, the dominant contributor to atmospheric emissions of '(a) Carbon Dioxide (CO₂, fossil)', per 1000 kg of production from each operation, is from Hilton/Mt. Isa stream concentration operations. However, for the unallocated model (Graph 10.48), the contribution from McArthur River/BZL stream smelting operations appears to be exceeded by that from Hilton/Mt. Isa stream concentration operations. This greater relative consumption by McArthur River/BZL stream smelting operations, in the unallocated, compared with that in the Category 1 graph (Graph 10.34), occurs because the overall throughput through the Hilton/Mt. Isa stream is greater than that for the McArthur River/BZL stream. As a result, this form of normalisation tends to increase the size of the bars associated with the McArthur River/BZL stream relative to those for the Hilton/ Mt. Isa stream.

With this form of normalisation, the relative domination of the contributions from the comprising atoms differ from that of the 'Category 1' graphs. Since, dominance analyses have not been conducted for this form of normalisation, interpretation of the 'Category 2' graphs, currently, is limited. Hence, this represents an area for further research.

g) (a) Sulphur Oxides (SO_x, as SO₂)¹⁰⁴:

Relevant graphs:	Graph 10.7:	Category 1, Allocated model
	Graph 10.21:	Category 2, Allocated model
	Graph 10.35:	Category 1, Unallocated model
	Graph 10.49:	Category 2, Unallocated model

Category 1 graphs:

Both Graphs 10.7 and 10.35 show that, relative to the total output from the modelled system, the Hilton/Mt. Isa stream appears to give rise to substantially greater total emissions to atmosphere of '(a) Sulphur Oxides (SO_x, as SO₂)' than the McArthur River/BZL stream. For the allocated model, this dominance appears to be almost total. Both models also indicate that the emissions, from both streams, originate, almost exclusively, from smelting operations.

Dominance analysis for both models demonstrates that 97.98 % of emissions '(a) Sulphur Oxides (SO_x, as SO₂)' by mass, in the allocated model, and 94.42 % of emissions by mass, in the unallocated model, are associated with one Hilton/Mt. Isa stream atomic node. This node is 'MIM: Lead Smelting at Mount Isa'.

This emission source is in the foreground, and the data have been supplied by site personnel. Therefore, they are expected to be reasonably accurate. In consequence, the findings indicated above are considered to be robust. It has not been necessary, therefore, to resort to sensitivity analyses to arrive at these conclusions, due to the clear cut nature of the differences.

¹⁰⁴ Throughout the discussion, the names of the inventory flows, and atoms, are those supplied the TEAMTM software. In consequence, names for many chemical compounds do not comply fully with conventional methodology. For further information, see section 10.4.4.5 of this chapter.

Category 2 graphs:

Both, Graph 10.21 (of the allocated model) and Graph 10.49 (of the unallocated model) indicate that, per 1000 kg of output from the operations shown, emissions of '(a) Sulphur Oxides (SO_x, as SO₂)' from smelting operations are by far the largest. Indeed, emissions from the other operations appear to be relatively insignificant. The differences are so extreme that these findings are considered robust.

For both models, the Hilton/Mt. Isa stream emissions, per 1000 kg of principal output from smelting operations, are also considerably larger than those from the McArthur River/BZL stream. Since the measurements upon which these data are based are considered reasonably accurate, and since the differences are so large, this finding is also considered robust.

h) (w) Arsenic (As₃₊, As₅₊)¹⁰⁵:

Relevant graphs:	Graph 10.8:	Category 1, Allocated model
	Graph 10.22:	Category 2, Allocated model
	Graph 10.36:	Category 1, Unallocated model
	Graph 10.50:	Category 2, Unallocated model

Category 1 graphs:

For the allocated model, Graph 10.8 shows that, relative to the total output from the modelled system, the Hilton/Mt. Isa stream appears to give rise to substantially greater total emissions to water of '(w) Arsenic (As₃₊, As₅₊)', than the McArthur River/BZL stream. However, Graph 10.36 suggests that, for the unallocated model, also relative to the total output from the modelled system, the greater emissions may be from the McArthur River/BZL stream.

Dominance analysis for the allocated model demonstrates that emissions to water of '(w) Arsenic (As₃₊, As₅₊)' may be attributed principally to:

1. '232 Diesel Oil: Production.5' which connects to '602 Road Transport (Truck, 40t, Diesel Oil, kg.1)', and is within the system node: 'MIM: Zinc-Lead-Silver Ore Concentration Operations at Mt. Isa'.
2. '274 Zinc (Zn): Production.1' which connects to 'BRM:[Tr.] Zinc', and then to 'BRM: Lead Refining (Isa stream)', both of which are within the system node: 'BRM: Lead Refining Operations (Isa stream)'.
3. '274 Zinc (Zn): Production.1' which connects to 'BRM:[Tr.] Zinc', and then to 'BRM: Lead Refining (BRM floor throughput)', both of which are within the system node: 'BRM: Lead Refining Operations (BRM floor throughput)'.
4. '232 Diesel Oil: Production.1' which connects to '602 Road Transport (Truck 40t, Diesel Oil, kg.km).1', and is within the system node: 'MIM: Lead Smelting Processes at Mt. Isa'.
5. '403 Natural Gas: combustion.1' which connects to 'BRM: Lead Refining (Isa stream)', and is within the system node: 'BRM: Lead Refining Operations (Isa stream)'.
6. '232 Diesel Oil: Production.1' which connects to '602 Road Transport (Truck 40t, Diesel Oil, kg.km).1'. The 'Transport Road (diesel oil, kg.km)' output from this is, in turn, connected to 'Hilton Mined Ore Truck transport by KMC & MIM to Mt. Isa'. All are within the system node: 'Hilton Operations'.

Sensitivity analyses have been conducted for these dominating atoms, as indicated in Document 11 (of volume 5 of the Portfolio).

For the unallocated model, dominance analysis demonstrates that emissions to water of '(w) Arsenic (As³⁺, As⁵⁺)' may be attributed principally to:

1. '232 Diesel Oil: Production.5', which connects to '602 Road Transport (Truck, 40t, Diesel Oil, kg.1)', and is within the system node: 'MIM: Zinc-Lead-Silver Ore Concentration Operations at Mt. Isa'.

¹⁰⁵ Throughout the discussion, the names of the inventory flows, and atoms, are those supplied the TEAMTM software. In consequence, names for many chemical compounds do not comply fully with conventional methodology. For further information, see section 10.4.4.5 of this chapter.

2. '232 Diesel Oil: Production.1' which connects to 'HTS: Road Transport of Mixed Concentrate to Bing Bong', and is within the system node: 'HTS: Operations Associated with Transport of Mixed Concentrate to Bing Bong'.
3. '274 Aluminium (Al, 25% recycling): Production.1' which connects first to 'BZL: [Tr.] Aluminium' and then 'BZL: Cadmium and Zinc Refining Plant'. All are within the system node: 'BZL: Cadmium and Zinc Refining Operations'.
4. '274 Zinc (Zn): Production.1' which connects to 'BRM:[Tr.] Zinc', and then to 'BRM: Lead Refining (Isa stream)', both of which are within the system node: 'BRM: Lead Refining Operations (Isa stream)'.

Sensitivity analyses have been conducted for these dominating atoms, as indicated in Document 14 (of volume 5 of the Portfolio).

The dominance analyses demonstrate that the emissions to water of '(w) Arsenic (As³⁺, As⁵⁺)', at the whole system level, in the allocated model, are attributable principally to diesel oil and zinc production, and to natural gas combustion, whilst in the unallocated model they are attributable principally to diesel oil and aluminium production.

All of the dominating atoms, in both models, are in the background. Since the flows in and out of DEAMTM modules (which have been used to construct these atoms) are not variables, the '(w) Arsenic (As³⁺, As⁵⁺)' flow out from these atoms, cannot be modified on their own. Therefore, they have been modified by altering the linked flow(s) in the foreground atomic node(s), to which they are connected. The linked foreground flows, and the paths by which they are linked, are indicated in Documents 11 and 14 (of volume 5 of the Portfolio).

Graph 10.8 suggests, for the allocated model, a difference at the overall system level of $0.00821 - 0.0014 = 0.0068$ g between the Hilton/Mt. Isa and McArthur River/BZL streams and Graph 10.36, for the unallocated model, a difference of $0.034 - 0.020 = 0.014$ g. The quantity changes in '(w) Arsenic (As³⁺, As⁵⁺)' emissions to water resulting from sensitivity analyses, applied to both models, are indicated in Documents 11 and 14 (of volume 5 of the Portfolio). Assuming the potential variation ranges are twice the changes identified in the sensitivity analyses (for similar reasons to those given in part a)), the predicted variation ranges attributable to the dominant flows, in the allocated model are:

- $2 \times 0.000006310 = 0.00001262 \text{ g}^{106}$,
- $2 \times 0.00194369 = 0.00388738 \text{ g}$,
- $2 \times 0.001037 = 0.002074 \text{ g}$,
- $2 \times 0.000056 = 0.000112 \text{ g}$,
- $2 \times 0.000034 = 0.000068 \text{ g}$, and
- $2 \times 0.000193 = 0.000386 \text{ g}$.

For the unallocated model, they are:

- $2 \times 0.0000231 = 0.0000462 \text{ g}$,
- $2 \times 0.0005709 = 0.0011418 \text{ g}$,
- $2 \times 0.0020211 = 0.0040422 \text{ g}$, and
- $2 \times 0.0034626 = 0.0069252 \text{ g}$.

These ranges have been used in the discussion which follows.

For both the allocated and unallocated models, all of the above variation ranges are less than the differences between the Hilton/Mt. Isa and McArthur River/BZL streams (identified by Graphs 10.8 and 10.36), when considered individually. It may be concluded, therefore, that with both models, the Hilton/Mt. Isa stream gives rise to significantly greater emissions to water of '(w) Arsenic (As³⁺, As⁵⁺)' than the McArthur River/BZL stream. In both models, the differences between the two streams are so great that, even if all three dominant contributors were biased by their maximum predicted extent (giving total variation ranges of 0.00654 g and 0.0121554 g respectively), the difference between the two streams would still be greater (at 0.0068 g and 0.014 g respectively). Hence, it may be concluded overall, the assertions that the total emissions to water of '(w) Arsenic (As³⁺, As⁵⁺)' are significantly higher from the Hilton/Mt. Isa stream than from the McArthur River/BZL stream in the allocated model, and significantly lower in the unallocated model, are robust.

¹⁰⁶ Throughout the discussion, the number of decimal places reflects the number calculated by the TEAM™ software. It does not suggest a particular level of accuracy.

In the allocated model (Graph 10.8) Hilton/Mt. Isa stream lead refining operations appear to be the largest source of '(w) Arsenic (As³⁺, As⁵⁺)' emissions to water, followed by Hilton/Mt. Isa stream concentration operations. With regard to lead refining operations, Hilton/Mt. Isa stream emissions also appear to be greater than those from McArthur River/BZL stream. The dominant contributors relevant to Hilton/Mt. Isa stream lead refining operations, from the list provided earlier, are:

1. '274 Zinc (Zn): Production.1' which connects to 'BRM:[Tr.] Zinc', and then to 'BRM: Lead Refining (Isa stream)', both of which are within the system node: 'BRM: Lead Refining Operations (Isa stream)'.
2. '403 Natural Gas: combustion.1' which connects to 'BRM: Lead Refining (Isa stream)', and is within the system node: 'BRM: Lead Refining Operations (Isa stream)'.

These give rise to predicted potential variation ranges of 0.00388738 g and 0.000068 g respectively.

The dominant contributor of relevance to the McArthur River/BZL stream (from the earlier list) for Hilton/Mt. Isa lead refining operations is '274 Zinc (Zn): Production.1' which connects to 'BRM:[Tr.] Zinc', and then to 'BRM: Lead Refining (BRM floor throughput)', both of which are within the system node: 'BRM: Lead Refining Operations (BRM floor throughput)'. This gives rise to a predicted potential variation range of 0.002074 g (from earlier). The difference between the two streams for refining operations is $0.0045 - 0.00094 = 0.00256$ g. This difference is less than the predicted potential variation range of 0.00388738 g attributable to the '274 Zinc (Zn): Production.1' atomic node within the 'BRM: Lead Refining Operations (Isa stream)' system node. However, the difference is greater than the predicted variation attributable to either of the other two dominant contributors, either individually or combined. It may be concluded, therefore, that whilst there may be a significant difference between the two streams, the uncertainty associated with the modelling is such that it is not possible to confirm this.

With regard to the relative contributions from Hilton/Mt. Isa stream lead refining and concentration operations in the allocated model, the difference between the two is indicated in Graph 10.8 to be $0.0045 - 0.0021 = 0.0024$ g. The dominant contributors to emissions

from Hilton/Mt. Isa stream lead refining operations are associated with predicted potential variation ranges of 0.00388738 g and 0.000068 g. For concentration operations the dominant contributor is '232 Diesel Oil: Production.5' which connects to '602 Road Transport (Truck, 40t, Diesel Oil, kg.1', and is within the system node: 'MIM: Zinc-Lead-Silver Ore Concentration Operations at Mt. Isa'. Emissions from this node are associated with a predicted potential variation range of 0.00001262 g. The difference between Hilton/Mt. Isa stream lead refining and concentration operations (of 0.0024 g) is less than the predicted potential variation range of 0.00388738 g, though greater than the ranges of 0.000068 g and 0.00001262 g. It may be concluded, therefore, that whilst there may be a significant difference between the two streams, the uncertainty associated with the modelling is such that it is not possible to confirm this.

If Hilton/Mt. Isa stream mining operations are compared with Hilton/Mt. Isa stream lead refining and concentration operations, the differences in emissions to water of '(w) Arsenic (As³⁺, As⁵⁺)', in the allocated model, are 0.00045 - 0.0008 = 0.0037 g, and 0.0021 - 0.0008 = 0.0013 g respectively. Between Hilton/Mt. Isa stream mining and lead refining operations, the predicted potential variation ranges of the dominant contributors to emissions are 0.00388738 g and 0.002074 g, whilst between Hilton/Mt. Isa stream mining and concentration operations the dominant contributor give rise to a potential variation range of 0.00001262 g. These ranges are associated with the lead refining and concentration operations only. This is because, in the allocated model, at the whole system scale, there are no dominating contributors to emissions, for Hilton/Mt. Isa stream mining operations. The difference between the larger of the variation ranges associated with lead refining operations is larger than the difference between the lead refining and mining operations. However, the difference between the concentration and mining operations, is larger than the predicted potential variation range associated with the dominant contributor. It may be concluded, therefore, for the allocated model, that it has not been possible, due to the potential variability of the data, to demonstrate a significant difference between the emissions to water of '(w) Arsenic (As³⁺, As⁵⁺)' from Hilton/Mt. Isa stream lead refining and mining operations, but between Hilton/Mt. Isa stream concentration and mining operations a significant difference is highly probable.

For the unallocated model (Graph 10.36), the largest single contributor to emissions to water of '(w) Arsenic (As³⁺, As⁵⁺)' appears to be McArthur River/BZL stream smelting

operations and then Hilton/Mt. Isa stream lead refining and concentration operations (whose contributions appear to be similar). The differences are $0.025 - 0.0080 = 0.017$ g, and $0.025 - 0.0075 = 0.0175$ g respectively.

The dominant contributor to McArthur River/ BZL stream smelting operations is '274 Aluminium (Al, 25% recycling): Production.1' which connects first to 'BZL: [Tr.] Aluminium' and then 'BZL: Cadmium and Zinc Refining Plant', within the system node: 'BZL: Cadmium and Zinc Refining Operations'. Emissions from this node are associated with a potential variation range of 0.0040422 g. For Hilton/Mt. Isa stream concentration operations, the dominant contributor is '232 Diesel Oil: Production.5', which connects to '602 Road Transport (Truck, 40t, Diesel Oil, kg.1', and is within the system node: 'MIM: Zinc-Lead-Silver Ore Concentration Operations at Mt. Isa'. Emissions from this node are associated with a predicted potential variation range of 0.0000462 g. Since the difference between McArthur River/BZL stream lead refining operations and Hilton/Mt. Isa stream concentration operations is greater than either the individual or combined variation ranges of the dominant contributors, it may be concluded, the assertion that there is a significant difference between the two is robust.

With regard to the difference between McArthur River/ BZL stream smelting operations and Hilton/Mt. Isa stream lead refining operations, there are no dominating contributors at the whole site scale for Hilton/Mt. Isa stream lead refining operations, and the predicted potential variation range associated with the dominant contributor is 0.0040422 g. This range is less than the difference between the operations. Hence, it may be concluded, the assertion there is a significant difference is also robust.

Category 2 graphs:

Graph 10.22 suggests that, for the allocated model, the dominant contributor to atmospheric emissions of '(w) Arsenic (As³⁺, As⁵⁺)', per 1000 kg of production from each operation, is from Hilton/Mt. Isa stream lead refining operations. It also suggests there are significant contributions from McArthur River stream lead refining operations, as well as from smelting and concentration operations from both streams. However, for the

unallocated model (Graph 10.50), the main contribution appears to be from McArthur River/BZL stream smelting operations only.

The main difference apparent in these graphs compared with the Category 1 graphs (Graphs 10.8 and 10.36) is the greater relative consumptions by McArthur River/BZL stream operations, in both models. This has occurred because the overall throughput through the Hilton/Mt. Isa stream is greater than that for the McArthur River/BZL stream. As a result, this form of normalisation tends to increase the size of the bars associated with the McArthur River/BZL stream relative to those for the Hilton/ Mt. Isa stream.

With this form of normalisation, the relative domination of the contributions from the comprising atoms differ from that of the 'Category 1' graphs. Since, dominance analyses have not been conducted for this form of normalisation, interpretation of the 'Category 2' graphs, currently, is limited. Hence, this represents an area for further research.

i) (w) Cadmium (Cd+)¹⁰⁷:

Relevant graphs:	Graph 10.9:	Category 1, Allocated model
	Graph 10.23:	Category 2, Allocated model
	Graph 10.37:	Category 1, Unallocated model
	Graph 10.51:	Category 2, Unallocated model

Category 1 graphs:

Both Graphs 10.9 and 10.37 show that, relative to the total output from the modelled system, the McArthur River/BZL stream appears to give rise to substantially greater total emissions to atmosphere of '(w) Cadmium (Cd+)' than the Hilton/Mt. Isa stream. For the allocated model, this dominance appears to be almost total. Both models also indicate that the emissions, from both streams, originate, almost exclusively, from smelting operations.

¹⁰⁷ Throughout the discussion, the names of the inventory flows, and atoms, are those supplied the TEAMTM software. In consequence, names for many chemical compounds do not comply fully with conventional methodology. For further information, see section 10.4.4.5 of this chapter.

Dominance analysis for both models demonstrates that 69.18 % of emissions '(w) Cadmium (Cd+)' by mass, in the allocated model, and 90.27 % of emissions by mass, in the unallocated model, are associated with one McArthur River/BZL stream atomic node. This node is 'BZL: Effluent treatment (in on-site plant)'. The 'Lead Bullion' input, used to model the MHD bullion input to the 'BRM: Lead Refining (BRM floor throughput)' foreground node, also makes a small, but significant input (i.e. greater than 5% by mass) to total emissions. However, all of the other emissions sources account for less than 5%, individually, of the total system emissions. In consequence, the overall system and individual operations emissions of '(w) Cadmium (Cd+)' are expected to be relatively robust to potential inaccuracies and biases in any of the other individual atoms within both modelled systems.

The 'BZL: Effluent treatment (in on-site plant)' node is in the foreground and the emissions are based on measured data, which have been collected and processed on a regular basis, by site personnel using techniques of current best practice. Therefore, the measurements are expected to be reasonably accurate. In consequence, sensitivity analyses have been conducted for the 'Lead Bullion' node only. However, this atom represents a background process. Since the flows in and out of the module (used to construct it) are not variables, the '(w) Cadmium (Cd+)' flow out from this atom, cannot be modified on its own. It has been modified, therefore, by altering the linked flow in the foreground atomic node, to which it is connected. The linked foreground flow, and the path by which it is linked, is indicated in volume 5 of the Portfolio, in Document 11, for the allocated model, and in Document 14, for the unallocated model.

For smelting operations, sensitivity analyses performed on the 'Lead Bullion' node, indicate changes of 0.02345 g and 0.09311 g, for the allocated and unallocated models respectively.¹⁰⁸ Hence, the predicted potential variation ranges are $2 \times 0.02345 = 0.0469$ g, and $2 \times 0.09311 = 0.18622$ g respectively (for reasons explained in part a)). However, the difference between the two streams, for the allocated model, is $0.15 - 0.0010 = 0.149$ g, and is $2.47 - 0.0019 = 2.468$ g, for the unallocated model. Both of these differences are substantially greater than the potential predicted variation ranges associated with the 'Lead

¹⁰⁸ Throughout the discussion, the number of decimal places reflects the number calculated by the TEAM™ software. It does not suggest a particular level of accuracy.

Bullion' node. Hence, it may be concluded, the difference between the two streams, for smelting operations, is robust.

At the whole system level, the differences between the two streams are $0.209 - 0.0056 = 0.2034$ g, and $2.719 - 0.018 = 2.701$ g respectively. These differences are also greater than the potential predicted variation ranges associated with the 'Lead Bullion' node, for both models. Hence, it may be concluded, the difference between the two streams, at the whole system scale, is also robust.

Category 2 graphs:

Both, Graph 10.23 (of the allocated model) and Graph 10.51 (of the unallocated model) indicate that, per 1000 kg of output from the operations shown, emissions '(w) Cadmium (Cd+)' from McArthur River/BZL stream smelting operations are by far the largest. Indeed, emissions from the other operations appear to be relatively insignificant. The differences are so extreme that these findings are considered robust.

j) (w) Copper (Cu+, Cu2+)¹⁰⁹:

Relevant graphs:	Graph 10.10:	Category 1, Allocated model
	Graph 10.24:	Category 2, Allocated model
	Graph 10.38:	Category 1, Unallocated model
	Graph 10.52:	Category 2, Unallocated model

Category 1 graphs:

Both Graphs 10.10 and 10.38 show that, relative to the total output from the modelled system, the McArthur River/BZL stream appears to give rise to substantially greater total emissions to atmosphere of '(w) Copper (Cu+, Cu2+)' than the Hilton/Mt. Isa stream. For the unallocated model, this dominance appears to be almost total. Both models also

indicate that the emissions, from both streams, originate, almost exclusively, from smelting operations.

Dominance analysis for both models, demonstrates that 71.18 % of emissions to water of '(w) Copper (Cu⁺, Cu²⁺)' by mass, in the allocated model, and 88.34 % of emissions by mass, in the unallocated model, are associated with one McArthur River/BZL stream atomic node. This node is 'BZL: Effluent treatment (in on-site plant)'. In the unallocated model, there are no additional significant contributors.

The BZL: Effluent treatment (in on-site plant)' emission source is in the foreground, and the data have been supplied by site personnel. Therefore, they are expected to be reasonably accurate. In consequence, for the unallocated model, the findings indicated above are considered to be robust. It has not been necessary, therefore, to resort to sensitivity analyses to arrive at these conclusions, due to the clear cut nature of the differences.

In the allocated model, however, dominance analysis demonstrates that the following atomic nodes also make significant contributions to '(w) Copper (Cu⁺, Cu²⁺)' emissions to water:

1. '274 Zinc (Zn): Production.1' which connects to 'BRM:[Tr.] Zinc', and then to 'BRM: Lead Refining (Isa stream)', both of which are within the system node: 'BRM: Lead Refining Operations (Isa stream)'.
2. '232 Diesel Oil: Production.5' which connects to '602 Road Transport (Truck, 40t, Diesel Oil, kg.1', and is within the system node: 'MIM: Zinc-Lead-Silver Ore Concentration Operations at Mt. Isa'.

¹⁰⁹ Throughout the discussion, the names of the inventory flows, and atoms, are those supplied the TEAMTM software. In consequence, names for many chemical compounds do not comply fully with conventional methodology. For further information, see section 10.4.4.5 of this chapter.

All other emissions sources account for less than 5%, individually, of the total system emissions. In consequence, the overall system and individual operations emissions of '(w) Copper (Cu+, Cu2+)' are expected to be relatively robust to potential inaccuracies and biases in any of the other individual atoms within both modelled systems.

The 'BZL: Effluent treatment (in on-site plant)' node is in the foreground and the emissions are based on measured data, which have been collected and processed on a regular basis, by site personnel using techniques of current best practice. Therefore, the measurements are expected to be reasonably accurate. In consequence, sensitivity analyses have been conducted for the two dominant nodes associated with the allocated model only. However, these atoms represent background processes. Since the flows in and out of the DEAMTM modules (used to construct them) are not variables, the '(w) Copper (Cu+, Cu2+)' flows out from them, cannot be modified on their own. They have been modified, therefore, by altering the linked flows in the foreground atomic nodes, to which they are connected. The linked foreground flows, and the paths by which they are linked, are indicated in Document 11 (of volume 5 of the Portfolio).

For smelting operations in the allocated model, sensitivity analyses performed on the dominant contributors, indicate changes of 0.000021 g and 0.004844 g¹¹⁰. (Data from Document 11, of volume 5 of the Portfolio.) Hence, the predicted potential variation ranges are $2 \times 0.000021 = 0.000042$ g, and $2 \times 0.004844 = 0.009688$ g respectively (for reasons explained in part a)). However, the difference between the two streams, for the allocated model, is $0.074 - 0.0022 = 0.0718$ g.. This difference is greater than the potential predicted variation ranges associated with the dominant contributors. Hence, it may be concluded, that in the allocated model, the difference between the two streams, for smelting operations, is also robust.

With regard to the whole system level in the allocated model, the differences between the two streams are $0.077 - 0.0026 = 0.051$ g. This difference is also greater than the potential predicted variation ranges associated with the dominant contributors. Hence, it may be concluded, the difference between the two streams for the allocated model, at the whole system scale, is also robust.

¹¹⁰ Throughout the discussion, the number of decimal places reflects the number calculated by the TEAMTM software. It does not suggest a particular level of accuracy.

Category 2 graphs:

Both, Graph 10.24 (of the allocated model) and Graph 10.52 (of the unallocated model) indicate that, per 1000 kg of output from the operations shown, emissions “(w) Copper (Cu⁺, Cu²⁺)’ from McArthur River/BZL stream smelting operations are by far the largest. Indeed, emissions from the other operations appear to be relatively insignificant. The differences are so extreme that these findings are considered robust.

k) (w) Lead (Pb⁺⁺, Pb⁴⁺)¹¹¹:

Relevant graphs:	Graph 10.11:	Category 1, Allocated model
	Graph 10.25:	Category 2, Allocated model
	Graph 10.39:	Category 1, Unallocated model
	Graph 10.53:	Category 2, Unallocated model

Category 1 graphs:

Both Graphs 10.11 and 10.39 show that, relative to the total output from the modelled system, the McArthur River/BZL stream appears to give rise to substantially greater total emissions to atmosphere of ‘(w) Lead (Pb⁺⁺, Pb⁴⁺)’ than the Hilton/Mt. Isa stream. For the unallocated model, this dominance appears to be almost total. Both models also indicate that the emissions, from both streams, originate, almost exclusively, from smelting operations.

Dominance analysis for both models demonstrates that 61.59 % of emissions ‘(w) Cadmium (Cd⁺)’ by mass, in the allocated model, and 85.81 % of emissions by mass, in the unallocated model, are associated with one McArthur River/BZL stream atomic node. This node is ‘BZL: Effluent treatment (in on-site plant)’. The ‘Lead Bullion’ input, used to model the MHD bullion input to the ‘BRM: Lead Refining (BRM floor throughput)’

foreground node, also makes a significant input (i.e. greater than 5% by mass) to total emissions. However, all of the other emissions sources account for less than 5%, individually, of the total system emissions. In consequence, the overall system and individual operations emissions of '(w) Lead (Pb⁺⁺, Pb⁴⁺)' are expected to be relatively robust to potential inaccuracies and biases in any of the other individual atoms within both modelled systems.

The 'BZL: Effluent treatment (in on-site plant)' node is in the foreground and the emissions are based on measured data, which have been collected and processed on a regular basis, by site personnel using techniques of current best practice. Therefore, the measurements are expected to be reasonably accurate. In consequence, sensitivity analyses have been conducted for the 'Lead Bullion' node only. However, this atom represents a background process. Since the flows in and out of the module (used to construct it) are not variables, the '(w) Lead (Pb⁺⁺, Pb⁴⁺)' flow out from this atom, cannot be modified on its own. It has been modified, therefore, by altering the linked flow in the foreground atomic node, to which it is connected. The linked foreground flow, and the path by which it is linked, is indicated in volume 5 of the Portfolio, in Document 11, for the allocated model, and in Document 14, for the unallocated model.

For smelting operations, sensitivity analyses performed on the 'Lead Bullion' node, indicate changes of 0.07033 g and 0.2793 g, for the allocated and unallocated models respectively¹¹². (Data from Documents 11 and 14, of volume 5 of the Portfolio.) Hence, the predicted potential variation ranges are $2 \times 0.07033 = 0.14066$ g, and $2 \times 0.2793 = 0.5586$ g respectively (for reasons explained in part a)). However, the difference between the two streams, for the allocated model, is $0.35 - 0.00103 = 0.34897$ g, and is $5.85 - 0.0023 = 5.8477$ g, for the unallocated model. Both of these differences are substantially greater than the potential predicted variation ranges associated with the 'Lead Bullion' node. Hence, it may be concluded, the difference between the two streams, for smelting operations, is robust.

¹¹¹ Throughout the discussion, the names of the inventory flows, and atoms, are those supplied the TEAMTM software. In consequence, names for many chemical compounds do not comply fully with conventional methodology. For further information, see section 10.4.4.5 of this chapter.

¹¹² Throughout the discussion, the number of decimal places reflects the number calculated by the TEAMTM software. It does not suggest a particular level of accuracy.

At the whole system level, the differences between the two streams are $0.53 - 0.0023 = 0.507$ g, and $6.59 - 0.051 = 6.539$ g respectively. These differences are also substantially greater than the potential predicted variation ranges associated with the 'Lead Bullion' node, for both models. Hence, it may be concluded, the difference between the two streams, at the whole system scale, is also robust.

Category 2 graphs:

Both, Graph 10.25 (of the allocated model) and Graph 10.53 (of the unallocated model) indicate that, per 1000 kg of output from the operations shown, '(w) Lead (Pb⁺⁺, Pb⁴⁺)' from McArthur River/BZL stream smelting operations are by far the largest. Indeed, emissions from the other operations appear to be relatively insignificant. The differences are so extreme that these findings are considered robust.

l) (w) Zinc (Zn⁺⁺)¹¹³:

Relevant graphs:	Graph 10.12:	Category 1, Allocated model
	Graph 10.26:	Category 2, Allocated model
	Graph 10.40:	Category 1, Unallocated model
	Graph 10.54:	Category 2, Unallocated model

Category 1 graphs:

Both Graphs 10.12 and 10.40 show that, relative to the total output from the modelled system, the McArthur River/BZL stream appears to give rise to substantially greater total emissions to atmosphere of '(w) Zinc (Zn⁺⁺)' than the Hilton/Mt. Isa stream. For the unallocated model, this dominance appears to be almost total. Both models also indicate that the emissions, from both streams, originate, almost exclusively, from smelting operations.

Dominance analysis for both models demonstrates that 52.60 % of emissions '(w) Zinc (Zn++)' by mass, in the allocated model, and 81.48 % of emissions by mass, in the unallocated model, are associated with one McArthur River/BZL stream atomic node. This node is 'BZL: Effluent treatment (in on-site plant)'. The 'Lead Bullion' input, used to model the MHD bullion input to the 'BRM: Lead Refining (BRM floor throughput)' foreground node, also makes a significant input (i.e. greater than 5% by mass) to total emissions. However, all of the other emissions sources account for less than 5%, individually, of the total system emissions. In consequence, the overall system and individual operations emissions of '(w) Zinc (Zn++)' are expected to be relatively robust to potential inaccuracies and biases in any of the other individual atoms within both modelled systems.

The 'BZL: Effluent treatment (in on-site plant)' node is in the foreground and the emissions are based on measured data, which have been collected and processed on a regular basis, by site personnel using techniques of current best practice. Therefore, the measurements are expected to be reasonably accurate. In consequence, sensitivity analyses have been conducted for the 'Lead Bullion' node only. However, this atom represents a background process. Since the flows in and out of the module (used to construct it) are not variables, the '(w) Zinc (Zn++)' flow out from this atom, cannot be modified on its own. It has been modified, therefore, by altering the linked flow in the foreground atomic node, to which it is connected. The linked foreground flow, and the path by which it is linked, is indicated in volume 5 of the Portfolio, in Document 11, for the allocated model, and in Document 14, for the unallocated model.

For smelting operations, sensitivity analyses performed on the 'Lead Bullion' node, indicate changes of 0.1524 g and 0.6053 g, for the allocated and unallocated models respectively¹¹⁴. Hence, the predicted potential variation ranges are $2 \times 0.1524 = 0.3048$ g, and $2 \times 0.6053 = 1.2106$ g respectively (for reasons explained in part a)). However, the difference between the two streams, for the allocated model, is $0.54 - 0.0033 = 0.5317$ g, and is $9.17 - 0.019 = 9.151$ g, for the unallocated model. Both of these differences are

¹¹³ Throughout the discussion, the names of the inventory flows, and atoms, are those supplied the TEAMTM software. In consequence, names for many chemical compounds do not comply fully with conventional methodology. For further information, see section 10.4.4.5 of this chapter.

¹¹⁴ Throughout the discussion, the number of decimal places reflects the number calculated by the TEAMTM software. It does not suggest a particular level of accuracy.

substantially greater than the potential predicted variation ranges associated with the 'Lead Bullion' node. Hence, it may be concluded, the difference between the two streams, for smelting operations, is robust.

At the whole system level, the differences between the two streams are $0.95 - 0.084 = 0.866$ g, and $10.81 - 0.23 = 10.58$ g respectively. These differences are also substantially greater than the potential predicted variation ranges associated with the 'Lead Bullion' node, for both models. Hence, it may be concluded, the difference between the two streams, at the whole system scale, is also robust.

Category 2 graphs:

Both, Graph 10.26 (of the allocated model) and Graph 10.54 (of the unallocated model) indicate that, per 1000 kg of output from the operations shown, '(w) Zinc (Zn++)' from McArthur River/BZL stream smelting operations are by far the largest. Indeed, emissions from the other operations appear to be relatively insignificant. The differences are so extreme that these findings are considered robust.

m) E Total Primary Energy:

Relevant graphs:	Graph 10.13:	Category 1, Allocated model
	Graph 10.27:	Category 2, Allocated model
	Graph 10.41:	Category 1, Unallocated model
	Graph 10.55:	Category 2, Unallocated model

Category 1 graphs:

Both Graphs 10.13 and 10.41 show that, relative to the total output from the modelled system, the Hilton/Mt. Isa stream appears to have a substantially greater total demand for 'E Total Primary Energy' than the McArthur River/BZL stream. Both models also indicate that the greatest demand in the Hilton/Mt. Isa stream is from concentration operations.

Dominance analysis for the allocated model demonstrates that the consumption of 'E Total Primary Energy' may be attributed principally to:

1. '241 Water (Softened): Production.1', which connects to 'MCPS: Electricity Production (Mica Creek Power Station)', and is within the system node: 'MCPS: Electricity Production Operations (Mica Creek Power Station)'.
2. '401 Electricity (Australia, 1995): Production.2' which connects to '232 Diesel Oil: Production.2', both of which are within the system node: 'MCPS: Electricity Production Operations (Mica Creek Power Station)'.

Sensitivity analyses have been conducted for these dominating atoms, as indicated in Document 11 (of volume 5 of the Portfolio).

For the unallocated model, dominance analysis demonstrates that the consumption of 'E Total Primary Energy' may be attributed principally to:

1. '241 Water (Softened): Production.1', which connects to 'MCPS: Electricity Production (Mica Creek Power Station)', and is within the system node: 'MCPS: Electricity Production Operations (Mica Creek Power Station)'.
2. '231 Coke: Production.1' which connects to 'BZL: [Tr.] Coke', and is within the system node: 'BZL: Lead Bullion Production: Imperial Smelting Furnace'.
3. '401 Electricity (Australia, 1995): Production.2' which connects to '232 Diesel Oil: Production.2', both of which are within the system node: 'MCPS: Electricity Production Operations (Mica Creek Power Station)'.

Sensitivity analyses have also been conducted for these dominating atoms, as indicated in Document 14 (of volume 5 of the Portfolio).

These dominance analyses demonstrate that the 'E Total Primary Energy' consumptions, in both the allocated and unallocated models, are attributable to the production of the 'Water (Softened)' used by the Mica Creek Power Station (MCPS), and to the generation of electricity consumed in the production of diesel oil which is then also consumed by the MCPS. In the unallocated model, production of coke, used by the BZL Imperial Smelting Furnace is also a dominant contributor.

For both the allocated and unallocated models, the dominance analyses also show that, individually, all other individual contributions to 'E Total Primary Energy' consumption, account for less than 5%, by mass, of the total for the system. In consequence, in both models, the overall system consumptions of 'E Total Primary Energy' are expected to be relatively robust to potential inaccuracies and biases in any of the other atoms, within any of the system nodes.

All of the dominating atoms, in both models, are in the background. Since the flows in and out of DEAM™ modules (which have been used to construct these atoms) are not variables, the 'E Total Primary Energy' flow within these atoms, cannot be modified on their own. Therefore, they have been modified by altering the linked flow(s) in the foreground atomic node(s), to which they are connected. The linked foreground flows, and the paths by which they are linked, are indicated in Documents 11 and 14 (of volume 5 of the Portfolio).

Graph 10.13 suggests a difference, at the overall system level, of $40413.90 - 5474.97 = 34938.93$ MJ between the Hilton/Mt. Isa and McArthur River/BZL streams for the allocated model, and Graph 10.41 a difference of $136199.00 - 61221.00 = 74978.00$ MJ for the unallocated model. The quantity changes in 'E Total Primary Energy' consumption resulting from sensitivity analyses, applied to both models, are indicated in Documents 11 and 14 (of volume 5 of the Portfolio). Assuming the potential variation ranges are twice the changes identified in the sensitivity analyses (for similar reasons to those given in part a)), the predicted variation ranges attributable to the dominant flows, in the allocated model are:

- $2 \times 7397.87 = 14795.75$ MJ¹¹⁵, and
- $2 \times 0.62 = 1.25$ MJ.

¹¹⁵ Throughout the discussion, the number of significant figures reflects the number calculated by the TEAM™ software. It does not suggest a particular level of accuracy.

For the unallocated model, they are:

- $2 \times 26835.21 = 53670.42$ MJ,
- $2 \times 2310.20 = 4620.40$ MJ, and
- $2 \times 2.27 = 4.54$ MJ.

For both models, the differences in 'E Total Primary Energy' consumption between the Hilton/Mt. Isa stream and the McArthur River/BZL streams, at the whole site scale, are greater than the predicted potential variation ranges associated with the dominant contributors, either individually or even when all are combined. It may be concluded, therefore, that the Hilton/Mt. Isa stream, has a significantly greater demand for 'E Total Primary Energy' consumption than the McArthur River/BZL stream, and that this finding is robust.

For both models, the differences in 'E Total Primary Energy' consumption between the mining, concentration and smelting operations for the Hilton/Mt. Isa stream are due, principally, to differences in the relative consumptions of electricity supplied to them by the MCPS. In both the allocated model and in the unallocated model, the largest single consumption source from the Hilton/Mt. Isa stream is from concentration operations. The second largest is from mining operations and the third largest from smelting operations. Since there are no other dominant contributors to 'E Total Primary Energy' consumption for these operations, this relative order is considered reasonably robust.

Table 10.21 indicates the actual relative differences in the consumptions of electricity from the MCPS, by operations associated with the Hilton/Mt. Isa stream, during the period modelled. In Table 10.25, these data have been used to calculate scaling fractions, which may be applied to attribute the differences, identified by the sensitivity analysis for the '241 Water (Softened): Production.1' and '401 Electricity (Australia, 1995): Production.2' nodes, to the various Mt. Isa based Hilton/Mt. Isa stream operations.

Operations	Contributor			
	241 Water (Softened): Production.1		401 electricity (Australia, 1995): Production.2	
	Change in fractional consumption	Predicted variation range	Change in fractional consumption	Predicted variation range
Allocated model: (Change identified by sensitivity analysis: 241 Water (Softened): Production.1 = 7397.87 MJ 401 Electricity (Australia, 1995): Production.2 = 0.6248 MJ)				
Smelting	0.1366931 x 7,397.87 = 1,011.238 MJ	2 x 1011.238 = 2,022.476 MJ	0.1366931 x 0.6248 = 0.085406 MJ	2 x 0.085406 = 0.170812 MJ
Concentration	0.685286981 x 7,397.87 = 5,069.664 MJ	2 x 5069.664 = 10,139.33 MJ	0.685286981 0.6248 x = 0.428167 MJ	2 x 0.428167 = 0.856335 MJ
Hilton and Mt. Isa mining combined	0.071575015 x 7,397.87 = 529.5027 MJg	2 x 529.5027 = 1,059.005 MJ	0.071575015 x 0.6248 = 0.04472 MJ	2 x 0.04472 = 0.08944 MJ
Unallocated model (Change identified by sensitivity analysis: 241 Water (Softened): Production.1 = 26835.21 MJ 401 Electricity (Australia, 1995): Production.2 = 2310.20 MJ)				
Smelting	0.1366931 x 26,835.21 = 3,668.185 MJ	2 x 3,668.185 = 7,336.371 MJ	0.1366931 x 2,310.20 = 315.7882 MJ	2 x 315.7882 = 631.5763 MJ
Concentration	0.685286981 x 26,835.21 = 18,389.82 MJ	2 x 18,389.82 = 36,779.64 MJ	0.685286981 x 2,310.20 = 1,583.15 MJ	2 x 1,583.15 = 31,66.3 MJ
Hilton and Mt. Isa mining combined	0.071575015 x 26,835.21 = 1,920.731 MJ	2 x 1,920.731 = 3,841.461 MJ	0.071575015 x 2,310.20 = 165.3526 MJ	2 x 165.3526 = 330.7052 MJ

Table 10.25: Calculation of the variation ranges in 'E Total primary Energy' consumption, associated with the MCPS operations atoms: '241 Water (Softened): Production.1' and '401 Electricity (Australia, 1995): Production.2'

Graph 10.13 indicates, for concentration operations, a difference between the Hilton/Mt. Isa and McArthur River/BZL streams of $23,932.89 - 290.72 = 23,642.17$ MJ, for the allocated model, and Graph 10.41 indicates a difference of $86,920.11 - 7,494.27 = 79,425.84$ MJ, for the unallocated model. When considered both individually and combined, these are greater than the variation ranges attributable to the dominant contributors (Table 10.25), which are 10,139.33 MJ and 0.856335 MJ for the allocated model, and are 36,779.64 MJ and 3,166.3 MJ for the unallocated model. For mining

operations, the differences between the two streams are $6,553.57 - 73.65 = 6,479.92$ MJ for the allocated model, and $23,810.92 - 1,898.67 = 21,912.25$ MJ, for the unallocated model. When considered both individually and combined, these are greater than the predicted potential variation ranges attributable to the dominant contributors (Table 10.25), which are 1,059.005 MJ and 0.08944 MJ for the allocated model, and 1,920.731 MJ and 330.7052 MJ for the unallocated model. On the basis of these considerations, it may be concluded for both models, the assertion that consumptions by concentration and mining operations are significantly greater by the Hilton/Mt. Isa stream than those by the McArthur River/ BZL stream is robust.

For smelting operations, in the allocated model, the Hilton/Mt. Isa stream appears to have a greater consumption than the McArthur River/BZL stream. However, in the unallocated model this appears to be reversed. The difference between the two streams in the allocated model is $5,672.60 - 2,807.26 = 2,865.34$ MJ, and in the unallocated model is $37,028.07 - 17,888.79 = 19,139.28$ MJ. When considered both individually and combined, for the allocated model, these are greater than the predicted potential variation ranges attributable to the dominant contributors (Table 10.25), which are 2,022.476 MJ and 0.170812 MJ. For the unallocated model, the potential predicted variation range associated with the production of the coke used by the BZL Imperial Smelting Furnace, in addition to those in Table 10.25, need to be considered. These are 4.54 MJ, plus 7,336.371 MJ and 631.5763 MJ respectively. When considered both individually and combined, these too are greater than the predicted potential variation ranges attributable to the dominant contributors. On the basis of these considerations, both of the above assertions are considered to be robust.

Category 2 graphs:

Both Graph 10.27, for the allocated model, and Graph 10.55, for the unallocated model, suggest that, the dominant contributor to the consumption of 'E Total Primary Energy', per 1000 kg of production from each operation, is from McArthur River/BZL stream smelting operations, followed by Hilton/Mt. Isa stream concentration operations. For both streams, lead refining and mining operations appear to make only minor contributions.

The dominance of McArthur River/BZL stream over Hilton/Mt. Isa stream smelting operations in the unallocated model (Graph 10.55), is also observed in the Category 1 graph (Graph 10.41). However, for the allocated model, unlike Graph 10.27, the Category 1 graph (Graph 10.13) shows Hilton/Mt. Isa stream smelting operations to dominate over McArthur River/BZL stream smelting operations. In addition, the Category 1 graphs, for both models, indicate that Hilton/Mt. Isa stream concentration operations dominate overall, rather than the McArthur River/BZL stream smelting operations as in these graphs.

The reason for these differences is the fact that the overall throughput through the Hilton/Mt. Isa stream is greater than that for the McArthur River/BZL stream. As a result, this form of normalisation tends to increase the size of the bars associated with the McArthur River/BZL stream relative to those for the Hilton/ Mt. Isa stream.

With this form of normalisation, the relative domination of the contributions from the comprising atoms differ from that of the ‘Category 1’ graphs. Since, dominance analyses have not been conducted for this form of normalisation, interpretation of the ‘Category 2’ graphs, currently, is limited. Hence, this represents an area for further research.

n) Total Electricity:

Relevant graphs:	Graph 10.14:	Category 1, Allocated model
	Graph 10.28:	Category 2, Allocated model
	Graph 10.42:	Category 1, Unallocated model
	Graph 10.56:	Category 2, Unallocated model

Category 1 graphs:

Graphs 10.14 shows, for the allocated model, that, relative to the total output from the modelled system, the Hilton/Mt. Isa stream appears to have a substantially greater total demand for ‘Total Electricity’ than the McArthur River/BZL stream. However, Graph 10.42, for the unallocated model, shows that relative to the total output from the modelled system, the McArthur River/BZL stream appears to have a substantially greater total demand for ‘Total Electricity’ than the Hilton/Mt. Isa stream. Both models appear to

indicate that the greatest demand in the Hilton/Mt. Isa stream is from concentration operations.

Dominance analysis for the allocated model demonstrates that the consumption of 'Total Electricity' may be attributed principally to:

1. '241 Water (Softened): Production.1', which connects to 'MCPS: Electricity Production (Mica Creek Power Station)', and is within the system node: 'MCPS: Electricity Production Operations (Mica Creek Power Station)'.
2. 'Lead Bullion: Production' which connects successively to 'BRM: [Tr.] MHD Lead Bullion (truck1)', 'BRM: [Tr.] MHD Lead Bullion (ship)', 'BRM: [Tr.] MHD Lead Bullion (truck)', 'BRM: Overheads (MHD bullion processing)', and then 'BRM: lead Refining (BRM floor throughput)'.

Sensitivity analyses have been conducted for these dominating atoms, as indicated in Document 11 (of volume 5 of the Portfolio).

For the unallocated model, dominance analysis demonstrates that the consumption of 'Total Electricity' may be attributed principally to:

1. '241 Water (Softened): Production.1', which connects to 'MCPS: Electricity Production (Mica Creek Power Station)', and is within the system node: 'MCPS: Electricity Production Operations (Mica Creek Power Station)'.
2. 'BZL: Lead Bullion Production: Imperial Smelting Furnace'.
3. 'MRM: Mixed Concentrate Production at McArthur River'.
4. '401 Electricity (Australia, 1995): Production.2' which connects to '232 Diesel Oil: Production.2', both of which are within the system node: 'MCPS: Electricity Production Operations (Mica Creek Power Station)'.

Sensitivity analyses have also been conducted for these dominating atoms, as indicated in Document 14 (of volume 5 of the Portfolio).

For both the allocated and unallocated models, the dominance analyses also show that, individually, all other individual contributions to 'Total Electricity' consumption, account

for less than 5%, by mass, of the total for the system. In consequence, in both models, the overall system consumptions of 'Total Electricity' are expected to be relatively robust to potential inaccuracies and biases in any of the other atoms, within any of the system nodes.

All of the dominating atoms, in the allocated model as well as the '241 Water (Softened): Production.1' and '401 Electricity (Australia, 1995): Production.2' atoms in the unallocated model, are in the background. However, the 'BZL: Lead Bullion Production: Imperial Smelting Furnace' and 'MRM: Mixed Concentrate Production at McArthur River' dominating atoms, in the unallocated model, are in the foreground. For these foreground atoms, in the sensitivity analyses, the electricity inflows have been altered in isolation of all other inflows and outflows for these atoms. This is possible due to the fact that all flows relating to all atoms in the foreground have been modelled as variables in TEAMTM. However, since the flows in and out of the DEAMTM and other modules (which have been used to construct the background atoms) are not variables, the 'Total Electricity' flows within these background atoms, cannot be modified on their own. Therefore, they have been modified by altering the linked flow(s) in the foreground atomic node(s), to which they are connected. The linked foreground flows, and the paths by which they are linked, are indicated in Documents 11 and 14 (of volume 5 of the Portfolio).

Graph 10.14 suggests a difference, at the overall system level, of $2,166.26 - 751.88 = 1,414.38$ MJ between the Hilton/Mt. Isa and McArthur River/BZL streams for the allocated model, and Graph 10.43 a difference of $8,130.30 - 7,377.60 = 752.7$ MJ for the unallocated model. The quantity changes in 'Total Electricity' consumption resulting from sensitivity analyses, applied to both models, are indicated in Documents 11 and 14 (of volume 5 of the Portfolio). Assuming the potential variation ranges are twice the changes identified in the sensitivity analyses (for similar reasons to those given in part a)), the predicted variation ranges attributable to the dominant flows, in the allocated model are:

- $2 \times 93.5861 = 187.1722$ MJ¹¹⁶, and
- $2 \times 97.9754 = 195.9508$ MJ.

¹¹⁶ Throughout the discussion, the number of decimal places reflects the number calculated by the TEAMTM software. It does not suggest a particular level of accuracy.

For the unallocated model, they are:

- $2 \times 339.4756 = 678.9512$ MJ,
- $2 \times 24.9363 = 49.8726$ MJ,
- $2 \times 26.9397 = 53.8794$ MJ, and
- $2 \times 0.001427 = 0.002854$ MJ.

For allocated model, the differences in ‘Total Electricity’ consumption between the Hilton/Mt. Isa stream and the McArthur River/BZL streams, at the whole site scale, are greater than the predicted potential variation ranges associated with the dominant contributors, either individually or even when all are combined. It may be concluded, therefore, that the Hilton/Mt. Isa stream, in the allocated model, has a significantly greater demand for ‘Total Electricity’ consumption than the McArthur River/BZL stream, and that this finding is robust. For the unallocated model, however, the differences in ‘Total Electricity’ consumption between the Hilton/Mt. Isa stream and the McArthur River/BZL streams, at the whole site scale, are less than the predicted potential variation ranges associated with the dominant contributors, when all are combined, but are greater than them when they are considered individually. It may be concluded, therefore, that whilst it is quite likely, at the overall system level, the consumption of ‘Total Electricity’ by the McArthur River/BZL stream is greater than that of the Hilton/Mt. Isa stream, the uncertainties associated with the modelling are such that it is not possible to demonstrate this unequivocally.

For both models, the differences in ‘Total Electricity’ consumption between the mining, concentration and smelting operations for the Hilton/Mt. Isa stream are due, principally, to differences in the relative consumptions of electricity supplied to them by the MCPS. In both the allocated model and in the unallocated model, the largest single consumption source from the Hilton/Mt. Isa stream is from concentration operations. The second largest is from mining operations and the third largest from smelting operations. Since there are no other dominant contributors to ‘Total Electricity’ consumption for these operations, this relative order is considered reasonably robust.

Table 10.21 indicates the actual relative differences in the consumptions of electricity from the MCPS, by operations associated with the Hilton/Mt. Isa stream, during the period

modelled. In Table 10.26, these data have been used to calculate scaling fractions, which may be applied to attribute the differences, identified by the sensitivity analysis for the '241 Water (Softened): Production.1' node in the allocated model, and the '241 Water (Softened): Production.1' plus '401 Electricity (Australia, 1995): Production.2' nodes in the unallocated model, to the various Mt. Isa based Hilton/Mt. Isa stream operations.

<i>Allocated model: (Change identified by sensitivity analysis: 241 Water (Softened): Production.1 = 93.5861 MJ)</i>				
Operations	Contributions from: 241 Water (Softened): Production.1			
	Change in fractional consumption		Predicted variation range	
Smelting	0.1366931 x 93.5861 = 12.79257 MJ		2 x 12.79257 = 25.58515 MJ	
Concentration	0.685286981 x 93.5861 = 64.13334 MJ		2 x 64.13334 = 128.2667 MJ	
Hilton and Mt. Isa mining combined	0.071575015 x 93.5861 = 6.698427 MJ		2 x 6.698427 = 13.3969 MJ	
<i>Unallocated model (Change identified by sensitivity analysis: 241 Water (Softened): Production.1 = 339.4756 MJ 401 Electricity (Australia, 1995): Production.2 = 0.001427 MJ)</i>				
Operations	Contributor			
	241 Water (Softened): Production.1		401 Electricity (Australia, 1995): Production.2	
	Change in fractional consumption	Predicted variation range	Change in fractional consumption	Predicted variation range
Smelting	0.1366931 x 339.4756 = 46.4040 MJ	2 x 46.40397 = 92.8079 MJ	0.1366931 x 0.001427 = 0.000195 MJ	2 x 0.000195 = 0.00039 MJ
Concentration	0.685286981 x 339.4756 = 232.6382 MJ	2 x 232.6382 = 465.2764 MJ	0.685286981 x 0.001427 = 0.000978 MJ	2 x 0.000978 = 0.001956 MJ
Hilton and Mt. Isa mining combined	0.071575015 x 339.4756 = 24.2980 MJ	2 x 24.29797 = 48.5959 MJ	0.071575015 x 0.001427 = 0.000102 MJ	2 x 0.000102 = 0.000204 MJ

Table 10.26: Calculation of the variation ranges in 'Total Electricity' consumption, associated with the MCPS operations atoms: '241 Water (Softened): Production.1' and '401 Electricity (Australia, 1995): Production.2'

Graphs 10.14 and 10.42 indicate, for mining operations, the differences between the two streams are $466.08 - 12.55 = 453.53$ MJ, for the allocated model, and $1,697.32 - 323.49 = 1,373.83$ MJ, for the unallocated model, respectively. When considered both individually and combined, these are greater than the predicted potential variation ranges attributable to the dominant contributors (Table 10.26), which are 13.3969 MJ, for the allocated model, and 48.5959 MJ and 0.000204 MJ, for the unallocated model. On the basis of these considerations, it may be concluded for both models, the assertion that consumption by Hilton/Mt. Isa stream mining operations is significantly greater than that by McArthur River/ BZL stream mining operations, is robust.

For concentration operations, in the allocated model, the difference between the Hilton/Mt. Isa and McArthur River/BZL streams is $1,225.32 - 53.17 = 1,172.15$ MJ. This is greater than the variation range attributable to the dominant contributor, which is 128.2667 MJ (Table 10.26). Hence, it may be concluded the assertion that, in the allocated model, consumption by Hilton/Mt. Isa stream smelting operations is significantly greater than that by the McArthur River/ BZL stream smelting operations, is robust. For concentration operations, in the unallocated model, Graph 10.42 indicates a difference of $4,451.80 - 1,370.57 = 3,081.23$ MJ. For the unallocated model, to make comparisons, the predicted potential variation ranges associated with the electricity consumed by MRM mixed concentrate production, in addition to those in Table 10.26 need to be considered. These are 53.8794 MJ, plus 465.2764 MJ and 0.001956 MJ respectively. When considered both individually and combined, the difference between the two streams is greater than the predicted potential variation ranges attributable to the dominant contributors. Hence, it may be concluded the assertion that, in the unallocated model, consumption by Hilton/Mt. Isa stream smelting operations is significantly greater than that by the McArthur River/ BZL stream smelting operations, is also robust.

For smelting operations, in the allocated model, the Hilton/Mt. Isa stream appears to have a greater consumption than the McArthur River/BZL stream. However, in the unallocated model this appears to be reversed. The difference between the two streams in the allocated model is $260.50 - 174.22 = 86.28$ MJ, and in the unallocated model is $3,291.72 - 846.61 = 2,445.11$ MJ. When considered both individually and combined, for the allocated model, the difference is greater than the predicted potential variation ranges attributable to the dominant contributor, which is 25.58515 MJ (Table 10.26). For the unallocated model, the

potential predicted variation range associated with the electricity consumed by the BZL Imperial Smelting Furnace, in addition to those in Table 10.26, need to be considered. These are 49.8726 MJ, plus 92.8079 MJ and 0.00039 MJ respectively. When considered both individually and combined, the differences between the two streams are also greater than the predicted potential variation ranges attributable to the dominant contributors. On the basis of these considerations, the assertions that Hilton/Mt. Isa stream smelting operations have a greater consumption than McArthur River/BZL stream smelting operations in the allocated model, whilst in the unallocated model the dominance is reversed, are both considered to be robust.

Category 2 graphs:

Both Graph 10.28, for the allocated model, and Graph 10.56, for the unallocated model, suggest that, the dominant contributor to the consumption of 'Total Electricity', per 1000 kg of production from each operation, is from McArthur River/BZL stream smelting operations, followed by Hilton/Mt. Isa stream concentration operations. For both streams, lead refining and mining operations appear to make only minor contributions.

The dominance of McArthur River/BZL stream over Hilton/Mt. Isa stream smelting operations in the unallocated model (Graph 10.56), is also observed in the Category 1 graph (Graph 10.42). However, for the allocated model, unlike Graph 10.28, the Category 1 graph (Graph 10.14) shows Hilton/Mt. Isa stream smelting operations to dominate over McArthur River/BZL stream smelting operations. In addition, the Category 1 graphs, for both models, indicate that Hilton/Mt. Isa stream concentration operations dominate overall, rather than the McArthur River/BZL stream smelting operations as in these graphs.

The reason for these differences is the fact that the overall throughput through the Hilton/Mt. Isa stream is greater than that for the McArthur River/BZL stream. As a result, this form of normalisation tends to increase the size of the bars associated with the McArthur River/BZL stream relative to those for the Hilton/ Mt. Isa stream.

With this form of normalisation, the relative domination of the contributions from the comprising atoms differ from that of the 'Category 1' graphs. Since, dominance analyses

have not been conducted for this form of normalisation, interpretation of the ‘Category 2’ graphs, currently, is limited. Hence, this represents an area for further research.

10.4.4.5.2 Effect graphs

a) CML -Air Acidification:

Relevant graphs:	Graph 10.57:	Category 1, Allocated model
	Graph 10.71:	Category 2, Allocated model
	Graph 10.85:	Category 1, Unallocated model
	Graph 10.99:	Category 2, Unallocated model

Category 1 graphs:

Dominance analysis indicates 98.36% of the effect, for the allocated model, and 96.6% of the effect, for the unallocated model is attributable to emissions to the atmosphere of ‘(a) Sulphur Oxides (SO_x, as SO₂)’.¹¹⁷ (Documents 12 and 15, of volume 5 of the Portfolio respectively.) In consequence, therefore, the relative sizes of bars representing the various operations in Graphs 10.57 and 10.85 are similar to those in Graphs 10.7 and 10.25 (which show the Category 1 graphs for ‘(a) Sulphur Oxides (SO_x, as SO₂)’ for the allocated and unallocated models respectively). It also means the assertions made regarding ‘(a) Sulphur Oxides (SO_x, as SO₂)’ emissions for these graphs, are fully applicable here for contributions to ‘CML -Air Acidification’.

Graphs 10.57, for the allocated model, and Graph 10.85, for the unallocated model, show that relative to the total output from the modelled system, Hilton/Mt. Isa stream smelting operations make a substantially greater contribution to ‘CML -Air Acidification’ than McArthur River/BZL smelting operations, and, overall, Hilton/Mt. Isa stream operations make a substantially greater contribution to ‘CML -Air Acidification’ than do McArthur River/BZL stream operations. On the basis of the arguments provided in part g) of section 10.4.4.5.2, both assertions are considered to be robust.

Category 2 graphs:

The arguments and assertions for Graphs 10.35 and 10.49 (which show ‘(a) Sulphur Oxides (SO_x, as SO₂)’ for the allocated and unallocated models respectively), are also directly applicable here. It is concluded, therefore that, per 1000 kg of output from the operations shown, smelting operations make by far the greatest contribution to ‘CML -Air Acidification’, and the contributions from other operations are relatively insignificant. In addition, for both models, the contributions from Hilton/Mt. Isa stream smelting operations are significantly larger than those from McArthur River/BZL stream smelting operations. On the basis of the arguments provided in part g) of section 10.4.4.5.2, these assertions are considered to be robust.

b) CML -Aquatic Eco-toxicity:

Relevant graphs:	Graph 10.58:	Category 1, Allocated model
	Graph 10.72:	Category 2, Allocated model
	Graph 10.86:	Category 1, Unallocated model
	Graph 10.100:	Category 2, Unallocated model

Category 1 graphs:

Dominance analysis indicates 94.97 % of the effect, for the allocated model, and 98.20 % of the effect, for the unallocated model is attributable to emissions to water of ‘(w) Cadmium (Cd+)’¹¹⁸. (Documents 10 and 13, of volume 5 of the Portfolio respectively.) In consequence, therefore, the relative sizes of bars representing the various operations in Graphs 10.58 and 10.86 are similar to those in Graphs 10.9 and 10.23 (which show the Category 1 graphs ‘(w) Cadmium (Cd+)’ for the allocated and unallocated models

¹¹⁷ Throughout the discussion, the names of the inventory flows, and atoms, are those supplied the TEAMTM software. In consequence, names for many chemical compounds do not comply fully with conventional methodology. For further information, see section 10.4.4.5 of this chapter.

¹¹⁸ Throughout the discussion, the names of the inventory flows, and atoms, are those supplied the TEAMTM software. In consequence, names for many chemical compounds do not comply fully with conventional methodology. For further information, see section 10.4.4.5 of this chapter.

respectively). It also means the assertions made regarding '(w) Cadmium (Cd+)' emissions for these graphs, are fully applicable here for contributions to 'CML -Aquatic Eco-toxicity'.

Graphs 10.58, for the allocated model, and Graph 10.86, for the unallocated model, show that relative to the total output from the modelled system, McArthur River/BZL stream smelting operations make a substantially greater contribution to 'CML -Aquatic Eco-toxicity' than Hilton/Mt. Isa smelting operations, and, overall, McArthur River/BZL stream operations make a substantially greater contribution to 'CML -Aquatic Eco-toxicity' than do Hilton/Mt. Isa stream operations. On the basis of the arguments provided in part g) of section 10.4.4.5.2, both assertions are considered to be robust.

Category 2 graphs:

The arguments and assertions for Graphs 10.35 and 10.49 (which show '(a) Sulphur Oxides (SO_x, as SO₂)' for the allocated and unallocated models respectively), are also directly applicable here. It is concluded, therefore that, per 1000 kg of output from the operations shown, smelting operations make by far the greatest contribution to 'CML -Air Acidification', and the contributions from other operations are relatively insignificant. In addition, for both models, the contributions from Hilton/Mt. Isa stream smelting operations are significantly larger than those from McArthur River/BZL stream smelting operations. On the basis of the arguments provided in part g) of section 10.4.4.5.2, these assertions are considered to be robust.

c) CML -Depletion of non-renewable resources:

Relevant graphs:	Graph 10.59:	Category 1, Allocated model
	Graph 10.73:	Category 2, Allocated model
	Graph 10.87:	Category 1, Unallocated model
	Graph 10.101:	Category 2, Unallocated model

Category 1 graphs:

Both Graphs 10.59 and 10.87 (of the allocated and unallocated models respectively) appear to show that McArthur River/BZL stream operations account for a significantly greater contribution, overall, than Hilton/Mt. Isa stream operations, to the effect category ‘CML - Depletion of non-renewable resources’.

For the allocated model, dominance analysis shows that 72.96 % of the effect is from ‘(r) Lead (Pb, ore)’ consumption, 11.73 % from ‘(r) Tin (Sn, ore)’ consumption, and 13.98 % from ‘(r) Zinc (Zn, ore)’ consumption. Whilst for the unallocated model, 71.26 % is from ‘(r) Lead (Pb, ore)’ consumption, 3.63 % from ‘(r) Tin (Sn, ore)’ consumption, and 24.16% from ‘(r) Zinc (Zn, ore)’ consumption. Furthermore, dominance analysis, for both models, shows the effect category ‘CML -Depletion of non-renewable resources’ may be attributed principally to:

1. ‘Lead Concentrates’, which is within the system node: ‘BZL: Materials Handling Operations’.
2. ‘Mixed Concentrates (other than MRM, purchased by BZL)’, which is within the system node: ‘BZL: Materials Handling Operations’.
3. ‘Zinc Concentrates’, which is within the system node: ‘BZL: Materials Handling Operations’.
4. ‘Lead Bullion: Production’ which connects successively to ‘BRM: [Tr.] MHD Lead Bullion (truck1), ‘BRM: [Tr.] MHD Lead Bullion (ship), ‘BRM: [Tr.] MHD Lead Bullion (truck), ‘BRM: Overheads (MHD bullion processing). and then ‘BRM: lead Refining (BRM floor throughput)’.

Sensitivity analyses have been conducted for these dominating atoms, as indicated in volume 5 of the Portfolio (in Document 12, for the allocated model, and in Document 15, for the unallocated model).

All of these dominating atoms, in both models, are in the background. Since the flows in and out of DEAM™ modules (which have been used to construct these atoms) are not variables, the flows within these atoms contributing to the effect cannot be modified on their own. Therefore, they have been modified by altering the linked flows in the foreground atomic nodes, to which they are connected. The linked foreground flows, and the paths by which they are linked, are indicated in Documents 12 and 15 (of volume 5 of the Portfolio).

The quantity changes in effect resulting from sensitivity analyses, applied to both models, are indicated in Documents 12 and 15 (of volume 5 of the Portfolio). Assuming the potential variation ranges are twice the changes identified in the sensitivity analyses (for similar reasons to those given in part a) of section 10.4.4.5.1), the predicted variation ranges attributable to the dominant flows, in the allocated model are:

- $2 \times 7.1708\text{E-}12 = 1.4342\text{E-}11$ fraction of reserve¹¹⁹,
- $2 \times 4.3638\text{E-}12 = 8.7276\text{E-}12$ fraction of reserve,
- $2 \times 3.8020\text{E-}12 = 7.6040\text{E-}12$ fraction of reserve, and
- $2 \times 9.7839\text{E-}11 = 1.9568\text{E-}10$ fraction of reserve.

For the unallocated model, they are:

- $2 \times 7.4923\text{E-}11 = 1.4985\text{E-}10$ fraction of reserve,
- $2 \times 4.559\text{E-}11 = 9.118\text{E-}11$ fraction of reserve,
- $2 \times 3.9723\text{E-}11 = 7.9446\text{E-}11$ fraction of reserve, and
- $2 \times 3.8854\text{E-}10 = 7.7708\text{E-}10$ fraction of reserve.

Graph 10.59 suggests a difference between the McArthur River/BZL and Hilton/Mt. Isa streams, in contribution to the effect at the overall system level, of $4.057\text{E-}10 - 6.216\text{E-}11 =$

3.435E-10 fraction of reserve, for the allocated model, and Graph 10.43 a difference of $2.609E-09 - 1.201E-10 = 2.489E-09$ fraction of reserve, for the unallocated model. When considered both individually and combined, the differences between the two streams is greater than the predicted potential variation ranges attributable to the dominant contributors. Therefore, the assertion that the McArthur River/BZL stream makes a greater contribution to the effect than the Hilton/Mt. Isa stream, at the whole operations level and in both models, is considered to be robust.

Graphs 10.59 and 10.87 (of the allocated and unallocated models respectively) also show that the individually considered McArthur River/BZL stream operations, do not account for the majority of the effect attributable to the stream. This is because it is associated principally with the 'Lead Concentrates', 'Mixed Concentrates (other than MRM)', 'Zinc Concentrates', and 'Lead Bullion' atoms (identified previously), which are not accounted for in the individually considered operations.

Category 2 graphs:

Both Graph 10.73 (for the allocated model) and Graph 10.101 (for the unallocated model) indicate that, per 1000 kg of product from each operation, Hilton/Mt. Isa stream lead refining operations account for by far the greatest contributions to the effect. This domination, for both models, appears to be so great that it is likely to be robust.

The domination by the Hilton/ Mt. Isa stream, is explained partly by the fact that (in common with the Category 1 graphs) the contributions from the Lead Concentrates', 'Mixed Concentrates (other than MRM)', 'Zinc Concentrates' and 'Lead Bullion' atoms, have been excluded from the operations shown.

¹¹⁹ Throughout the discussion, the number of decimal places reflects the number calculated by the TEAM™ software. It does not suggest a particular level of accuracy.

d) CML -Eutrophication:

Relevant graphs:	Graph 10.60:	Category 1, Allocated model
	Graph 10.74:	Category 2, Allocated model
	Graph 10.88:	Category 1, Unallocated model
	Graph 10.102:	Category 2, Unallocated model

Category 1 graphs:

Both Graphs 10.60 and 10.88 (of the allocated and unallocated models respectively) appear to show that Hilton/Mt. Isa stream operations account for a significantly greater contribution, overall, than McArthur River/BZL stream operations, to the effect category 'CML -Eutrophication'. They also indicate that the greatest contribution to the effect is from Hilton/Mt. Isa concentration operations.

For the allocated model, dominance analysis shows that 94.88 % of the effect is from emissions to the atmosphere of '(a) Nitrogen Oxides (NO_x, as NO₂)'¹²⁰, and 3.57 % from '(a) Nitrous Oxide (NO₂)' emissions. Whilst for the unallocated model, 95.00 % is from '(a) Nitrogen Oxides (NO_x, as NO₂)' emissions, and 3.57 % from '(a) Nitrous Oxide (NO₂)' emissions.

Furthermore, dominance analysis, for the allocated model, shows the effect category 'CML - Eutrophication' may be attributed principally to:

1. '156 Starch: Production' which connects to MIM: Zinc-Lead-Silver Ore Concentration at Mount Isa', and is within the system node: 'MIM: Zinc-Lead-Silver Ore Concentration Operations at Mount Isa'.
2. '602 Road Transport (Truck, 28 t, Diesel Oil, kg.km).3' which connects to 'MIM: [Tr.] Cement (truck)' and then 'MIM: Zinc-Lead-Silver Ore Concentration at Mount Isa'. All are within the system node: 'MIM: Zinc-Lead-Silver Ore Concentration Operations at Mount Isa'.

¹²⁰ Throughout the discussion, the names of the inventory flows, and atoms, are those supplied the TEAMTM software. In consequence, names for many chemical compounds do not comply fully with conventional methodology. For further information, see section 10.4.4.5 of this chapter.

3. '266 Cement: Production' which connects to MIM: Zinc-Lead-Silver Ore Concentration at Mount Isa', and is within the system node: 'MIM: Zinc-Lead-Silver Ore Concentration Operations at Mount Isa'.
4. '241 Water (Softened): Production.1', which connects to 'MCPS: Electricity Production (Mica Creek Power Station)', and is within the system node: 'MCPS: Electricity Production Operations (Mica Creek Power Station)'.
5. '232 Diesel Oil: Production.1' which connects to '602 Road Transport (Truck 40t, Diesel Oil, kg.km).1'. The 'Transport Road (diesel oil, kg.km)' output from this is, in turn, connected to 'Hilton Mined Ore Truck transport by KMC & MIM to Mt. Isa'. All are within the system node: 'Hilton Operations'.

Sensitivity analyses have been conducted for these dominating atoms, as indicated in Document 12 (of volume 5 of the Portfolio).

Dominance analysis, for the unallocated model, shows the effect may be attributed principally to:

1. '602 Road Transport (Truck, 28 t, Diesel Oil, kg.km).3' which connects to 'MIM: [Tr.] Cement (truck)' and then 'MIM: Zinc-Lead-Silver Ore Concentration at Mount Isa'. All are within the system node: 'MIM: Zinc-Lead-Silver Ore Concentration Operations at Mount Isa'.
2. '266 Cement: Production' which connects to MIM: Zinc-Lead-Silver Ore Concentration at Mount Isa', and is within the system node: 'MIM: Zinc-Lead-Silver Ore Concentration Operations at Mount Isa'.
3. '241 Water (Softened): Production.1', which connects to 'MCPS: Electricity Production (Mica Creek Power Station)', and is within the system node: 'MCPS: Electricity Production Operations (Mica Creek Power Station)'.
4. '232 Diesel Oil: Production.1' which connects to '602 Road Transport (Truck 40t, Diesel Oil, kg.km).1'. The 'Transport Road (diesel oil, kg.km)' output from this is, in turn, connected to 'HTS: Road Transport of Mixed Concentrate to Bing Bong'. All are within the system node: 'HTS: Operations Associated with Transport of Mixed Concentrate to Bing Bong'.

Sensitivity analyses have been conducted for these dominating atoms, as indicated in Document 15 (of volume 5 of the Portfolio).

All of these dominating atoms, in both models, are in the background. Since the flows in and out of DEAMTM modules (which have been used to construct these atoms) are not variables, the flows within these atoms contributing to the effect cannot be modified on their own. Therefore, they have been modified by altering the linked flows in the foreground atomic nodes, to which they are connected. The linked foreground flows, and the paths by which they are linked, are indicated in Documents 12 and 15 (of volume 5 of the Portfolio).

The quantity changes in effect, resulting from sensitivity analyses, applied to both models, are indicated in Documents 12 and 15 (of volume 5 of the Portfolio). Assuming the potential variation ranges are twice the changes identified in the sensitivity analyses (for similar reasons to those given in part a) of section 10.4.4.5.1), the predicted variation ranges attributable to the dominant flows, in the allocated model are:

- $2 \times 105.7147 = 211.4294$ g eq. PO_4^{121} ,
- $2 \times 37.0326 = 74.0652$ g eq. PO_4 ,
- $2 \times 146.7267 = 293.4534$ g eq. PO_4 ,
- $2 \times 96.6498 = 193.2995$ g eq. PO_4 , and
- $2 \times 24.4869 = 48.9738$ g eq. PO_4 .

For the unallocated model, they are:

- $2 \times 135.5472 = 271.0944$ g eq. PO_4 ,
- $2 \times 537.0338 = 1,074.0676$ g eq. PO_4 ,
- $2 \times 350.5568 = 701.1136$ g eq. PO_4 , and
- $2 \times 72.4948 = 144.9896$ g eq. PO_4 .

Graph 10.60 suggests a difference between the McArthur River/BZL and Hilton/Mt. Isa streams, in contribution to the effect at the overall system level, of $1,140.02 - 202.42 =$

937.6 g eq. PO₄, for the allocated model, and Graph 10.88 a difference of 3,600.22 - 1,836.31 = 1,763.91 g eq. PO₄, for the unallocated model. When considered both individually and combined, the differences between the two streams, for the allocated model, is greater than the predicted potential variation ranges attributable to the dominant contributors. Therefore, for the allocated model, the assertion that the Hilton/Mt. Isa stream makes a greater contribution to the effect than the McArthur River/BZL stream, at the whole operations level, is considered to be robust. For the unallocated model, the difference in the contributions to the effect between the Hilton/Mt. Isa stream and the McArthur River/BZL streams, at the whole site scale, are less than the predicted potential variation ranges associated with the dominant contributors, when all are combined. However, they are greater than them when considered individually. It may be concluded, therefore, that whilst it is quite likely, at the overall system level, the contribution to the effect by the Hilton/Mt. Isa stream is greater than that of the McArthur River/BZL stream, the uncertainties associated with the modelling are such that it is not possible to demonstrate this unequivocally.

For both models, the contribution to the total effect associated with the atom '241 Water (Softened): Production.1' (which connects to 'MCPS: Electricity Production (Mica Creek Power Station)') needs to be apportioned between the mining, concentration and smelting operations for the Hilton/Mt. Isa stream, which receive electric power from the Mica Creek Power Station (MCPS). Table 10.21 indicates the actual relative differences in the consumptions of electricity from the MCPS, by operations associated with the Hilton/Mt. Isa stream, during the period modelled. In Table 10.27, these data have been used to calculate scaling fractions, to attribute the differences, identified by the sensitivity analysis for the '241 Water (Softened): Production.1' node in both models, to the various Mt. Isa based Hilton/Mt. Isa stream operations.

¹²¹ Throughout the discussion, the number of decimal places reflects the number calculated by the TEAMTM software. It does not suggest a particular level of accuracy.

Operation	Change in fractional 'CML -Eutrophication' effect	Predicted variation range
<i>Allocated model: (Change identified by sensitivity analysis = 96.6498 g eq. PO₄)</i>		
Smelting	$0.1366931 \times 96.6498 = 13.2114 \text{ g eq. PO}_4$	$2 \times 13.21136 = 26.4227 \text{ g eq. PO}_4$
Concentration	$0.685286981 \times 96.6498 = 66.23285 \text{ g eq. PO}_4$	$2 \times 66.23285 = 132.4657 \text{ g eq. PO}_4$
Hilton and Mt. Isa mining combined	$0.071575015 \times 96.6498 = 6.9177 \text{ g eq. PO}_4$	$2 \times 6.9177 = 13.8354 \text{ g eq. PO}_4$
<i>Unallocated model (Change identified by sensitivity analysis = 350.5568 g eq. PO₄)</i>		
Smelting	$0.1366931 \times 350.5568 = 47.91866 \text{ g eq. PO}_4$	$2 \times 47.91866 = 95.83732 \text{ g eq. PO}_4$
Concentration	$0.685286981 \times 350.5568 = 240.232 \text{ g eq. PO}_4$	$2 \times 240.232 = 480.464 \text{ g eq. PO}_4$
Hilton and Mt. Isa mining combined	$0.071575015 \times 350.5568 = 25.0911 \text{ g eq. PO}_4$	$2 \times 25.09111 = 50.1822 \text{ g eq. PO}_4$

Table 10.27: Calculation of the variation ranges of contributions to 'CML - Eutrophication', associated with the MCPS operations atom: '241 Water (Softened): Production.1'

From Graph 10.60, for the allocated model, it appears that the order of relative contribution to the effect for the Hilton/Mt. Isa stream, from greatest to least, is: concentration, mining, smelting, lead refining and transport operations. The relative contributions of mining, smelting and lead refining operations all appear to be relatively similar.

To make comparisons between Hilton/Mt. Isa stream concentration operations and any other operations, in both models, the following predicted potential variation ranges need to be considered:

1. Those shared with other Mt. Isa based Hilton/Mt. Isa stream operations (identified in Table 10.27).
2. Those attributable to various dominating atomic nodes associated solely with Hilton/Mt. Isa stream concentrations operations.
3. Any which are associated with the other operation being compared.

For the allocated model, the range identified in Table 10.27 is 132.4657 g eq. PO₄), and the nodes attributed solely to Hilton/Mt. Isa concentration operations, plus their predicted potential variation ranges, are: '156 Starch: Production' (211.4294 g eq. PO₄), 602 Road Transport (Truck, 28t, Diesel Oil, kg.km).3' (74.0652 g eq. PO₄), and '266 Cement: Production' (293.4534 g eq. PO₄). In the event that all of the atoms in categories 1 and 2 above are biased by their greatest predicted potential amounts, the combined potential variation range would be 711.4137 g eq. PO₄. This combined range is greater than the individual contribution from Hilton/Mt. Isa concentrations, which is 608.38 g eq. PO₄. Whilst it is unlikely that all of the dominant nodes would be thus biased, it is theoretically possible. It may be concluded, therefore, that due to the variability of the dominant contributors, it is not possible to ascertain whether the contributions of any other of the Hilton/Mt. Isa stream operations, in the allocated model, are significantly different from the Hilton/Mt. Isa stream concentration operations. This does not mean there is no significant difference between them, only that it is not possible to demonstrate such a difference unequivocally.

The differences between Hilton/Mt. Isa stream mining and smelting operations and between Hilton/Mt. Isa stream mining and lead refining operations, for the allocated model, are: $172.93 - 143.35 = 29.58$ g eq. PO₄, and $172.93 - 137.27 = 35.66$ g eq. PO₄ respectively. The predicted potential variation range attributable to the dominant contributor, when comparing both groups of operations, is 48.9738 g eq. PO₄ (calculated earlier), which is greater than the difference between the two operations. The difference between Hilton/Mt. Isa stream smelting and lead refining operations is $143.35 - 137.27 = 6.08$ g eq. PO₄, which is less, than the predicted potential variation range attributable to the dominant contributor, of 26.4227 g eq. PO₄ (from Table 10.27). Therefore, in neither case, is it possible to ascertain whether or not a significant difference exists between these groups of operations.

The difference between Hilton/Mt. Isa stream transport and mining operations, in the allocated model is $172.93 - 77.54 = 95.39$ g eq. PO₄, whilst the predicted potential variation range attributable to the dominant contributor of relevance is 48.9738 g eq. PO₄. This is less than the difference between the two operations. Between Hilton/Mt. Isa stream transport and smelting operations, the difference is $143.35 - 77.54 = 65.81$ g eq. PO₄, which is greater than the range of 26.4227 g eq. PO₄ attributable to the dominant contributor. Between Hilton/Mt. Isa stream transport and lead refining operations, the difference is $137.27 - 77.54 = 59.73$ g eq. PO₄. Since there are no dominant contributors associated with either operation, the difference should be relatively robust to individual biases in their comprising data. It may be concluded, therefore, that between Hilton/Mt. Isa stream transport operations, and all of these other Hilton/Isa stream operations, the differences are robust.

From Graph 10.88, for the unallocated model, it appears the dominant contributor is Hilton/Mt. Isa concentration operations, followed by Hilton/Mt. Isa stream mining operations, and then McArthur River/BZL stream transport operations. The range identified in Table 10.27, for the unallocated model, is 480.464 g eq. PO₄), and the nodes attributed solely to Hilton/Mt. Isa concentration operations, plus their predicted potential variation ranges, are: 602 Road Transport (Truck, 28t, Diesel Oil, kg.km).3' (271.0944 g eq. PO₄), and '266 Cement: Production' (1,074.0676 g eq. PO₄). In the event that all of these atoms are biased by their greatest predicted potential amounts, the combined potential variation range would be 1,825.626 g eq. PO₄. This combined range is less than the individual contribution from Hilton/Mt. Isa concentrations, which is $2,220.80 - 256.69 = 1,964.11$ g eq. PO₄. It may be concluded, therefore, the assertion that the contribution to the effect from Hilton/Mt. Isa stream concentration is significantly greater than that from McArthur River/BZL stream concentration operations, in the unallocated model, is robust.

The difference between Hilton/Mt. Isa stream concentration and mining operations, for the unallocated model, is $2,220.80 - 631.39 = 1,589.41$ g eq. PO₄, whilst the predicted potential variation ranges attributable to the dominant contributors to the effect are: 271.0944 g eq. PO₄, and 1,074.0676 g eq. PO₄ (from above), 480.464 g eq. PO₄ and 50.1822 g eq. PO₄ (from Table 10.27), plus 144.9896 g eq. PO₄ (from earlier). In the event that all of the atoms associated with these ranges are biased by their greatest predicted potential amounts, the combined potential variation range would be 2,020.7978 g eq. PO₄. Hence, the

difference between the two streams is less than the combined potential variation range. Whilst it is unlikely that all of the dominant nodes would be thus biased, it is theoretically possible. It may be concluded, therefore, that due to the variability of the dominant contributors, it is not possible to ascertain whether the contributions of Hilton/Mt. Isa stream mining and transport operations, in the unallocated model, are significantly different from each other.

The difference between Hilton/Mt. Isa stream concentration operations and McArthur River/BZL stream transport operations, in the unallocated model, is $2,220.80 - 444.71 = 1,776.09$ g eq. PO_4 . The predicted potential variation ranges attributable to the dominant contributors to the effect are: 271.0944 g eq. PO_4 , and 1,074.0676 g eq. PO_4 (from above), and 480.464 g eq. PO_4 (from Table 10.27). In the event that all of the atoms associated with these ranges are biased by their greatest predicted potential amounts, the combined potential variation range would be 1,825.626 g eq. PO_4 . Hence, the difference between the two streams is less than the combined potential variation range. Whilst it is unlikely that all of the dominant nodes would be thus biased, it is theoretically possible. It may be concluded, therefore, that due to the variability of the dominant contributors, it is not possible to ascertain whether the contributions to the effect of Hilton/Mt. Isa stream concentration and McArthur River/BZL stream transport operations, in the unallocated model, are significantly different.

Finally, the difference between Hilton/Mt. Isa stream mining operations and McArthur River/BZL stream transport operations is $631.39 - 444.71 = 186.68$ g eq. PO_4 . The predicted potential variation ranges attributable to the dominant contributors to the effect are: 50.1822 g eq. PO_4 (from Table 10.27), and 144.9896 g eq. PO_4 (from earlier). In the event that both of the atoms associated with these ranges are biased by their greatest predicted potential amounts, the combined potential variation range would be 195.1718 g eq. PO_4 . Hence, the difference between the two streams is less than the combined potential variation range. It may be concluded, therefore, that due to the variability of the dominant contributors, it is not possible to ascertain whether the contributions to the effect of Hilton/Mt. Isa stream mining and McArthur River/BZL stream transport operations, in the unallocated model, are significantly different.

Category 2 graphs:

Both Graph 10.74 (for the allocated model) and Graph 10.102 (for the unallocated model) suggest that, per 1000 kg of output from each operation, the contributions to the effect of 'CML -Eutrophication' are greatest from Hilton/Mt. Isa stream concentration operations. The graph for the unallocated model (Graph 10.102) also suggests that McArthur River/BZL stream smelting and lead refining operations account for the second and third largest contributions respectively. However, the graph for the allocated model (Graph 10.74) suggests the second largest contribution is shared approximately equally by Hilton/Mt. Isa stream and McArthur River/BZL stream smelting operations. McArthur River/BZL stream lead refining operations appear to account for the third largest contribution to the effect in the allocated model.

One of the principal differences between the Category 1 graphs (Graphs 10.60 and 10.88) and the Category 2 graphs (Graphs 10.74 and 10.102) is the greater relative contribution to the effect of McArthur River/ BZL stream operations. This occurs because the overall throughput through the Hilton/Mt. Isa stream is greater than that for the McArthur River/BZL stream. As a result, the form of normalisation, used for Category 2 graphs, tends to increase the size of the bars associated with the McArthur River/BZL stream relative to those for the Hilton/ Mt. Isa stream.

With this form of normalisation also, the relative domination of the contributions from the comprising atoms differ from that of the 'Category 1' graphs. Since, dominance analyses have not been conducted for this form of normalisation, interpretation of the 'Category 2' graphs, currently, is limited. Hence, this represents an area for further research.

e) CML -Eutrophication (water):

Relevant graphs:	Graph 10.61:	Category 1, Allocated model
	Graph 10.75:	Category 2, Allocated model
	Graph 10.89:	Category 1, Unallocated model
	Graph 10.103:	Category 2, Unallocated model

Category 1 graphs:

Both Graphs 10.61 and 10.89 (of the allocated and unallocated models respectively) appear to show that Hilton/Mt. Isa stream operations account for a significantly greater contribution, overall, than McArthur River/BZL stream operations, to the effect category 'CML -Eutrophication (water)'. They also indicate that the greatest contribution to the effect is from Hilton/Mt. Isa concentration operations.

For the allocated model, dominance analysis shows the contributions to the effect to be from emissions to water of:

'(w) Ammonia (NH ₄ ⁺ , NH ₃ , as N) ¹²²	29.30 %
'(w) Phosphates (PO ₄ ³⁻ , HPO ₄ , H ₃ PO ₄ , as P)'	46.24 %
'(w) COD (Chemical Oxygen Demand)'	9.25 %
'(w) Nitrates (NO ₃ ⁻)'	7.55 %
'(w) Nitrogenous Matter (unspecified, as N)'	6.90 %

Whilst for the unallocated model, dominance analysis shows the contributions of the effect to be as follows:

'(w) Ammonia (NH ₄ ⁺ , NH ₃ , as N)'	27.30 %
'(w) Phosphates (PO ₄ ³⁻ , HPO ₄ , H ₃ PO ₄ , as P)'	37.56 %
'(w) COD (Chemical Oxygen Demand)'	20.45 %
'(w) Nitrates (NO ₃ ⁻)'	7.39 %
'(w) Nitrogenous Matter (unspecified, as N)'	6.60 %

Furthermore, dominance analysis, for the allocated model, shows the effect category ‘CML - Eutrophication (water)’ may be attributed principally to:

1. ‘156 Starch: Production’ which connects to MIM: Zinc-Lead-Silver Ore Concentration at Mount Isa’, and is within the system node: ‘MIM: Zinc-Lead-Silver Ore Concentration Operations at Mount Isa’.
2. ‘241 Sodium Cyanide: Production’ which connects to MIM: Zinc-Lead-Silver Ore Concentration at Mount Isa’, and is within the system node: ‘MIM: Zinc-Lead-Silver Ore Concentration Operations at Mount Isa’.
3. ‘232 Diesel Oil: Production.5’ which connects to ‘602 Road Transport (Truck, 40t, Diesel Oil, kg.1’, and is within the system node: ‘MIM: Zinc-Lead-Silver Ore Concentration Operations at Mt. Isa’.
4. ‘BZL: Effluent Treatment (in on-site plant)’ , which is within the system node: ‘BZL: Effluent Treatment Operations’.

Sensitivity analyses have been conducted for these dominating atoms, as indicated in Document 12 (of volume 5 of the Portfolio).

Dominance analysis, for the unallocated model, shows the effect may be attributed principally to:

1. ‘156 Starch: Production’ which connects to MIM: Zinc-Lead-Silver Ore Concentration at Mount Isa’, and is within the system node: ‘MIM: Zinc-Lead-Silver Ore Concentration Operations at Mount Isa’.
2. ‘241 Sodium Cyanide: Production’ which connects to MIM: Zinc-Lead-Silver Ore Concentration at Mount Isa’, and is within the system node: ‘MIM: Zinc-Lead-Silver Ore Concentration Operations at Mount Isa’.
3. ‘232 Diesel Oil: Production.5’ which connects to ‘602 Road Transport (Truck, 40t, Diesel Oil, kg.1’, and is within the system node: ‘MIM: Zinc-Lead-Silver Ore Concentration Operations at Mt. Isa’.

¹²² Throughout the discussion, the names of the inventory flows, and atoms, are those supplied the TEAMTM software. In consequence, names for many chemical compounds do not comply fully with conventional methodology. For further information, see section 10.4.4.5 of this chapter.

4. Lead Bullion: Production' which connects successively to 'BRM: [Tr.] MHD Lead Bullion (truck1), 'BRM: [Tr.] MHD Lead Bullion (ship), 'BRM: [Tr.] MHD Lead Bullion (truck), 'BRM: Overheads (MHD bullion processing). and then 'BRM: lead Refining (BRM floor throughput)'.

Sensitivity analyses have been conducted for these dominating atoms, as indicated in Document15 (of volume 5 of the Portfolio).

The dominance analyses also demonstrate that, for the allocated model, the dominating atoms are associated with Hilton/Mt. Isa stream concentration operations. In the unallocated model, however, they are associated not only with these operations, but also with the McArthur River/BZL stream lead refining operations.

In the allocated model, the 'BZL: Effluent Treatment (in on-site plant)' atom is in the foreground, and the others are in the background, whereas, in the unallocated model, all of the dominating atoms are in the background. For the foreground atom, in the sensitivity analysis, the principal outflows associated with the effect have been altered in isolation of all other inflows and outflows associated with the atom. This is possible due to the fact that all flows relating to all atoms in the foreground have been modelled as variables in TEAMTM. However, since the flows in and out of the DEAMTM and other modules (which have been used to construct the background atoms) are not variables, the 'Total Electricity' flows within these background atoms, cannot be modified on their own. Therefore, they have been modified by altering the linked flow(s) in the foreground atomic node(s), to which they are connected. The linked foreground flows, and the paths by which they are linked, are indicated in Documents 12 and 15 (of volume 5 of the Portfolio).

Graph 10.61 suggests a difference, at the overall system level, of $15.29 - 3.15 = 12.14$ g eq. PO₄ between the Hilton/Mt. Isa and McArthur River/BZL streams for the allocated model, and Graph 10.89 a difference of $52.46 - 31.74 = 20.72$ g eq. PO₄ for the unallocated model. The quantity changes in the effect category 'CML -Eutrophication (water)' resulting from sensitivity analyses, applied to both models, are indicated in Documents 13 and 17 (of volume 5 of the Portfolio). Assuming the potential variation ranges are twice the changes identified in the sensitivity analyses (for similar reasons to those given in part a) of section

10.4.4.5.1), the predicted variation ranges attributable to the dominant flows, in the allocated model are:

- $2 \times 1.6041 = 3.2082$ g eq. PO_4^{123} ,
- $2 \times 1.4716 = 2.9432$ g eq. PO_4 ,
- $2 \times 0.009355 = 0.1871$ g eq. PO_4 , and
- $2 \times 0.6574 = 1.3148$ g eq. PO_4 .

For the unallocated model, they are:

- $2 \times 5.8709 = 11.7418$ g eq. PO_4 ,
- $2 \times 5.3859 = 10.7718$ g eq. PO_4 ,
- $2 \times 0.0343 = 0.0686$ g eq. PO_4 , and
- $2 \times 2.6105 = 5.221$ g eq. PO_4 .

When considered both individually and combined, the differences between the two streams, for the allocated model, is greater than the predicted potential variation ranges attributable to the dominant contributors. Therefore, for the allocated model, the assertion that the Hilton/Mt. Isa stream makes a greater contribution to the effect than the McArthur River/BZL stream, at the whole operations level, is considered to be robust. For the unallocated model, the difference in the contributions to the effect between the Hilton/Mt. Isa stream and the McArthur River/BZL streams, at the whole site scale, are less than the predicted potential variation ranges associated with the dominant contributors, when all are combined. However, they are greater than them when considered individually. It may be concluded, therefore, that whilst it is quite likely, at the overall system level, the contribution to the effect by the Hilton/Mt. Isa stream is greater than that of the McArthur River/BZL stream, the uncertainties associated with the modelling are such that it is not possible to demonstrate this unequivocally.

The difference between Hilton/Mt. Isa stream and McArthur River/BZL stream concentration operations for the allocated model is $12.13 - 0.10 = 12.03$ g eq. PO_4 , and for the unallocated model is $44.37 - 2.48 = 41.89$ g eq. PO_4 . The predicted potential variation

ranges attributable to the dominant contributors, for the allocated model, are: 3.2082 g eq. PO₄, and 0.1871 g eq. PO₄, and for the unallocated model are: 11.7418 g eq. PO₄ and 0.0686 g eq. PO₄. When considered both individually and combined, the differences between the two streams, for both models, are greater than the potential variation ranges attributable to the dominant contributors. Therefore, the assertion that Hilton/Mt. Isa stream concentration operations make a significantly greater contribution to the effect than McArthur River/ BZL stream concentration operations, is robust.

For the allocated model, Graph 10.61, suggests the second largest contributor to the effect is from Hilton/Mt. Isa stream mining operations. This assertion is confirmed by the fact that the difference between Hilton/Mt. Isa stream concentration and mining operations is $12.13 - 1.19 = 10.94$ g eq. PO₄, which is greater than the potential variation ranges attributable to the dominant contributors (of 3.2082 g eq. PO₄ and 0.1871 g eq. PO₄), when considered both individually and combined. For the unallocated model, Graph 10.89 suggests the second largest contributor is from McArthur River/BZL stream smelting operations. This assertion is confirmed by the fact that the difference between the two is $44.37 - 16.08 = 28.29$ g eq. PO₄, which is also greater than the potential variation ranges attributable to the dominant contributors (of 11.7418 g eq. PO₄ and 0.0686 g eq. PO₄), when considered both individually and combined. It may be concluded, therefore, that both assertions are robust.

Category 2 graphs:

Both Graph 10.75 (for the allocated model) and Graph 10.103 (for the unallocated model) suggest that, per 1000 kg of output from each operation, the contributions to the effect of 'CML -Eutrophication (water)' are greatest from Hilton/Mt. Isa stream smelting operations. Both graphs also suggest that Hilton/Mt. Isa stream concentration operations account for the second largest contribution. However, the graph for the allocated model (Graph 10.75) suggests the second largest contribution is only slightly less than the contribution from Hilton/Mt. Isa stream concentration operations.

¹²³ Throughout the discussion, the number of decimal places reflects the number calculated by the TEAM™ software. It does not suggest a particular level of accuracy.

One of the principal differences between the Category 1 graphs (Graphs 10.61 and 10.89) and the Category 2 graphs (Graphs 10.75 and 10.103) is the greater relative contribution to the effect of McArthur River/ BZL stream operations. This occurs because the overall throughput through the Hilton/Mt. Isa stream is greater than that for the McArthur River/BZL stream. As a result, the form of normalisation, used for Category 2 graphs, tends to increase the size of the bars associated with the McArthur River/BZL stream relative to those for the Hilton/ Mt. Isa stream.

With this form of normalisation also, the relative domination of the contributions from the comprising atoms differ from that of the 'Category 1' graphs. Since, dominance analyses have not been conducted for this form of normalisation, interpretation of the 'Category 2' graphs, currently, is limited. Hence, this represents an area for further research.

f) CML -Human Toxicity:

Relevant graphs:	Graph 10.62:	Category 1, Allocated model
	Graph 10.76:	Category 2, Allocated model
	Graph 10.90:	Category 1, Unallocated model
	Graph 10.104:	Category 2, Unallocated model

Category 1 graphs:

For the allocated model, dominance analysis shows the contributions to the effect to be from emissions to the atmosphere of:

'(a) Sulphur Oxides (SO _x , as SO ₂)' ¹²⁴	87.85 %
'(a) Arsenic (As)'	6.60 %
'(a) Lead (Pb)'	2.65 %

Whilst for the unallocated model, dominance analysis shows the contributions to the effect to be from emissions to the atmosphere of:

‘(a) Sulphur Oxides (SO _x , as SO ₂)’	87.43 %
‘(a) Arsenic (As)’	6.74 %
‘(a) Lead (Pb)’	3.52 %
‘(a) Nitrogen Oxides (NO _x , as NO ₂)’	2.68 %
‘(a) Carbon Monoxide (CO)’	1.07 %

Furthermore, dominance analysis, for both models, shows the effect category ‘CML - Human Toxicity’ may be attributed principally to the atomic node: ‘MIM: Lead Smelting at Mount Isa’, which accounts for 94.68 % and 87.98 % of the effect respectively. The Category 1 inventory graphs for ‘(a) Sulphur Oxides (SO_x, as SO₂)’, for the allocated and unallocated models (Graphs 10.7 and 10.25) also indicate the only dominant atom to be ‘MIM: Lead Smelting at Mount Isa’. In consequence, therefore, Graphs 10.62 and 10.90 are similar to those in Graphs 10.7 and 10.25. It also means the assertions made regarding ‘(a) Sulphur Oxides (SO_x, as SO₂)’ emissions for these graphs, are fully applicable here for contributions to ‘CML -Human Toxicity’.

Graph 10.62, for the allocated model, and Graph 10.90, for the unallocated model, show that relative to the total output from the modelled system, Hilton/Mt. Isa stream smelting operations make a substantially greater contribution to ‘CML -Human Toxicity’ than McArthur River/BZL smelting operations, and, overall, Hilton/Mt. Isa stream operations make a substantially greater contribution to ‘CML -Human Toxicity’ than do McArthur River/BZL stream operations. On the basis of the arguments provided in part g) of section 10.4.4.5.1, both assertions are considered to be robust.

¹²⁴ Throughout the discussion, the names of the inventory flows, and atoms, are those supplied the TEAMTM software. In consequence, names for many chemical compounds do not comply fully with conventional methodology. For further information, see section 10.4.4.5 of this chapter.

Category 2 graphs:

The arguments and assertions for Graphs 10.35 and 10.49 (which show '(a) Sulphur Oxides (SO_x, as SO₂)' for the allocated and unallocated models respectively), are also directly applicable here. It is concluded, therefore that, per 1000 kg of output from the operations shown, smelting operations make by far the greatest contribution to 'CML - Human Toxicity', and the contributions from other operations are relatively insignificant. In addition, for both models, the contributions from Hilton/Mt. Isa stream smelting operations are significantly larger than those from McArthur River/BZL stream smelting operations. On the basis of the arguments provided in part g) of section 10.4.4.5.1, these assertions are considered to be robust.

g) CML -Terrestrial Eco-toxicity:

Relevant graphs:	Graph 10.63:	Category 1, Allocated model
	Graph 10.77:	Category 2, Allocated model
	Graph 10.91:	Category 1, Unallocated model
	Graph 10.105:	Category 2, Unallocated model

Category 1 graphs:

For the allocated model, dominance analysis shows the contributions to the effect to be from emissions to the ground of:

'(s) Cadmium (Cd)'	47.96 %
'(s) Atrazine (C ₈ H ₁₄ C ₁ N ₅ S)', ¹²⁵	51.74 %

Whilst for the unallocated model, dominance analysis shows the contributions to the effect to be from emissions to the atmosphere of:

¹²⁵ Throughout the discussion, the names of the inventory flows, and atoms, are those supplied the TEAMTM software. In consequence, names for many chemical compounds do not comply fully with conventional methodology. For further information, see section 10.4.4.5 of this chapter.

‘(s) Cadmium (Cd)’	31.36 %
‘(s) Atrazine (C ₈ H ₁₄ ClNS)’	68.12 %

Furthermore, dominance analysis, for both models, shows the effect category ‘CML - Terrestrial Eco-toxicity’ may be attributed principally to:

1. ‘156 Starch: Production’ which connects to MIM: Zinc-Lead-Silver Ore Concentration at Mount Isa’, and is within the system node: ‘MIM: Zinc-Lead-Silver Ore Concentration Operations at Mount Isa’.
2. ‘MIM: Lead Smelting at Mount Isa’.

The atomic node: ‘MIM: Lead Smelting at Mount Isa’ contributes to ‘(s) Cadmium (Cd)’ emissions, and accounts for 47.96 % of the effect for the allocated model, and 31.36 % of the effect for the unallocated model. Whilst the atomic node ‘156 Starch: Production’ contributes to ‘(s) Atrazine (C₈H₁₄ClNS)’ emissions, and accounts for 51.74 % of the effect for the allocated model, and 66.98 % of the effect for the unallocated model. Hence, all of the emission of ‘(s) Cadmium (Cd)’ is associated with the node ‘MIM: Lead Smelting at Mount Isa’, and practically all of the emission of ‘(s) Atrazine (C₈H₁₄ClNS)’ is associated with the node ‘156 Starch: Production’.

The ‘MIM: Lead Smelting at Mount Isa’ atom is in the foreground, and the ‘156 Starch: Production’ atom is in the background. For the foreground atom, in the sensitivity analysis, the principal outflows associated with the effect have been altered in isolation of all other inflows and outflows associated with the atom. This is possible due to the fact that all flows relating to all atoms in the foreground have been modelled as variables in TEAMTM. However, since the flows in and out of the DEAMTM module (which has been used to construct this background atom) are not variables, the emission of ‘(s) Atrazine (C₈H₁₄ClNS)’ flows within the background atom, cannot be modified on its own. Therefore, it has been modified by altering the linked flow(s) in the foreground atomic node(s), to which it is connected. The linked foreground flow, and the path by which it is linked, is indicated in Documents 12 and 15 (of volume 5 of the Portfolio).

Both Graph 10.63, for the allocated model, and Graph 10.91, for the unallocated model, indicate that, at the all operations scale and relative to the total output from the modelled system, Hilton/Mt. Isa stream operations make a substantially greater contribution to the effect than McArthur River/BZL stream operations. They also show, that practically all of the effect is associated with Hilton/Mt. Isa stream concentration and smelting operations. Since, practically all of the effect for Hilton/Mt. Isa stream concentration operations is associated with the atomic node '156 Starch: Production', and all of the effect for Hilton/Mt. Isa stream smelting operations is associated with the atomic node 'MIM: Lead Smelting at Mount Isa', all of these indications are considered to be robust.

In both models, the relative contribution to the effect from Hilton/Mt. Isa stream concentration operations appears to be greater than that from Hilton/Mt. Isa stream smelting operations. The difference between the two operations is $8.42 - 7.82 = 0.60$ t for the allocated model, and $30.79 - 14.44 = 16.35$ t for the unallocated model. The quantity changes in effect, resulting from sensitivity analyses, applied to both models, are indicated in Documents 12 and 15 (of volume 5 of the Portfolio). Assuming the potential variation ranges are twice the changes identified in the sensitivity analyses (for similar reasons to those in part a) of section 10.4.4.5.1), the predicted potential variation ranges attributable to the dominant flows, in the allocated model are:

- $2 \times 2.0442 = 4.0884$ t¹²⁶, and
- $2 \times 3.9090 = 7.8180$ t.

For the unallocated model, they are:

- $2 \times 7.4820 = 14.964$ t, and
- $2 \times 7.2073 = 14.4146$ t.

When considered in combination, the differences between the two streams, for both models, are less than the potential variation ranges attributable to the dominant contributors. However, for the unallocated model, when the dominant contributors are considered individually, they are each less than the difference between the operations. It

¹²⁶ Throughout the discussion, the number of decimal places reflects the number calculated by the TEAM™ software. It does not suggest a particular level of accuracy.

may be concluded, therefore, that whilst it may be the case that Hilton/Mt. Isa stream concentration operations make a greater contribution to the effect than Hilton/Mt. Isa stream smelting operations, the uncertainties associated with the modelling are such that it is not possible to demonstrate this unequivocally. However, it does appear to be more likely that in the unallocated model there may be a significant difference.

Category 2 graphs:

Both Graph 10.77 (for the allocated model) and Graph 10.105 (for the unallocated model) indicate that, per 100 kg of output from each operation, the contributions to the effect of 'CML -Terrestrial Eco-toxicity' are almost exclusively from Hilton/Mt. Isa stream smelting and concentration operations. The contributions from the other operations and stream are so small, they are considered to be insignificant. The relative differences between the bars are so great, that all of these findings are considered to be robust. However, Graph 10.77 (for the allocated model) suggests the greater contribution to be from Hilton/Mt. Isa stream smelting operations, whilst Graph 10.105 (for the unallocated model) suggests the greater contribution to be from Hilton/Mt. Isa stream concentration operations. This assertion is considered below.

Documents 12 and 15 (of volume 5 of the Portfolio) indicate the predicted potential variation ranges attributable to the two dominant contributors, when normalised for both Category 1 and 2 graphs. Document 12 indicates, for the allocated model, the Category 2 graph changes calculated from sensitivity analyses to be: 2.5534 t for 'MIM: Lead Smelting at Mount Isa', and 9.5193 t for '156 Starch: Production'. For the unallocated model, Document 15 indicates the Category 2 graph changes calculated from sensitivity analyses to be: 5.06883 t for 'MIM: Lead Smelting at Mount Isa', and 9.8524 t for '156 Starch: Production'. Assuming the ranges are double the changes calculated from the sensitivity analyses (for similar reasons to those in part a) of section 10.4.4.5.1.), the predicted potential variation ranges attributable to the dominant contributors are 5.1068 t plus 19.0386 t, for the allocated model, and 10.13766 t plus 19.7048 t, for the unallocated model.

The differences between the two streams are: $19.03 - 10.52 = 8.51$ t, for the allocated model, and $20.86 - 19.74 = 1.12$ t, for the unallocated model. For both models, these differences are less than the combined ranges attributable to the dominant contributors. It may be concluded, therefore, the uncertainties associated with the modelling are such, that it is not possible to demonstrate unequivocally, for either model, whether or not there is a significant difference between the contributions from Hilton/Mt. Isa stream smelting operations and Hilton/Mt. Isa stream concentration operations.

h) IPCC -Greenhouse Effect (direct, 100 years):

Relevant graphs:	Graph 10.64:	Category 1, Allocated model
	Graph 10.78:	Category 2, Allocated model
	Graph 10.92:	Category 1, Unallocated model
	Graph 10.106:	Category 2, Unallocated model

Category 1 graphs:

Both Graphs 10.64 and 10.92 show that, relative to the total output from the modelled system, the Hilton/Mt. Isa stream appears to give rise to a substantially greater total contribution to the effect ‘IPCC -Greenhouse Effect (direct, 100 years)’ than the McArthur River/BZL stream. Both models also indicate that the greatest contribution in the Hilton/Mt. Isa stream is from concentration operations.

Dominance analysis shows that, in both models, contributions to the effect ‘IPCC - Greenhouse Effect (direct, 100 years)’ are from emissions to the atmosphere of ‘(a) Carbon Dioxide (CO₂, fossil)¹²⁷, as these account for 96.64 % of the effect in the allocated model, and 96.64 % of the effect in the unallocated model. Furthermore, dominance analyses also show that, in both models, the effect may be attributed principally to ‘241 Water (Softened): Production.1’, which connects to ‘MCPS: Electricity Production (Mica Creek Power Station)’, and is within the system node: ‘MCPS: Electricity Production Operations (Mica Creek Power Station)’. All of the other consumptions account for less than 5%,

individually, of the total system consumption. In consequence, the overall system contribution and the individual operations contributions to are the effect 'IPCC - Greenhouse Effect (direct, 100 years)' expected to be relatively robust to potential inaccuracies and biases in any of the other atoms within the system.

Since '(a) Carbon Dioxide (CO₂, fossil)' emissions contribute to over 96 % of the effect, for both models, Graphs 10.62 and 10.62, are similar to Graphs 10.6 and 10.34, which are the '(a) Carbon Dioxide (CO₂, fossil)' Category 1 inventory graphs for the allocated and unallocated models respectively. It also means the assertions made regarding '(a) Carbon Dioxide (CO₂, fossil)' emissions for these graphs, are fully applicable here for contributions to 'IPCC -Greenhouse Effect (direct, 100 years)'. Hence, the following assertions have been extrapolated from the discussion for '(a) Carbon Dioxide (CO₂, fossil)' (which forms part f) of section 10.4.4.5.1):

1. For both models, the Hilton/Mt. Isa stream makes a significantly greater contribution to the effect than the McArthur River/BZL stream, at the overall system scales.
2. For both models, the largest single contributor is from Hilton/Mt. Isa stream concentration operations. The other significant contributors are Hilton/Mt. Isa stream smelting and mining operations. The relative differences between the operations are attributable largely to differences in the relative amounts of electricity from the Mica Creek Power Station (MCPS) which they consume. The contributions from MCPS are themselves principally from the atom to '241 Water (Softened): Production.1'. Since, the electricity consumption data are considered to be relatively accurate, the relative differences between the operations are considered to be reasonably robust.
3. For both models, Hilton/Mt. Isa stream concentration operations make a significantly greater contribution to the effect than the McArthur River/BZL stream concentration operations.

¹²⁷ Throughout the discussion, the names of the inventory flows, and atoms, are those supplied the TEAMTM software. In consequence, names for many chemical compounds do not comply fully with conventional methodology. For further information, see section 10.4.4.5 of this chapter.

4. For both models, the uncertainties in the modelling are such, that it is not possible to ascertain whether or not there is any significant difference between the contributions from Hilton/Mt. Isa stream mining and Hilton/Mt. Isa stream smelting operations.

Category 2 graphs:

Graph 10.78 suggests that, for the allocated model, the dominant contributor to the effect 'IPCC -Greenhouse Effect (direct, 100 years)', per 1000 kg of production from each operation, is from Hilton/Mt. Isa stream concentration operations. However, for the unallocated model (Graph 10.105), the contribution from McArthur River/BZL stream smelting operations appears to be exceeded by that from Hilton/Mt. Isa stream concentration operations. This greater relative contribution by McArthur River/BZL stream smelting operations, in the unallocated model, compared with that in the Category 1 graph (Graph 10.64), occurs because the overall throughput through the Hilton/Mt. Isa stream is greater than that for the McArthur River/BZL stream. As a result, this form of normalisation tends to increase the size of the bars associated with the McArthur River/BZL stream relative to those for the Hilton/ Mt. Isa stream.

With this form of normalisation, the relative domination of the contributions from the comprising atoms differ from that of the 'Category 1' graphs. Since, dominance analyses have not been conducted for this form of normalisation, interpretation of the 'Category 2' graphs, currently, is limited. Hence, this represents an area for further research.

i) IPCC -Greenhouse Effect (direct, 20 years):

Relevant graphs:	Graph 10.65:	Category 1, Allocated model
	Graph 10.79:	Category 2, Allocated model
	Graph 10.93:	Category 1, Unallocated model
	Graph 10.107:	Category 2, Unallocated model

Category 1 graphs:

Both Graphs 10.65 and 10.93 show that, relative to the total output from the modelled system, the Hilton/Mt. Isa stream appears to give rise to a substantially greater total contribution to the effect ‘IPCC -Greenhouse Effect (direct, 20 years)’ than the McArthur River/BZL stream. Both models also indicate that the greatest contribution in the Hilton/Mt. Isa stream is from concentration operations.

Dominance analysis shows that, in both models, contributions to the effect ‘IPCC - Greenhouse Effect (direct, 20 years)’ are from emissions to the atmosphere of ‘(a) Carbon Dioxide (CO₂, fossil)’¹²⁸, as these account for 92.12 % of the effect in the allocated model, and 92.54 % of the effect in the unallocated model. Furthermore, dominance analyses also show that, in both models, the effect may be attributed principally to ‘241 Water (Softened): Production.1’, which connects to ‘MCPS: Electricity Production (Mica Creek Power Station)’, and is within the system node: ‘MCPS: Electricity Production Operations (Mica Creek Power Station)’.

The relative consumptions in the graphs, for both models, are similar to the Category 1 graphs for the effect ‘IPCC -Greenhouse Effect (direct, 100 years)’, which are discussed in part h). Therefore, the assertions made for those graphs, are considered to be applicable for this effect as well.

¹²⁸ Throughout the discussion, the names of the inventory flows, and atoms, are those supplied the TEAMTM software. In consequence, names for many chemical compounds do not comply fully with conventional methodology. For further information, see section 10.4.4.5 of this chapter.

Category 2 graphs:

The Category 2 graphs are also similar to the Category 2 graphs for the effect ‘IPCC - Greenhouse Effect (direct, 100 years)’, which are discussed in part h). Therefore, the assertions made for those graphs, are considered to be applicable for this effect as well.

j) IPCC -Greenhouse Effect (direct, 500 years):

Relevant graphs:	Graph 10.66:	Category 1, Allocated model
	Graph 10.80:	Category 2, Allocated model
	Graph 10.94:	Category 1, Unallocated model
	Graph 10.108:	Category 2, Unallocated model

Category 1 graphs:

Both Graphs 10.66 and 10.94 show that, relative to the total output from the modelled system, the Hilton/Mt. Isa stream appears to give rise to a substantially greater total contribution to the effect ‘IPCC -Greenhouse Effect (direct, 500 years)’ than the McArthur River/BZL stream. Both models also indicate that the greatest contribution in the Hilton/Mt. Isa stream is from concentration operations.

Dominance analysis shows that, in both models, contributions to the effect ‘IPCC - Greenhouse Effect (direct, 500 years)’ are from emissions to the atmosphere of ‘(a) Carbon Dioxide (CO₂, fossil)’¹²⁹, as these account for 98.77 % of the effect in the allocated model, and 98.65 % of the effect in the unallocated model. Furthermore, dominance analyses also show that, in both models, the effect may be attributed principally to ‘241 Water (Softened): Production.1’, which connects to ‘MCPS: Electricity Production (Mica Creek Power Station)’, and is within the system node: ‘MCPS: Electricity Production Operations (Mica Creek Power Station)’.

¹²⁹ Throughout the discussion, the names of the inventory flows, and atoms, are those supplied the TEAMTM software. In consequence, names for many chemical compounds do not comply fully with conventional methodology. For further information, see section 10.4.4.5 of this chapter.

The relative consumptions in the graphs, for both models, are similar to the Category 1 graphs for the effect ‘IPCC -Greenhouse Effect (direct, 100 years)’, which are discussed in part h). Therefore, the assertions made for those graphs, are considered to be applicable for this effect as well.

Category 2 graphs:

The Category 2 graphs are also similar to the Category 2 graphs for the effect ‘IPCC -Greenhouse Effect (direct, 100 years)’, which are discussed in part h). Therefore, the assertions made for those graphs, are considered to be applicable for this effect as well.

k) WMO -Depletion of the ozone layer (high):

Relevant graphs:	Graph 10.67:	Category 1, Allocated model
	Graph 10.81:	Category 2, Allocated model
	Graph 10.95:	Category 1, Unallocated model
	Graph 10.109:	Category 2, Unallocated model

Category 1 graphs:

Both Graphs 10.67 and 10.95 show that, relative to the total output from the modelled system, the Hilton/Mt. Isa stream appears to give rise to a greater total contribution to the effect ‘WMO -Depletion of the ozone layer (high)’ than the McArthur River/BZL stream. Both models also indicate that the greatest contribution in the Hilton/Mt. Isa stream is from concentration operations.

Dominance analysis shows that, in both models, contributions to the effect ‘WMO -Depletion of the ozone layer (high)’ are exclusively from emissions to the atmosphere of

‘(a) Halon 1301 (CF₃Br)’¹³⁰. Furthermore, dominance analyses show that, in the allocated model, the effect may be attributed principally to:

1. ‘232 Diesel Oil: Production.5’ which connects to ‘602 Road Transport (Truck, 40t, Diesel Oil, kg.1)’, and is within the system node: ‘MIM: Zinc-Lead-Silver Ore Concentration Operations at Mt. Isa’.
2. ‘232 Diesel Oil: Production.1’ which connects to ‘602 Road Transport (Truck 40t, Diesel Oil, kg.km).1’. The ‘Transport Road (diesel oil, kg.km)’ output from this is, in turn, connected to ‘Hilton Mined Ore Truck transport by KMC & MIM to Mt. Isa’. All are within the system node: ‘Hilton Operations’.
3. ‘232 Diesel Oil: Production.1’ which connects to ‘602 Road Transport (Truck 40t, Diesel Oil, kg.km).1’, and then successively to: ‘BRM: [Tr.] MHD Lead Bullion (truck1, ship and truck)’, ‘BRM: Overheads (MHD bullion processing)’, and ‘BRM: Lead Refining (BRM floor throughput)’.
4. ‘232 Diesel Oil: Production.1’ which connects to ‘601 Rail Transport (Diesel Oil, kg.km).1’, and is within the system node: ‘MIM: Mt. Isa Pb Crude Rail and Road Transport to Townsville’.
5. ‘232 Diesel Oil: Production.1’ which connects to ‘602 Road Transport (Truck, 40t, Diesel Oil, kg.km).1’, and is within the system node: ‘MIM: Mt. Isa Pb Crude Rail and Road Transport to Townsville’.

Sensitivity analyses have been conducted for these dominating atoms, as indicated in Document 12 (of volume 5 of the Portfolio).

Dominance analyses, for the allocated model, show that the effect may be attributed principally to:

1. ‘232 Diesel Oil: Production.5’ which connects to ‘602 Road Transport (Truck, 40t, Diesel Oil, kg.1)’, and is within the system node: ‘MIM: Zinc-Lead-Silver Ore Concentration Operations at Mt. Isa’.

¹³⁰ Throughout the discussion, the names of the inventory flows, and atoms, are those supplied the TEAM™ software. In consequence, names for many chemical compounds do not comply fully with conventional methodology. For further information, see section 10.4.4.5 of this chapter.

2. '266 Cement: Production' which connects successively to 602 Road Transport (Truck, 40t, Diesel Oil, kg.km).1' 'MIM: [Tr.] Soda Ash', and 'MIM: Zinc-Lead-Silver Ore Concentration at Mount Isa'. All are within the system node: 'MIM: Zinc-Lead-Silver Ore Concentration Operations at Mount Isa'.
3. '232 Diesel Oil: Production.5' which connects to '602 Road Transport (Truck, 40t, Diesel Oil, kg.1', and is within the system node: 'MIM: Zinc-Lead-Silver Ore Concentration Operations at Mt. Isa'.
4. '232 Diesel Oil: Production.1' which connects to '602 Road Transport (Truck 40t, Diesel Oil, kg.km).1'. The 'Transport Road (diesel oil, kg.km)' output from this is, in turn, connected to 'Hilton Mined Ore Truck transport by KMC & MIM to Mt. Isa'. All are within the system node: 'Hilton Operations'.
5. '232 Diesel Oil: Production.1' which connects to '602 Road Transport (Truck, 40t, Diesel Oil, kg.km).1', and is within the system node: 'MIM: Lead Smelting Processes at Mt. Isa.
6. '232 Diesel Oil: Production.1' which connects to '601 Rail Transport (Diesel Oil, kg.km).1', and is within the system node: 'MIM: Mt. Isa Pb Crude Rail and Road Transport to Townsville'.
7. '232 Diesel Oil: Production.1' which connects to '602 Road Transport (Truck, 40t, Diesel Oil, kg.km).1', and is within the system node: 'MIM: Mt. Isa Pb Crude Rail and Road Transport to Townsville'.
8. '232 Diesel Oil: Production.1' which connects to '602 Road Transport (Truck 40t, Diesel Oil, kg.km).1'. The 'Transport Road (diesel oil, kg.km)' output from this is, in turn, connected to 'HTS: Road Transport of Mixed Concentrate to Bing Bong'. All are within the system node: 'HTS: Operations Associated with Transport of Mixed Concentrate to Bing Bong'.

Sensitivity analyses have been conducted for these dominating atoms, as indicated in Document 15 (of volume 5 of the Portfolio).

With the exception of '266 Cement: Production' in the unallocated model, all of these dominating atoms are associated with the production of diesel oil, which is then used as fuel for transport processes. All of the dominating atoms, in both models, are also in the background. Since the flows in and out of DEAMTM modules (which have been used to construct these atoms) are not variables, the flows within the atoms contributing to the

effect cannot be modified on their own. Therefore, they have been modified by altering the linked flows in the foreground atomic nodes, to which they are connected. The linked foreground flows, and the paths by which they are linked, are indicated in Documents 12 and 15 (of volume 5 of the Portfolio).

The quantity changes in effect, resulting from sensitivity analyses, applied to both models, are indicated in Documents 12 and 15 (of volume 5 of the Portfolio). Assuming the potential variation ranges are twice the changes identified in the sensitivity analyses (for similar reasons to those given in part a) of section 10.4.4.5.1), the predicted variation ranges attributable to the dominant flows, in the allocated model are:

- $2 \times 0.0005349 = 0.0010698$ g eq. CFC-11¹³¹,
- $2 \times 0.01634 = 0.03268$ g eq. CFC-11,
- $2 \times 0.008646 = 0.017292$ g eq. CFC-11,
- $2 \times 0.006598 = 0.013196$ g eq. CFC-11, and
- $2 \times 0.001877 = 0.003754$ g eq. CFC-11.

For the unallocated model, they are:

- $2 \times 0.09263 = 0.18526$ g eq. CFC-11,
- $2 \times 0.2591 = 0.5182$ g eq. CFC-11,
- $2 \times 0.001956 = 0.003912$ g eq. CFC-11,
- $2 \times 0.05980 = 0.1196$ g eq. CFC-11,
- $2 \times 0.01594 = 0.03188$ g eq. CFC-11,
- $2 \times 0.01175 = 0.0235$ g eq. CFC-11,
- $2 \times 0.01784 = 0.03568$ g eq. CFC-11, and
- $2 \times 0.04837 = 0.09674$ g eq. CFC-11.

With respect to contribution to the effect at the overall system level, Graph 10.67, for the allocated model, indicates a difference between the McArthur River/BZL and Hilton/Mt. Isa streams, of $0.95 - 0.47 = 0.48$ g eq. CFC-11, and Graph 10.95, for the unallocated model, a difference of $0.30 - 0.026 = 0.274$ g eq. CFC-11. When considered both

individually and combined, the differences between the two streams, for the allocated model, is greater than the predicted potential variation ranges attributable to the dominant contributors. Therefore, for the allocated model, the assertion that the Hilton/Mt. Isa stream makes a greater contribution to the effect than the McArthur River/BZL stream, at the whole operations level, is considered to be robust. For the unallocated model, the difference in the contributions to the effect between the Hilton/Mt. Isa stream and the McArthur River/BZL streams, at the whole site scale, are less than the predicted potential variation ranges associated with the dominant contributors, when all are combined. It may be concluded, therefore, for the unallocated model, the uncertainties associated with the modelling are such that it is not possible to demonstrate whether or not the contribution to the effect by the Hilton/Mt. Isa stream is significantly different from that of the McArthur River/BZL stream.

Both Graph 10.67 and Graph 10.95 suggest that Hilton/Mt. Isa stream concentration operations are largest contributor to the effect. In the allocated model (Graph 10.67), the second largest contributions appear to be shared approximately equally by Hilton/Mt. Isa stream smelting and transport operations, whilst in the unallocated model (Graph 10.95), the second largest contributions appear to be shared approximately equally by Hilton/Mt. Isa stream mining operations and McArthur River /BZL stream transport operations.

In the allocated model, the difference between the contributions from Hilton/Mt. Isa stream and McArthur River/BZL stream concentration operations is $0.16 - 0.0031 = 0.1569$ g eq. CFC-11, and in the unallocated model is $0.58 - 0.079 = 0.501$ g eq. CFC-11. The predicted potential variation range attributable to the dominant contributor for the allocated model is: 0.0010698 g eq. CFC-11, whilst for the unallocated model they are: 0.18526 g eq. CFC-11, 0.5182 g eq. CFC-11, 0.003912 g eq. CFC-11. When considered both individually and combined, the difference between the Hilton/Mt. Isa stream and McArthur River/BZL stream concentration operations, in the allocated model, is greater than the predicted potential variation range attributable to the dominant contributor. In the unallocated model, however, when considered both individually and combined, the difference between the Hilton/Mt. Isa stream and McArthur River/BZL stream concentration operations are less than the predicted potential variation ranges attributable to the dominant contributors. It

¹³¹ Throughout the discussion, the number of decimal places reflects the number calculated by the TEAM™ software. It does not suggest a particular level of accuracy.

may be concluded, therefore, the assertion that Hilton/Mt. Isa stream concentration operations make a greater contribution to the effect than McArthur River/BZL stream concentration operations, is robust for the allocated model. For the unallocated model, however, the uncertainties are such that it has not been possible to demonstrate whether or not a significant difference exists.

In the allocated model, the difference between the Hilton/Mt. Isa stream concentration and mining operations is $0.16 - 0.062 = 0.098$ g eq. CFC-11, and between Hilton/Mt. Isa stream concentration and smelting operations is $0.16 - 0.052 = 0.108$ g eq. CFC-11. In the allocated model, for Hilton/Mt. Isa stream concentration and mining operations, the predicted potential variation ranges attributable to the dominant contributors are: 0.0010698 g eq. CFC-11, and 0.03268 g eq. CFC-11, whilst for Hilton/Mt. Isa stream concentration and transport operations, they are: 0.0010698 g eq. CFC-11, 0.013196 g eq. CFC-11, and 0.003754 g eq. CFC-11. When considered both individually and combined, the differences between Hilton/Mt. Isa stream concentration and mining operations and between Hilton/Mt. Isa stream concentration and smelting operations, are greater than the predicted potential variation ranges attributable to the dominant contributors. Therefore, for the allocated model, the assertion that Hilton/Mt. Isa stream concentration operations make a greater contribution to the effect than either Hilton/Mt. Isa stream mining or smelting operations, is considered to be robust.

In the unallocated model, the difference between the Hilton/Mt. Isa stream concentration and mining operations is $0.58 - 0.23 = 0.35$ g eq. CFC-11, and between Hilton/Mt. Isa stream concentration and McArthur River/BZL stream transport operations is $0.58 - 0.26 = 0.32$ g eq. CFC-11. In the unallocated model, for Hilton/Mt. Isa stream concentration and mining operations, the predicted potential variation ranges attributable to the dominant contributors are: 0.18526 g eq. CFC-11, 0.5182 g eq. CFC-11, 0.003912 g eq. CFC-11, and 0.1196 g eq. CFC-11, whilst for Hilton/Mt. Isa stream concentration and McArthur River/BZL stream transport operations, they are: 0.18526 g eq. CFC-11, 0.5182 g eq. CFC-11, 0.003912 g eq. CFC-11, and 0.09674 g eq. CFC-11. When considered in combination, the differences between Hilton/Mt. Isa stream concentration and mining operations, as well as between Hilton/Mt. Isa stream concentration and McArthur River/BZL stream transport operations, are less than the predicted potential variation ranges attributable to the dominant contributors. They are also less than some of the individual potential predicted

variation ranges. Therefore, for the unallocated model, the uncertainty associated with the modelling is such that it is not possible to demonstrate whether or not there is a significant difference between the contributions from Hilton/Mt. Isa stream concentrations and either Hilton/Mt. Isa stream mining operations or McArthur River/BZL stream transport operations.

In the allocated model, the difference between Hilton/Mt. Isa stream mining and smelting operations is $0.062 - 0.052 = 0.010$ g eq. CFC-11, and the predicted potential variation range attributable to the dominant contributor is: 0.03268 g eq. CFC-11. This variation range is greater than the difference between the two operations. In the unallocated model, the difference between Hilton/Mt. Isa stream mining operations and McArthur River/BZL stream transport operations is $0.26 - 0.23 = 0.03$ g eq. CFC-11, and the predicted potential variation range attributable to the dominant contributors are: 0.1196 g eq. CFC-11, and 0.09674 g eq. CFC-11. When considered both individually and in combination, these variation ranges are greater than the difference between the two operations. Therefore, in neither case has it been possible to demonstrate a significant difference between these operations.

Category 2 graphs:

Both Graph 10.81 (for the allocated model) and Graph 10.109 (for the unallocated model) suggest that, per 1000 kg of output from each operation, the contributions to the effect of 'WMO -Depletion of the ozone layer (high)' are greatest from Hilton/Mt. Isa stream smelting operations. Graph 10.81 (for the allocated model) suggests that Hilton/Mt. Isa stream concentration operations account for the second largest contribution. However, the graph for the unallocated model (Graph 10.109) suggests the second largest contribution is from McArthur River/BZL stream concentration operations.

One of the principal differences between the Category 1 graphs (Graphs 10.67 and 10.95) and the Category 2 graphs (Graphs 10.81 and 10.109) is the greater relative contribution to the effect of McArthur River/ BZL stream operations. This occurs because the overall throughput through the Hilton/Mt. Isa stream is greater than that for the McArthur River/BZL stream. As a result, the form of normalisation, used for Category 2 graphs,

tends to increase the size of the bars associated with the McArthur River/BZL stream relative to those for the Hilton/ Mt. Isa stream.

With this form of normalisation also, the relative domination of the contributions from the comprising atoms differ from that of the 'Category 1' graphs. Since, dominance analyses have not been conducted for this form of normalisation, interpretation of the 'Category 2' graphs, currently, is limited. Hence, this represents an area for further research.

l) WMO -Depletion of the ozone layer (low):

Relevant graphs:	Graph 10.68:	Category 1, Allocated model
	Graph 10.82:	Category 2, Allocated model
	Graph 10.96:	Category 1, Unallocated model
	Graph 10.110:	Category 2, Unallocated model

Category 1 graphs:

Since emissions of '(a) Halon 1301 (CF₃Br)',¹³² are the sole contributor to the effect, for both the 'high' and 'low' categories of the effect 'WMO -Depletion of the ozone layer', the relative contributions from each of the operations shown in Graphs 10.68 and 10.96 are identical to those in Graphs 10.67 and 10.95 respectively. Hence, the assertions made in part k) regarding 'WMO -Depletion of the ozone layer (high)' for the Category 1 graphs, are fully applicable for this effect as well.

Category 2 graphs:

The Category 2 graphs are also similar to the Category 2 graphs for the 'WMO -Depletion of the ozone layer (high)', which are discussed in part a). Hence, the assertions made for those graphs, are considered to be applicable for this effect as well.

¹³² Throughout the discussion, the names of the inventory flows, and atoms, are those supplied the TEAMTM software. In consequence, names for many chemical compounds do not comply fully with conventional methodology. For further information, see section 10.4.4.5 of this chapter.

m) WMO -Photochemical oxidant formation (high):

Relevant graphs:	Graph 10.69:	Category 1, Allocated model
	Graph 10.83:	Category 2, Allocated model
	Graph 10.97:	Category 1, Unallocated model
	Graph 10.111:	Category 2, Unallocated model

Category 1 graphs:

Both Graphs 10.69 and 10.97 suggest that, relative to the total output from the modelled system, the Hilton/Mt. Isa stream gives rise to a substantially greater total contribution to the effect 'WMO -Photochemical oxidant formation (high)' than the McArthur River/BZL stream. Both models also suggest that the greatest contribution in the Hilton/Mt. Isa stream is from concentration operations.

Dominance analysis shows that, in the allocated model, contributions to the effect 'WMO - Photochemical oxidant formation (high)' are from emissions to the atmosphere of:

'(a) Hydrocarbons (except methane)'	93.14 %
'(a) Methane (CH ₄)' ¹³³	2.95 %
'(a) Hydrocarbons (unspecified)'	1.71 %.

Whilst for the unallocated model, dominance analysis shows the contributions to the effect to be from emissions to the atmosphere of:

'(a) Hydrocarbons (except methane)'	93.54 %
'(a) Methane (CH ₄)'	2.58 %
'(a) Hydrocarbons (unspecified)'	1.81 %.

Furthermore, dominance analysis shows that, in the allocated model the effect may be attributed principally to '231 Coke: Production.1' (from which coke for the atomic node 'BZL: Lead Smelting -Imperial smelting furnace' is supplied), and to '241 Water

(Softened): Production.1' (which connects to 'MCPS: Electricity Production (Mica Creek Power Station)'). In the allocated model, dominance analysis shows the effect may be attributed principally to '232 Diesel Oil: Production.1' (from which diesel, used as fuel is supplied to the atomic node 'BZL: Lead Smelting -Imperial smelting furnace'), and to '241 Water (Softened): Production.1' (which connects to 'MCPS: Electricity Production (Mica Creek Power Station)'). Hence, in both models a material associated with the atomic node 'BZL: Lead Smelting -Imperial smelting furnace' and '241 Water (Softened): Production.1' associated with the Mica Creek Power Station, are the dominant contributors. All of the other consumptions account for less than 5%, individually, of the total system consumption. In consequence, the overall system contribution and the individual operations contributions to the effect 'WMO -Photochemical oxidant formation (high)' are expected to be relatively robust to potential inaccuracies and biases in any of the other atoms within the system.

The quantity changes in effect, resulting from sensitivity analyses, applied to both models, are indicated in Documents 12 and 15 (of volume 5 of the Portfolio). Assuming the potential variation ranges are twice the changes identified in the sensitivity analyses (for similar reasons to those given in part a) of section 10.4.4.5.1), the predicted variation ranges attributable to the dominant flows, in the allocated model are:

- $2 \times 124.2074 = 248.4148$ g eq. ethylene¹³⁴, and
- $2 \times 1,923.7904 = 3,847.5808$ g eq. ethylene.

For the unallocated model, they are:

- $2 \times 0.5244 = 1.0488$ g eq. ethylene, and
- $2 \times 6,978.5088 = 13,957.0176$ g eq. ethylene.

Graph 10.69 suggests a difference between the McArthur River/BZL and Hilton/Mt. Isa streams, in contribution to the effect at the overall system level, of $9,493.83 - 1,482.25 =$

¹³³ Throughout the discussion, the names of the inventory flows, and atoms, are those supplied the TEAMTM software. In consequence, names for many chemical compounds do not comply fully with conventional methodology. For further information, see section 10.4.4.5 of this chapter.

¹³⁴ Throughout the discussion, the number of decimal places reflects the number calculated by the TEAMTM software. It does not suggest a particular level of accuracy.

8,011.58 g eq. ethylene, for the allocated model, and Graph 10.97 a difference of 32,976.73 - 16,965.20 = 16,011.53 g eq. ethylene, for the unallocated model. When considered both individually and combined, the difference between the two streams, for both models, is greater than the predicted potential variation ranges attributable to the dominant contributors. Therefore, for both models, the assertion that the Hilton/Mt. Isa stream makes a greater contribution to the effect than the McArthur River/BZL stream, at the whole operations level, is considered to be robust.

For both models, the contribution to the total effect associated with the atom '241 Water (Softened): Production.1' (which connects to 'MCPS: Electricity Production (Mica Creek Power Station)') needs to be apportioned between the mining, concentration and smelting operations for the Hilton/Mt. Isa stream, which receive electric power from the Mica Creek Power Station (MCPS). Table 10.21 indicates the actual relative differences in the consumptions of electricity from the MCPS, by operations associated with the Hilton/Mt. Isa stream, during the period modelled. In Table 10.28, these data have been used to calculate scaling fractions, to attribute the differences, identified by the sensitivity analysis for the '241 Water (Softened): Production.1' node in both models, to the various Mt. Isa based Hilton/Mt. Isa stream operations.

Operation	Change in fractional 'WMO -Photochemical oxidant formation (high)' effect	Predicted variation range
<i>Allocated model: (Change identified by sensitivity analysis = 1,923.7904 g eq. ethylene)</i>		
Smelting	0.1366931 x 1,923.7904 = 262.9689 g eq. ethylene	2 x 262.9689 = 525.9377 g eq. ethylene
Concentration	0.685286981 x 1,923.7904 = 1318.349 g eq. ethylene	2 x 1,318.349 = 2,636.697 g eq. ethylene
Hilton and Mt. Isa mining combined	0.071575015 x 1,923.7904 = 137.6953 g eq. ethylene	2 x 137.6953 = 275.3907 g eq. ethylene
<i>Unallocated model (Change identified by sensitivity analysis = 6,978.5088 g eq. ethylene)</i>		
Smelting	0.1366931 x 6,978.5088 = 953.9133 g eq. ethylene	2 x 953.9133 = 1,907.827 g eq. ethylene
Concentration	0.685286981 x 6,978.5088 = 4782.2812 g eq. ethylene	2 x 4782.2812 = 9,564.562 g eq. ethylene
Hilton and Mt. Isa mining combined	0.071575015 x 6,978.5088 = 499.48687 g eq. ethylene	2 x 499.48687 = 998.9737 g eq. ethylene

Table 10.28: Calculation of the variation ranges of contributions to 'WMO - Photochemical oxidant formation (high)', associated with the MCPS operations atom: '241 Water (Softened): Production.1'

From Graph 10.69, for the allocated model, it appears the order of relative contribution to the effect, from greatest to least, is: Hilton/Mt. Isa stream concentration operations, Hilton/Mt. Isa stream mining operations, Hilton/Mt. Isa stream smelting operations, and McArthur River/BZL stream smelting operations. However, the relative contributions of all except for Hilton/Mt. Isa stream concentration operations appear to be relatively similar.

In the allocated model, the difference between the contributions from Hilton/Mt. Isa stream and McArthur River/BZL stream concentration operations is $5,913.44 - 35.06 = 5,878.38$ g eq. ethylene, and in the unallocated model is $21,468.76 - 903.56 = 20,565.2$ g eq. ethylene. The predicted potential variation range attributable to the dominant contributor for the allocated model is: 2,636.697 g eq. ethylene, whilst for the unallocated model it is: 9,564.562 g eq. ethylene. In both the allocated and unallocated models, the difference between the Hilton/Mt. Isa stream and McArthur River/BZL stream concentration operations is greater than the predicted potential variation range attributable to the dominant contributor. It may be concluded, therefore, the assertion that Hilton/Mt. Isa stream concentration operations make a greater contribution to the effect than McArthur River/BZL stream concentration operations, is robust for both models.

In the allocated model, the difference in contributions between the Hilton/Mt. Isa stream concentration and mining operations is $5,913.44 - 1,660.94 = 4,252.5$ g eq. ethylene, between the Hilton/Mt. Isa stream concentration and smelting operations is $5,913.44 - 1,513.11 = 4,400.33$ g eq. ethylene, and between the Hilton/Mt. Isa stream concentration and McArthur River/BZL stream smelting operations is $5,913.44 - 1,303.40 = 4,610.04$ g eq. ethylene. In the allocated model, the predicted potential variation ranges attributable to the dominant contributors are:

- 2,636.697 g eq. ethylene and 275.3907 g eq. ethylene, for Hilton/Mt. Isa stream concentration and mining operations,
- 2,636.697 g eq. ethylene and 525.9377 g eq. ethylene, for Hilton/Mt. Isa stream concentration and smelting operations, and
- 2,636.697 g eq. ethylene and 248.4148 g eq. ethylene, for Hilton/Mt. Isa stream concentration and McArthur River/BZL stream smelting operations.

When considered both individually and combined, the differences between Hilton/Mt. Isa stream concentration and mining operations, between Hilton/Mt. Isa stream concentration and smelting operations, and between Hilton/Mt. Isa stream concentration and McArthur River/BZL stream smelting operation are all greater than the predicted potential variation ranges attributable to the dominant contributors. Therefore, for the allocated model, the assertion that Hilton/Mt. Isa stream concentration operations makes a greater contribution to the effect than either Hilton/Mt. Isa stream mining or smelting operations or McArthur River/BZL stream smelting operations, is considered to be robust.

In the unallocated model, the difference in contributions between the Hilton/Mt. Isa stream concentration and mining operations is $21,468.76 - 6,034.02 = 15,434.74$ g eq. ethylene, between the Hilton/Mt. Isa stream concentration and smelting operations is $21,468.76 - 4,750.74 = 16,718.02$ g eq. ethylene, and between the Hilton/Mt. Isa stream concentration and McArthur River/BZL stream smelting operations is $21,468.76 - 14,440.35 = 7,028.41$ g eq. ethylene. In the unallocated model, the predicted potential variation ranges attributable to the dominant contributors are:

- 9,564.562 g eq. ethylene and 998.9737 g eq. ethylene, for Hilton/Mt. Isa stream concentration and mining operations,
- 9,564.562 g eq. ethylene and 1,907.827 g eq. ethylene, for Hilton/Mt. Isa stream concentration and smelting operations, and
- 9,564.562 g eq. ethylene and 1.0488 g eq. ethylene, for Hilton/Mt. Isa stream concentration and McArthur River/BZL stream smelting operations.

When considered both individually and combined, the differences between Hilton/Mt. Isa stream concentration and mining operations and between Hilton/Mt. Isa stream concentration and smelting operations, are greater than the predicted potential variation ranges attributable to the dominant contributors. Therefore, for the unallocated model, the assertion that Hilton/Mt. Isa stream concentration operations make a greater contribution to the effect than either Hilton/Mt. Isa stream mining or smelting operations, is considered to be robust. However, between Hilton/Mt. Isa stream concentration and McArthur River/BZL stream smelting operations, the difference between the contributions from the operations is not only less than the combined potential range of the dominant contributors, but is also less than one of the individual ranges. It is concluded, therefore, that between

these operations the uncertainty in the data are such that it is not possible to demonstrate whether or not there is a significant difference between the contributions.

In the allocated model, the difference between Hilton/Mt. Isa stream mining and smelting operations is $1,660.94 - 1,513.11 = 147.83$ g eq. ethylene, and the predicted potential variation ranges attributable to the dominant contributors are: 275.3907 g eq. ethylene, and 525.9377 g eq. ethylene. Also, the difference between Hilton/Mt. Isa stream mining and McArthur River/BZL stream smelting operations is $1,660.94 - 1,303.40 = 357.54$ g eq. ethylene, and the predicted potential variation ranges attributable to the dominant contributors are: 275.3907 g eq. ethylene and 248.4148 g eq. ethylene. Finally, the difference between Hilton/Mt. Isa stream smelting and McArthur River/BZL stream smelting operations is $1,513.11 - 1,303.40 = 209.71$ g eq. ethylene, and the predicted potential variation ranges attributable to the dominant contributors are: 525.9377 g eq. ethylene and 248.4148 g eq. ethylene. Between Hilton/Mt. Isa stream mining and smelting operations, and between Hilton/Mt. Isa stream smelting and McArthur River/BZL stream smelting operations, the predicted potential variation ranges are greater than the difference between the two operations, when considered both individually and combined. Between Hilton/Mt. Isa stream mining and McArthur River/BZL stream smelting operations, however, only the combined range is greater. It is concluded, therefore, that between all of these operations the uncertainty in the data mean it is not possible to demonstrate whether or not there is a significant difference between any of the contributions. However, a difference between Hilton/Mt. Isa stream mining and McArthur River/BZL stream smelting operations seems more likely than between the others.

In the unallocated model, the difference between McArthur River/BZL stream smelting and Hilton/Mt. Isa stream mining operations is $14,440.35 - 6,034.02 = 8,406.33$ g eq. ethylene, and the predicted potential variation ranges attributable to the dominant contributors are: 1.0488 g eq. ethylene, and 998.9737 g eq. ethylene. Also, the difference between McArthur River/BZL stream smelting and Hilton/Mt. Isa stream smelting operations is $14,440.35 - 4,750.74 = 9,689.61$ g eq. ethylene, and the predicted potential variation ranges attributable to the dominant contributors are: 1.0488 g eq. ethylene and 1,907.827 g eq. ethylene. Finally, the difference between Hilton/Mt. Isa stream smelting and Hilton/Mt. Isa stream mining operations is $6,034.02 - 4,750.74 = 1,283.28$ g eq. ethylene, and the predicted potential variation ranges attributable to the dominant contributors are: 1,907.827 g eq.

ethylene and 998.9737 g eq. ethylene. Between McArthur River/BZL stream smelting and Hilton/Mt. Isa stream mining operations, and between McArthur River/BZL stream smelting and Hilton/Mt. Isa stream smelting operations, the predicted potential variation ranges are less than the difference between the two operations, when considered both individually and combined. Between Hilton/Mt. Isa stream smelting and Hilton/Mt. Isa stream mining operations, however, the difference between the contribution, is not only less than the combined potential range of the dominant contributors, but is also less than one of the individual ranges. It is concluded, therefore, the assertions that McArthur River/BZL stream smelting operations and Hilton/Mt. Isa stream concentration operations make a greater contribution to the effect than Hilton/Mt. Isa stream mining operations, and that McArthur River/BZL stream smelting operations make a greater contribution to the effect than Hilton/Mt. Isa stream smelting operations, are robust. However, between Hilton/Mt. Isa stream smelting and Hilton/Mt. Isa stream mining operations, the uncertainty in the data mean it is not possible to demonstrate whether or not there is a significant difference between them.

Category 2 graphs:

Both Graph 10.83 (for the allocated model) and Graph 10.111 (for the unallocated model) suggest that the dominant contributor to the effect 'Photochemical oxidant formation (high)', per 1000 kg of production from each operation, is from McArthur River/BZL stream smelting operations. This greater relative contribution by McArthur River/BZL stream smelting operations, in both models, compared with that in the Category 1 graph (Graph 10.64), occurs because the overall throughput through the Hilton/Mt. Isa stream is greater than that for the McArthur River/BZL stream. As a result, this form of normalisation tends to increase the size of the bars associated with the McArthur River/BZL stream relative to those for the Hilton/ Mt. Isa stream.

With this form of normalisation, the relative domination of the contributions from the comprising atoms differ from that of the 'Category 1' graphs. Since, dominance analyses have not been conducted for this form of normalisation, interpretation of the 'Category 2' graphs, currently, is limited. Hence, this represents an area for further research.

n) WMO -Photochemical oxidant formation (low):

Relevant graphs:	Graph 10.70:	Category 1, Allocated model
	Graph 10.84:	Category 2, Allocated model
	Graph 10.98:	Category 1, Unallocated model
	Graph 10.112:	Category 2, Unallocated model

Category 1 graphs:

Dominance analysis shows that, in the allocated model, contributions to the effect 'WMO - Photochemical oxidant formation (low)' are from emissions to the atmosphere of:

'(a) Hydrocarbons (except methane)'	94.67 %
'(a) Ethylene (C ₂ H ₄)' ¹³⁵	2.70 %.

Whilst for the allocated model, contributions to the effect are from:

'(a) Hydrocarbons (except methane)'	94.82 %
'(a) Ethylene (C ₂ H ₄)'	2.53 %.

For both models, the contribution of the dominant emission (which is from '(a) Hydrocarbons (except methane)') differs by less than 2 % from that for the effect 'WMO - Photochemical oxidant formation (high)', which is discussed in part m). Furthermore, dominance analyses show that, in both models, the effect may be attributed principally to the same atomic nodes as for that effect.

As a result, the relative consumptions in the graphs, for both models are also similar to the Category 1 graphs for the effect 'WMO -Photochemical oxidant formation (high)'. Therefore, the assertions made for those graphs, are considered to be applicable for this effect as well.

Category 2 graphs:

The Category 2 graphs are also similar to the Category 2 graphs for the effect 'WMO - Photochemical oxidant formation (high)', which are discussed in part m). Therefore, the assertions made for those graphs, are considered to be applicable for this effect as well.

10.5. Conclusions and recommendations

10.5.1 General

Data from the allocated and unallocated models, and for both the Category 1 and Category 2 graphs, could be used to develop environmental performance indicators, in a manner similar to that adopted in the BRM case study (Graphs 9.23 to 9.44), where data for more than one year are available. Modelling data may also be used to aid identification of 'best' environmental practice. This may be achieved by comparing different modelled operations within the MIM case study, or by comparing modelled operations with various others. Comparisons may be made using various valuation criteria. One simple approach might be to assume that 'less is best'. However, numerous other valuation approaches could be adopted.¹³⁶ Whatever the approach, they should be only used as aids for identifying 'best' environmental practice. It should not be assumed they enable identification *per se*. This is because, the modelling and assessment procedures, which underlie comparisons, are based on implicit framing assumptions. As noted in section 4.4.2.2 (chapter 4), these need to be identified and challenged, and then accepted, rejected or modified as necessary, if the 'best' decisions are to be made. Since, this is a departure from much of common practice, it is discussed further in the Overall Conclusions and Recommendations (chapter 11).

It is apparent from sections 10.4.4.1 to 10.4.4.4, which consider the sources and types of uncertainty in the modelling, that all interpretations must be conducted in conjunction with

¹³⁵ Throughout the discussion, the names of the inventory flows, and atoms, are those supplied the TEAMTM software. In consequence, names for many chemical compounds do not comply fully with conventional methodology. For further information, see section 10.4.4.5 of this chapter.

¹³⁶ Valuation approaches are discussed further in the elective EngD module, enclosed as Document 15, in volume 2 of the Portfolio. This document has not been provided with this copy of the thesis.

an assessment of the potential influence of such uncertainty upon the findings. It is for this reason, that dominance and sensitivity analyses have been used to support all assertions made in the discussion of the graphs (section 10.4.4.5). It is also apparent from the discussion that, whilst the modelling provides quantitative data, the assertions which have been made regarding the findings are all qualitative i.e. they simply assert whether one emission source is dominant and/or is significantly different from another. It is theoretically possible to identify the actual variability from the 'true' value for all foreground and background data. For foreground data, this has been assessed by the 'variability of data' columns which have been completed for all data. For background data, however, this is currently not possible, because the suppliers of the data do not provide sufficient information for this. Since the dominance analysis (discussed along with the graph findings in section 10.4.4.5) reveals that most of the dominant contributors to the selected inventories and effects are associated with background atoms, the 'true' variability is not known. However, all of the background data are from recognised sources. This means that they are from the pool of data which is being used, currently, by other LCA practitioners. Therefore, any errors, inaccuracies and omissions within these data will be duplicated by these other practitioners in their own modelling. It also means that when (or if) comparisons between the modelling conducted here, and other models are made, they will be commensurate, at least with regard to this aspect.

Taking into account these considerations does not mean, necessarily, that the quantitative data (provided in the inventories in volume 4 of the Portfolio), cannot be used to support claims which people may wish to make. Rather, it means that where they are, they must be accompanied by uncertainty assessments of the kind provided in section 10.4.4.5 for each graph. This is because these discussions set the boundaries to the uncertainties underlying the numerical data.

It should also be noted, however, that as with all modelling, findings can only be made on the basis of what is known. Whilst strenuous efforts have been made, through discussion with the data suppliers, to ensure all potentially significant inflows and outflows have been either incorporated in the modelling, or their absence noted and their possible influence assessed, it is possible that some significant flows may have been missed.

Finally, it should be noted that the modelling, data output and findings merely provide a snapshot. Nevertheless, this is of a significant proportion of the global industry, since the Isa stream alone accounts for over 1/3 of the global annual supply of refined primary lead, and over 1/5 of the global annual supply of primary refined silver [MIM Holdings Limited (2000a)]. As a leader in the production of these materials, the inventories and effects, calculated for the MIM Pb life-cycle, represent a bench mark. However, since processes are constantly evolving, the modelling and findings, are only able to provide an historical record. Nevertheless, providing any changes which have been made since when the modelling was conducted are not significant, it will still provide an accurate reflection of the current circumstance. Though, until modelling is updated, it cannot be known with certainty whether changes, which have occurred, are significant.

Therefore, if the full potential of the modelling is to be achieved, the modelling and assessments will need to be updated on a regular basis into the foreseeable future. Key uncertainties in this modelling, could also be addressed in such future iterations. These questions are considered further in the Overall Conclusions and Recommendations (chapter 11).

10.5.2. Specifics

The dominance analyses conducted for both the allocated and unallocated models, indicate that, with two exceptions, substituted non-transport data atoms do not make a significant contribution overall to any of the graphed inventories and effects. The exceptions are the use of the data atoms:

- ‘241 Water (Softened): Production’, in both models, which has been used as a substitute for ‘fresh water’, ‘cooling water’, and ‘towns water’ (as indicated in Table 10.16), and
- ‘274 Aluminium (Al, 25% recycling): Production.1’, in the unallocated model, which has been used as a substitute for ‘master alloy’ and ‘sodium metal’ in the system node: ‘BZL: Cadmium and Zinc Refining Operations’.

Dominance analyses have shown, that '241 Water (Softened): Production' data atoms make a dominant contribution (i.e. greater than 5 % to the total) to the following graphed inventories:

- '(r) Natural Gas (in ground)',
- '(r) Oil (in ground)',
- '(a) Carbon Dioxide (CO₂, fossil)',¹³⁷,
- 'E Total Primary Energy', and
- 'Total Electricity',

It has also been shown to make a dominant contribution to the following graphed effects:

- 'CML -Eutrophication',
- 'IPCC -Greenhouse Effect (direct, 100, 20 and 500 years)', and
- 'WMO -Photochemical Oxidant Formation (high and low)'.

It is thought likely that the use of the '241 Water (Softened): Production' atom exaggerates the actual LCI inventory for the type of water being considered. This means that inventories and effects which are significantly influenced by the use of this atom represent 'worst case scenarios', a approach which is in full compliance with the Precautionary Principle (which is that, in the absence of actual data one should always assume a worst case). However, without actual modelling data, this cannot be known with certainty.

The atom '274 Aluminium (Al, 25% recycling): Production.1' makes a significant contribution to the inventory '(w) Arsenic (As³⁺, As⁵⁺)' only. It is used as a substitute for 'master alloy' and 'sodium metal'. However, not known how close an approximation it is for these substances, though 'master alloy' is composed of zinc and aluminium. Hence, does provide at least a partial approximation for the latter material.

It is recommended, therefore, that should assertions be made to the public, regarding any of the inventories and effects identified above, they must also include a comment about the

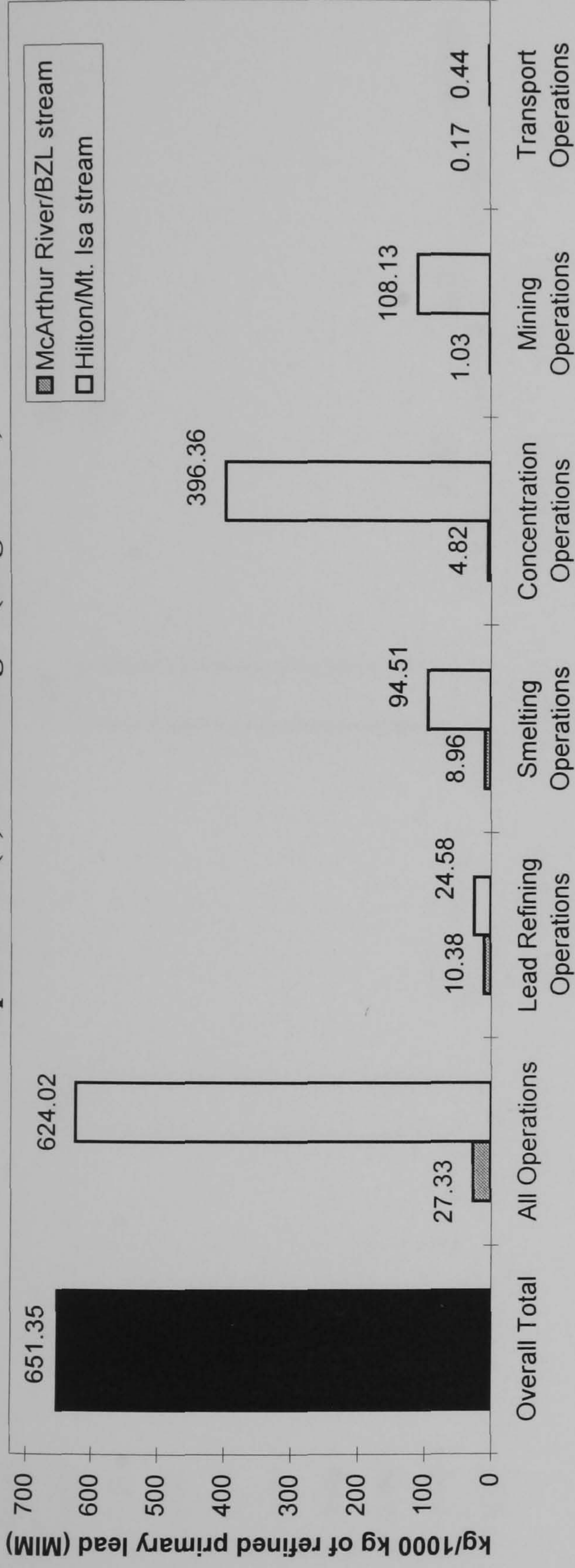
¹³⁷ Throughout the discussion, the names of the inventory flows, and atoms, are those supplied the TEAMTM software. In consequence, names for many chemical compounds do not comply fully with conventional methodology. For further information, see section 10.4.4.5 of this chapter.

influence of these substitute atoms on the findings. It is also recommended, that in future iterations of the modelling, actual LCI data be collected for 'master alloy', 'sodium metal', and all of the flows listed in Table 10.16. These data should then replace the use of the substitute atoms for modelling these materials.

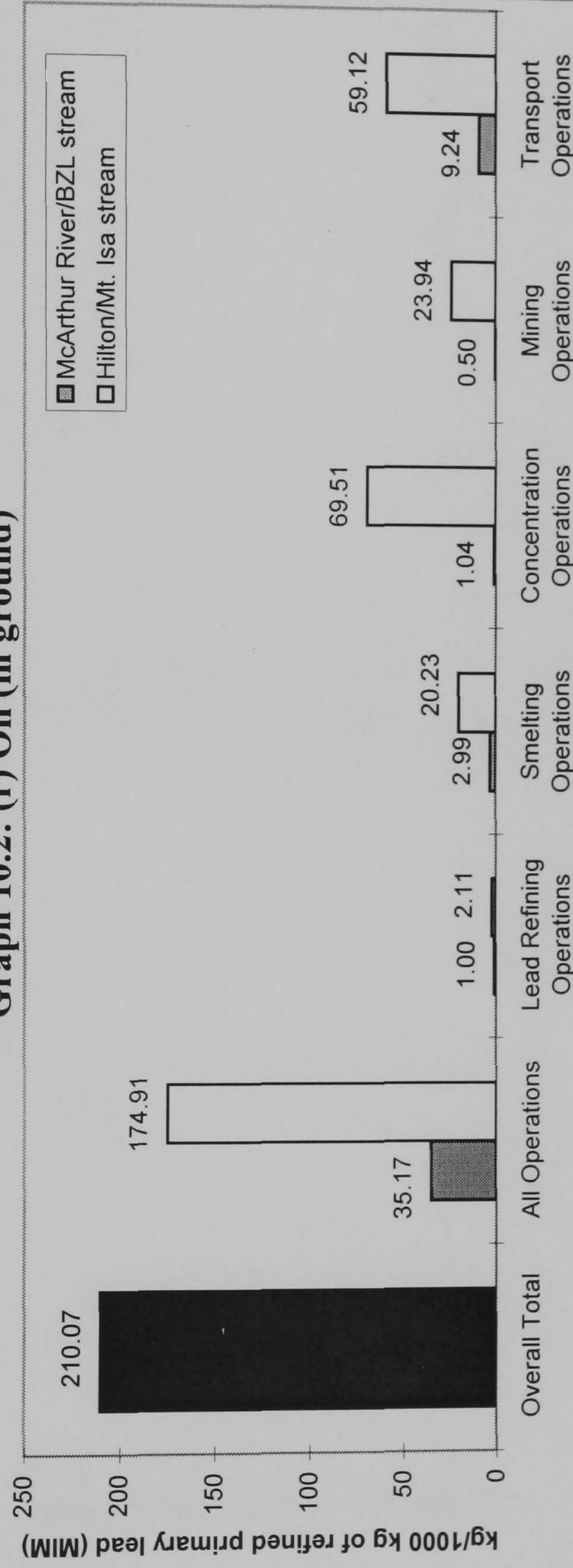
With regard to the modelling of truck transports, the DEAMTM 3.5, 60, 28 and 40 tonne truck transport modules were used. This is also considered to be a significant source of uncertainty. In particular, several of the transport movements of intermediate materials in Australia are by road train, a mode of truck transport which may convey up to 180 tonnes per trip. However, the largest truck size in the DEAMTM list of transport modules is 40 tonnes. The use of this data module to model these movements, is thought to exaggerate the inventories (and hence also any effects). This is because larger capacity vehicles, such as road trains, are likely to be more efficient, but this is not taken into account when using the 40 tonne DEAMTM modules. Since this approach is thought to exaggerate the inventories, it is also believed to be in compliance with the Precautionary Principle. Nevertheless, it is recommended that in future iterations of the modelling, the use of the DEAMTM transport modules be replaced by actual fuel consumption data.

10.6. Graphs of systems modelled

Graph 10.1: (r) Natural gas (in ground)

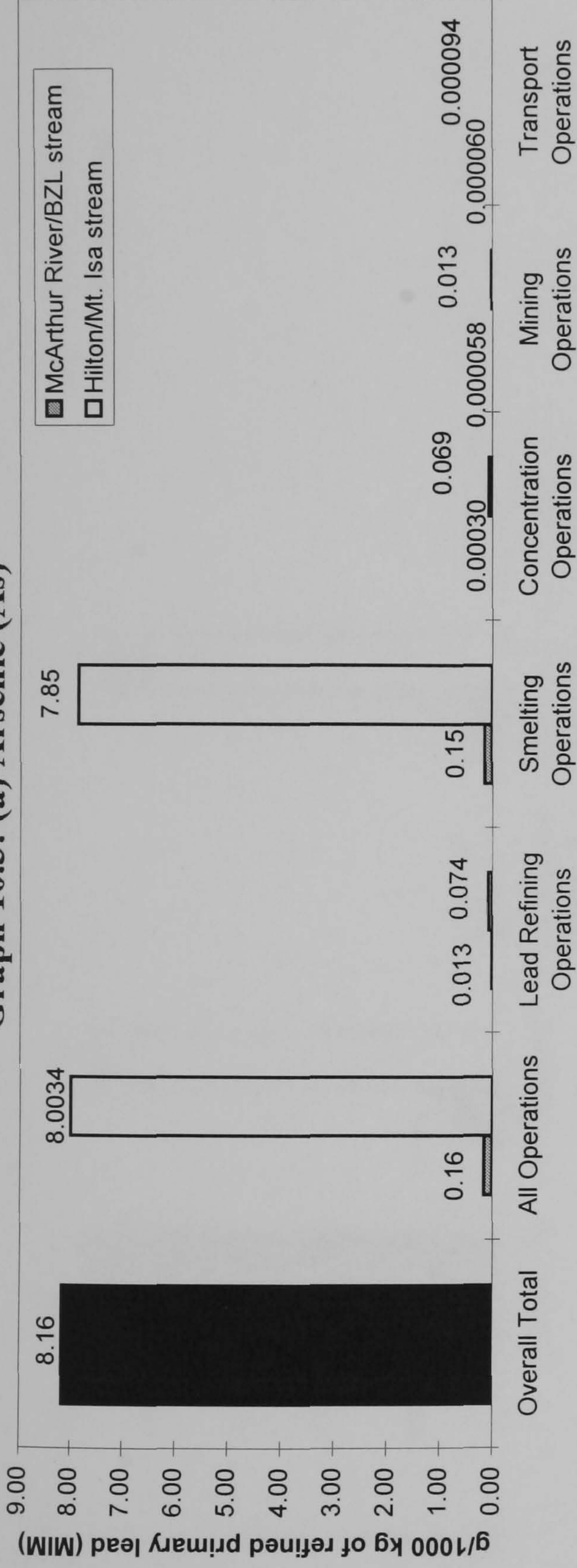


Graph 10.2: (r) Oil (in ground)

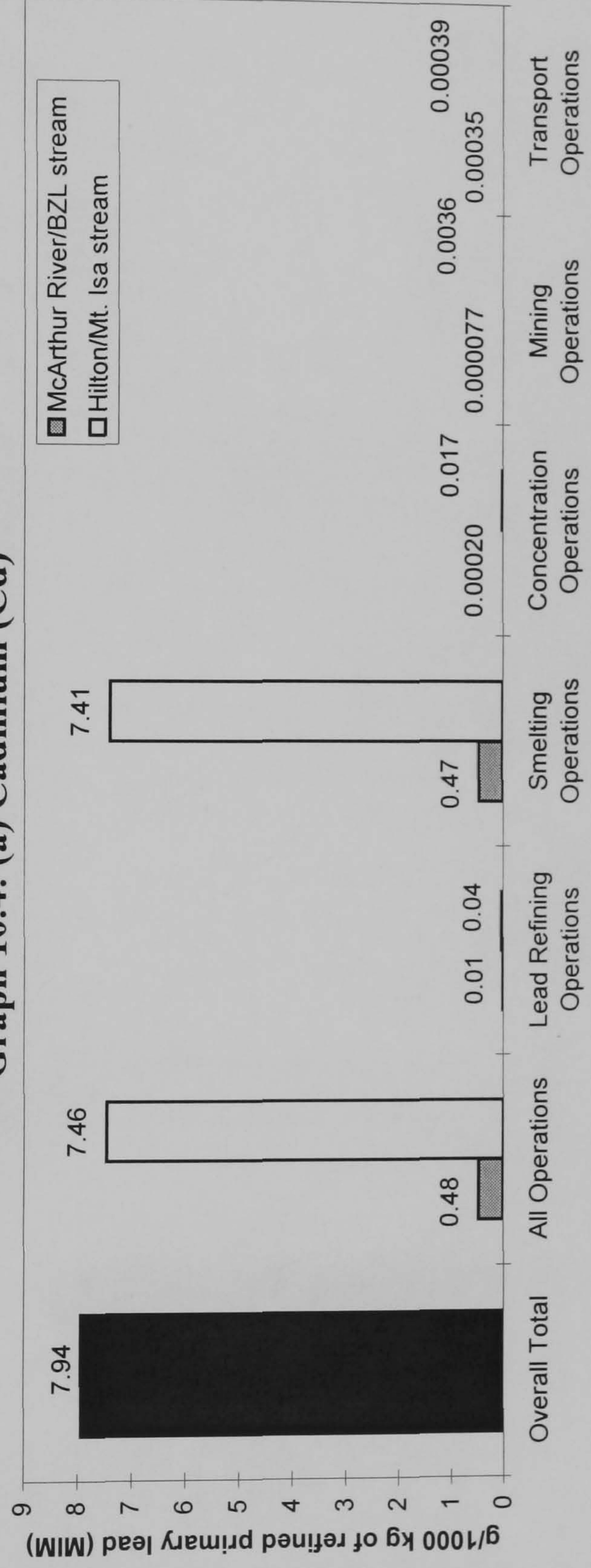


MIM Pb LCA (allocated)

Graph 10.3: (a) Arsenic (As)

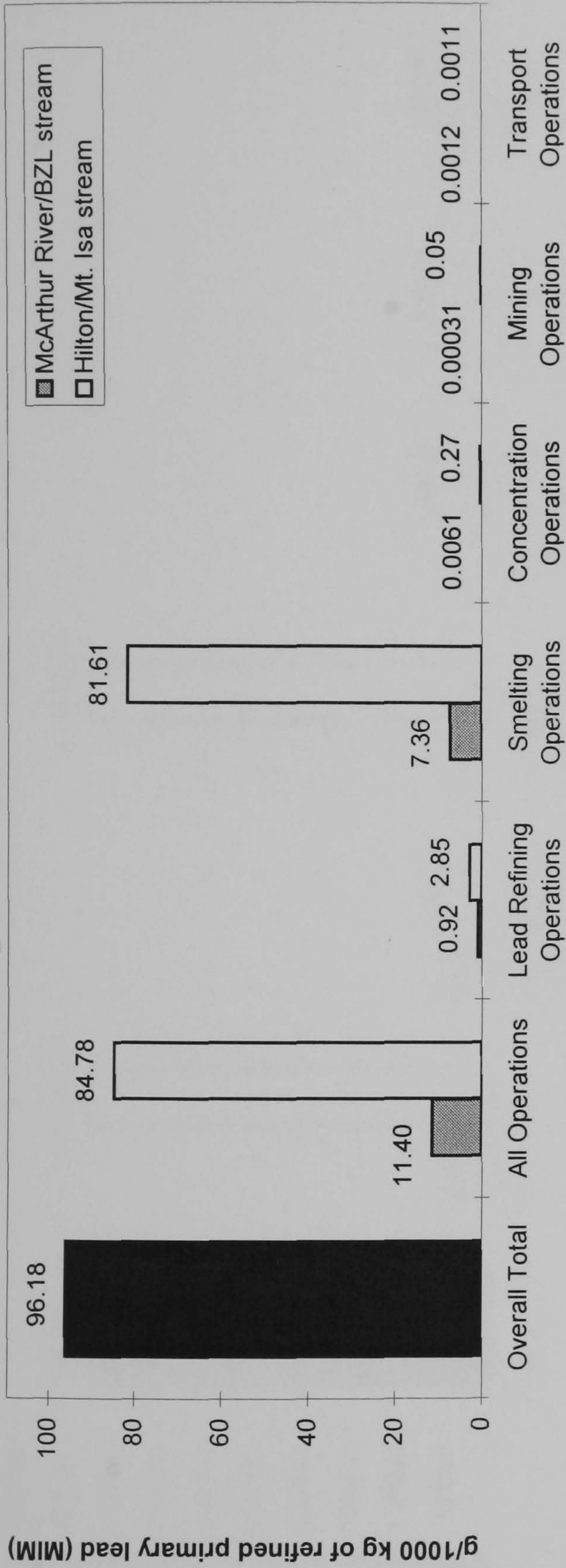


Graph 10.4: (a) Cadmium (Cd)

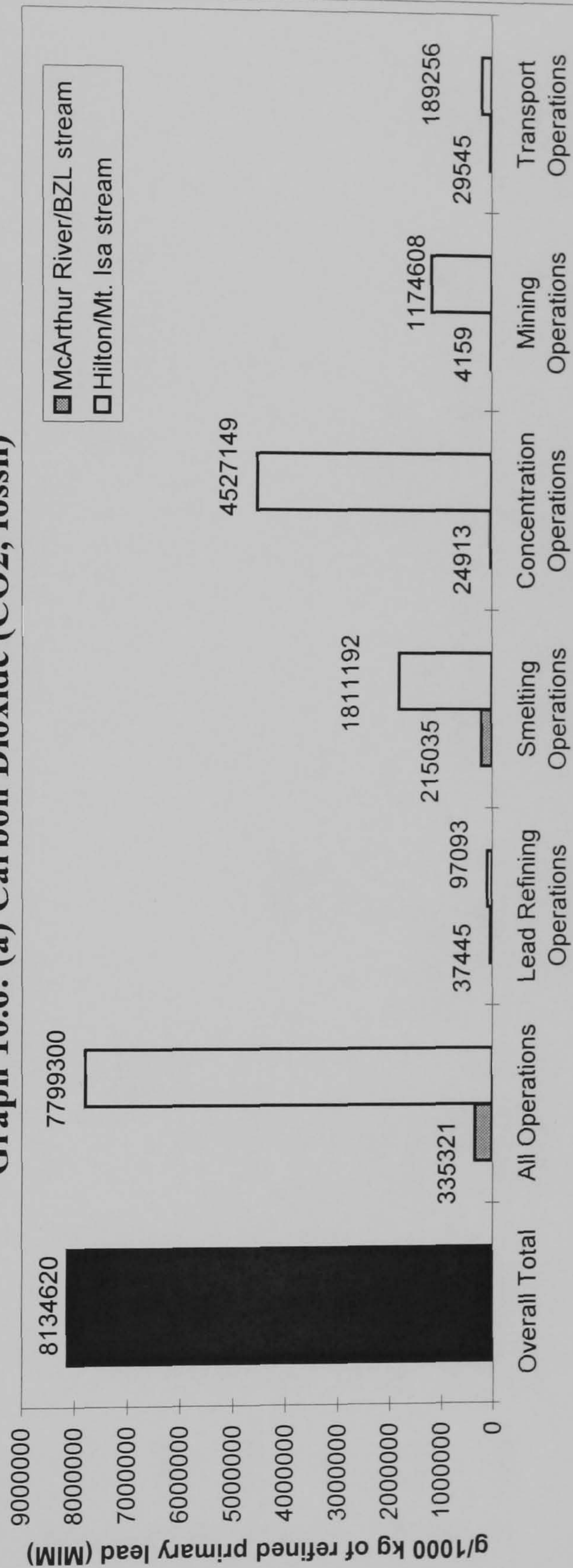


MIM Pb LCA (allocated)

Graph 10.5: (a) Lead (Pb)

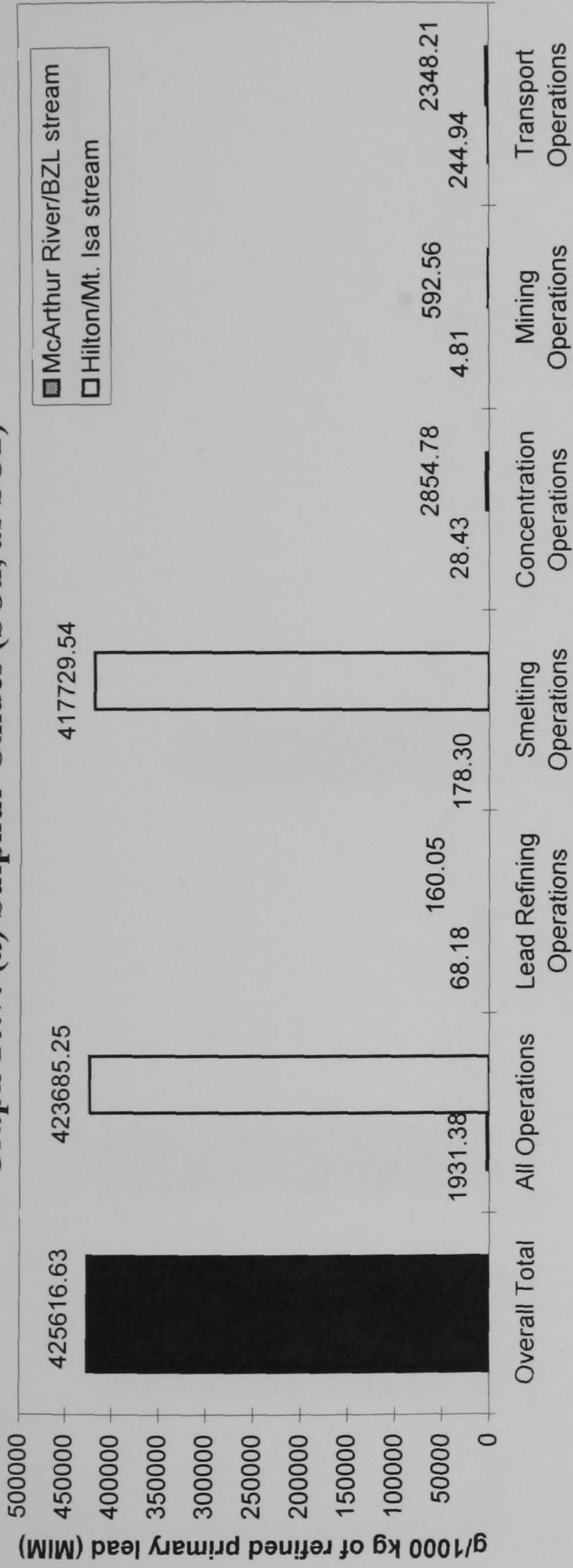


Graph 10.6: (a) Carbon Dioxide (CO2, fossil)

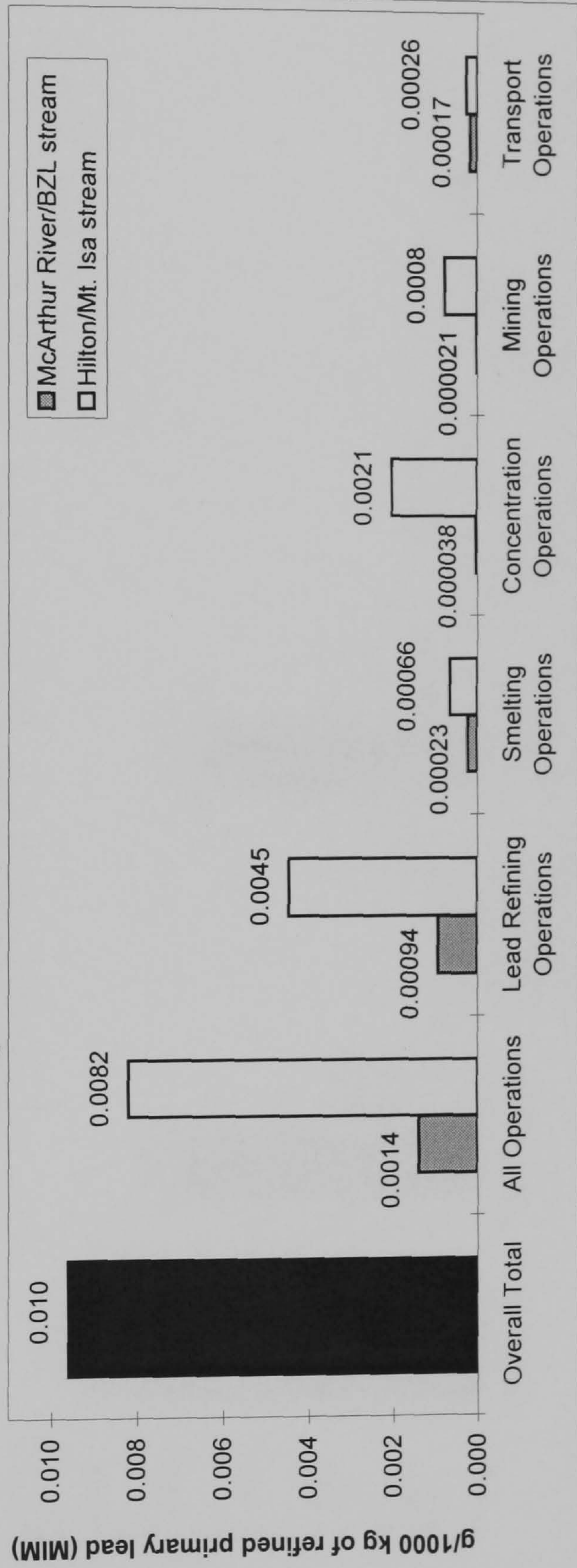


MIM Pb LCA (allocated)

Graph 10.7: (a) Sulphur Oxides (SOx, as SO2)

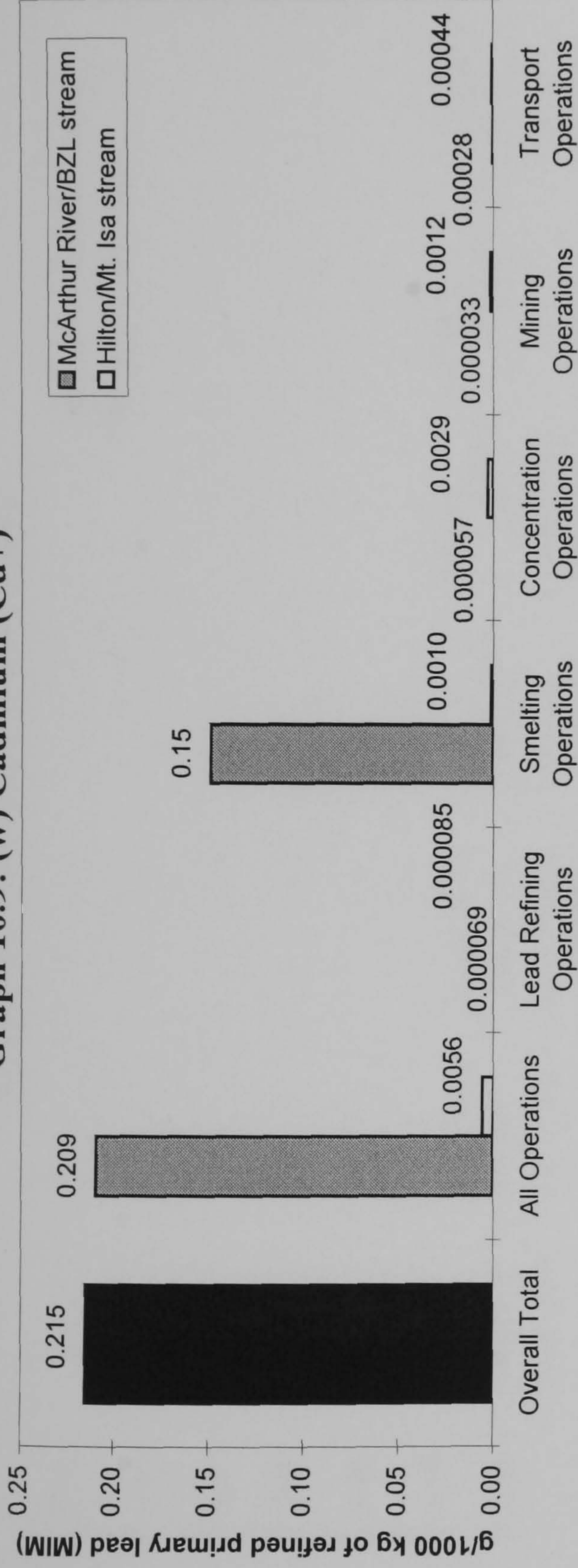


Graph 10.8: (w) Arsenic (As3+, As5+)

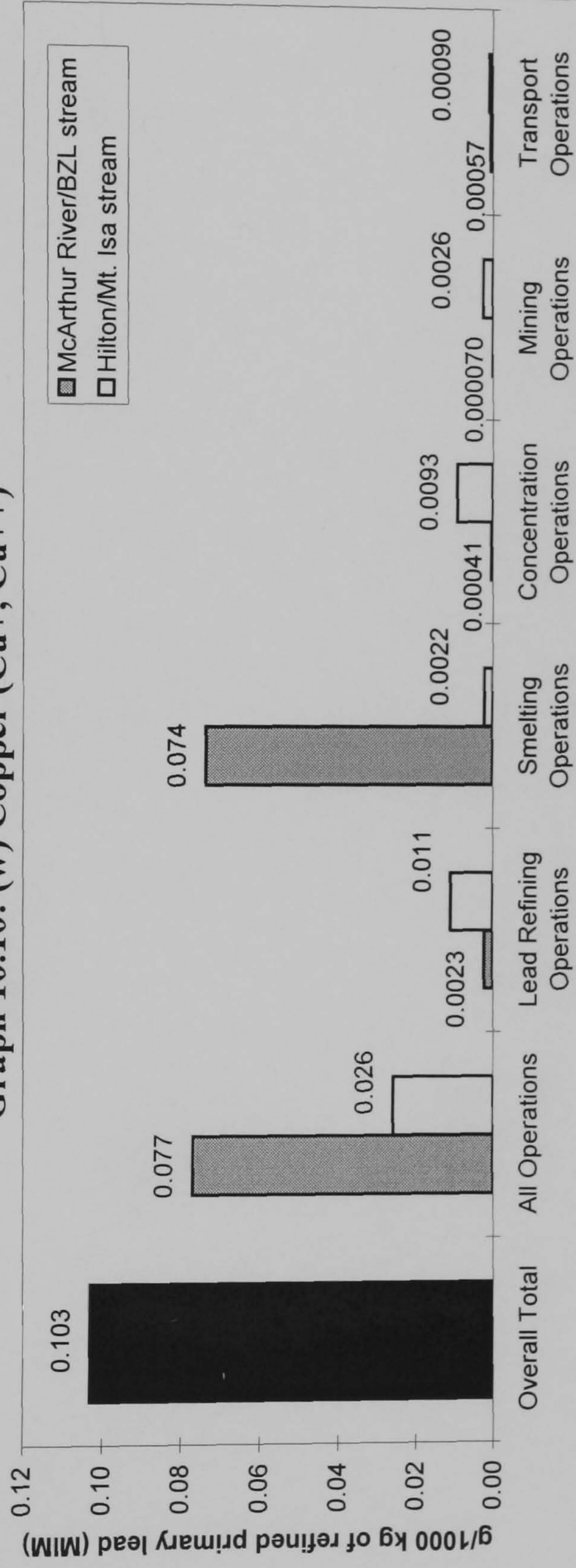


MIM Pb LCA (allocated)

Graph 10.9: (w) Cadmium (Cd+)

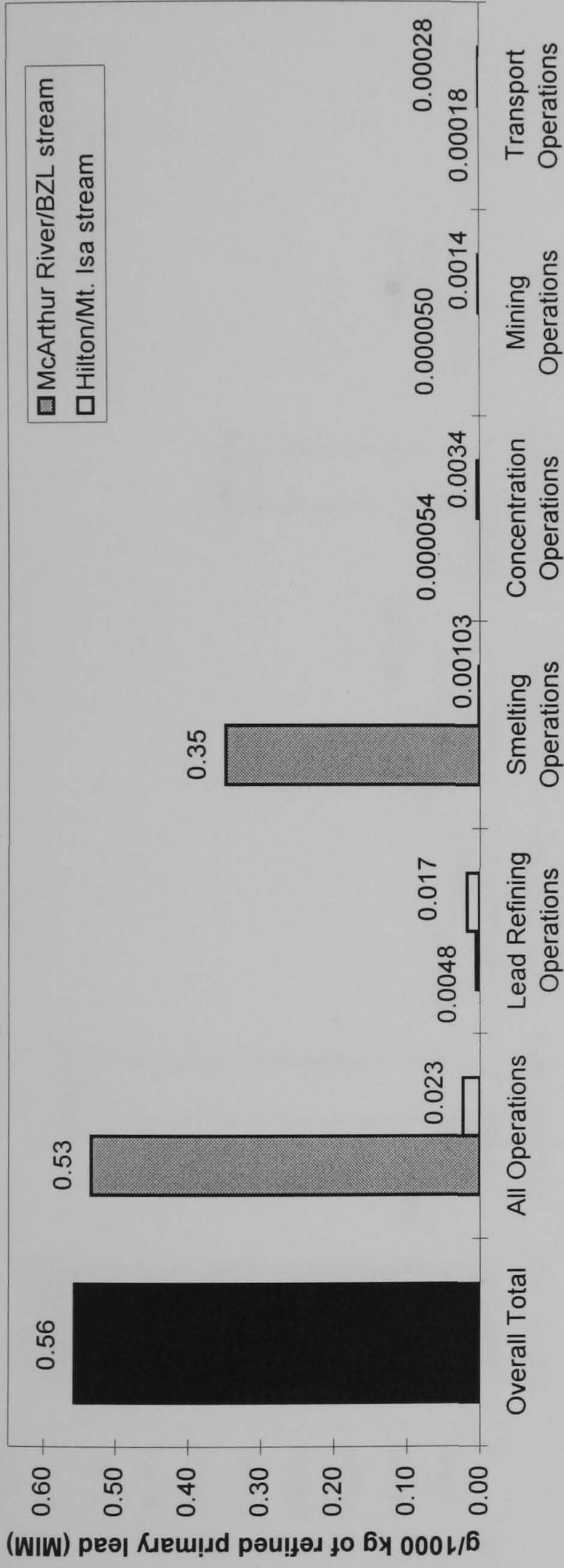


Graph 10.10: (w) Copper (Cu+, Cu++)

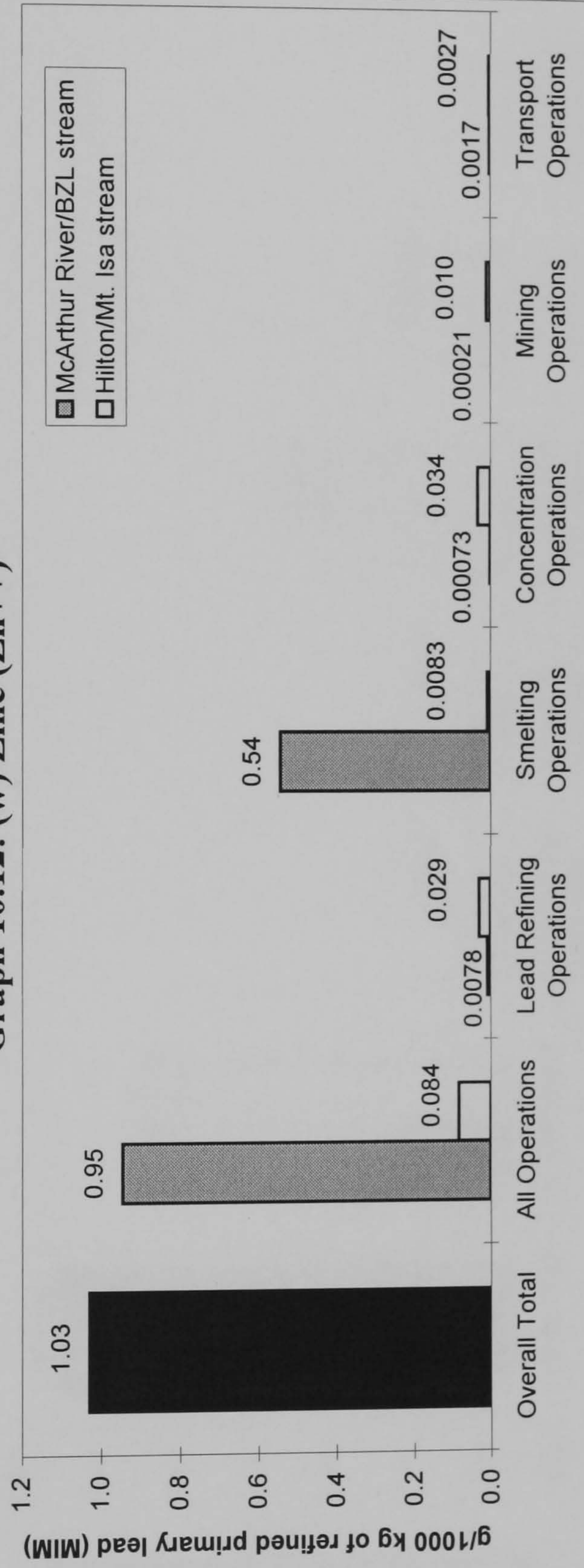


MIM Pb LCA (allocated)

Graph 10.11: (w) Lead (Pb⁺⁺, Pb₄₊)

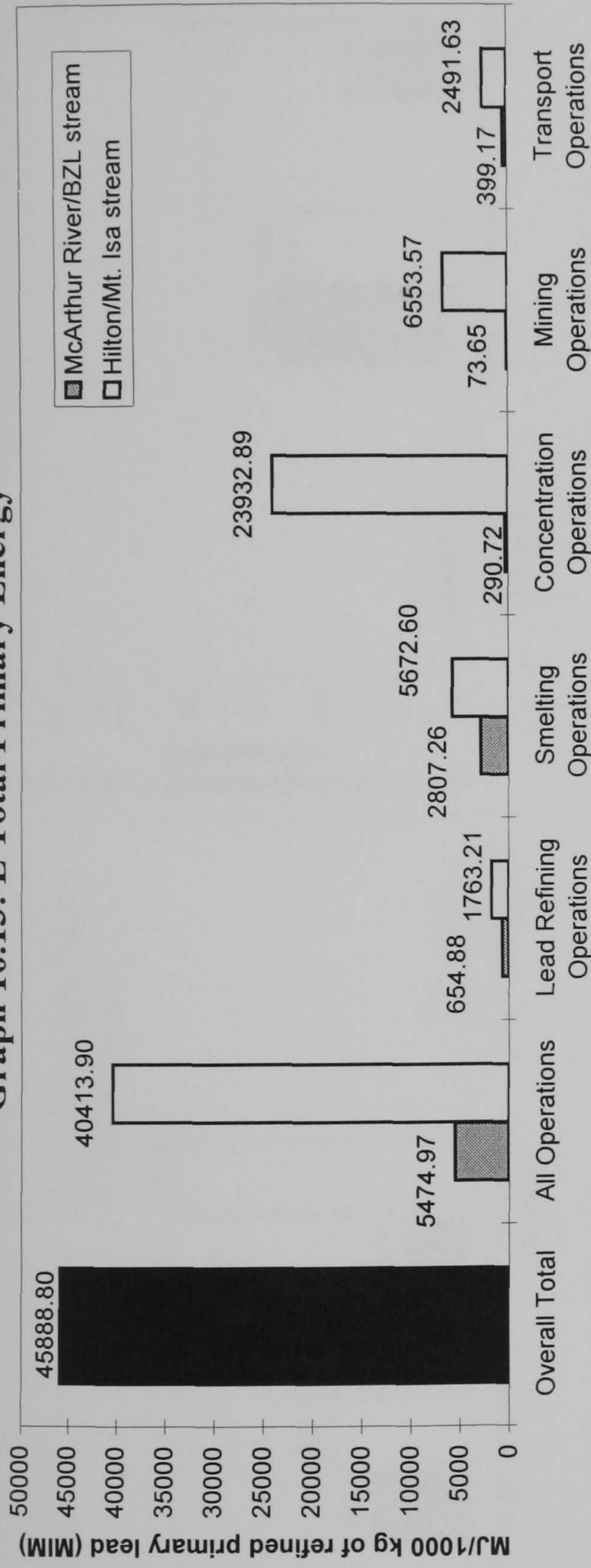


Graph 10.12: (w) Zinc (Zn⁺⁺)

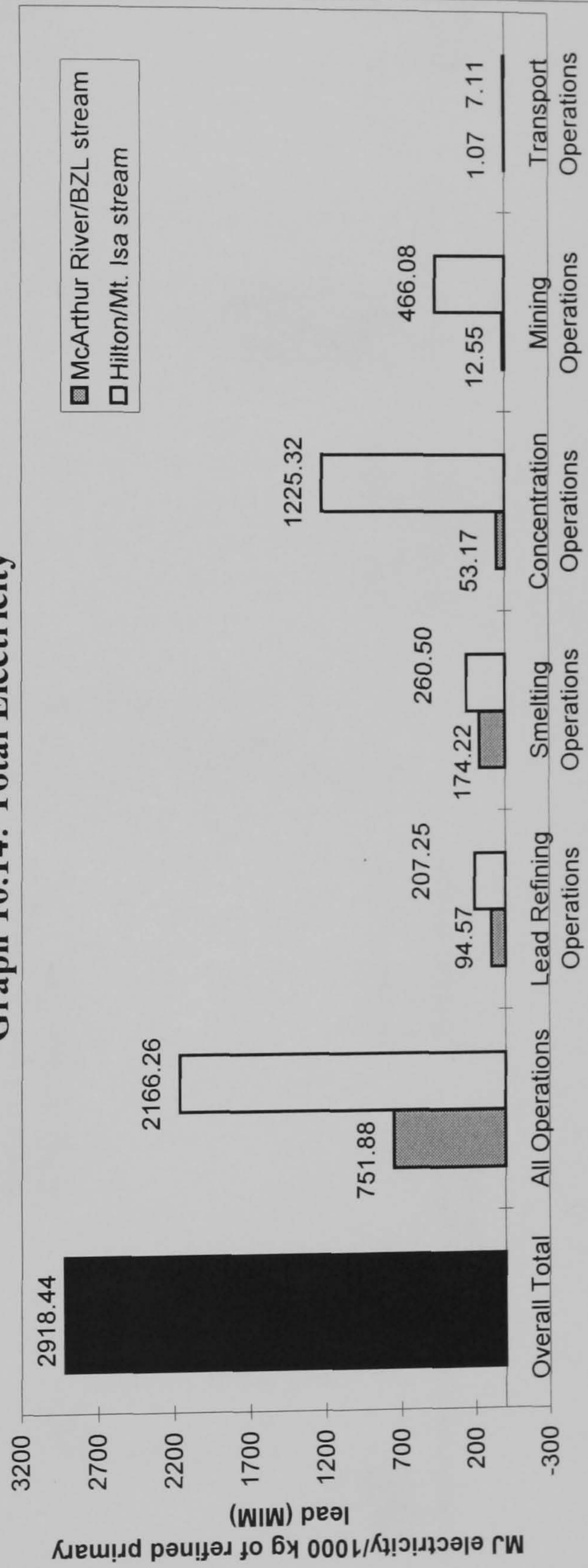


MIM Pb LCA (allocated)

Graph 10.13: E Total Primary Energy

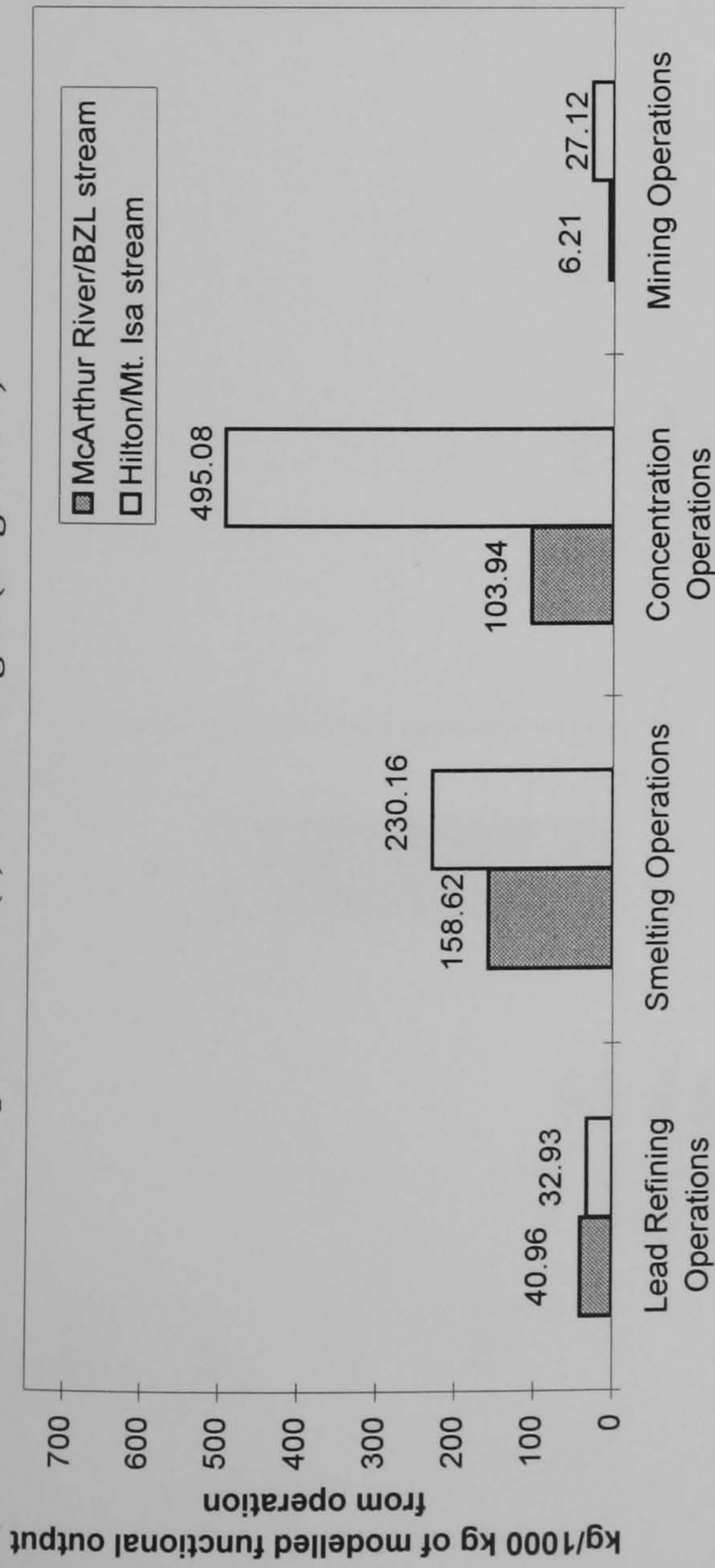


Graph 10.14: Total Electricity

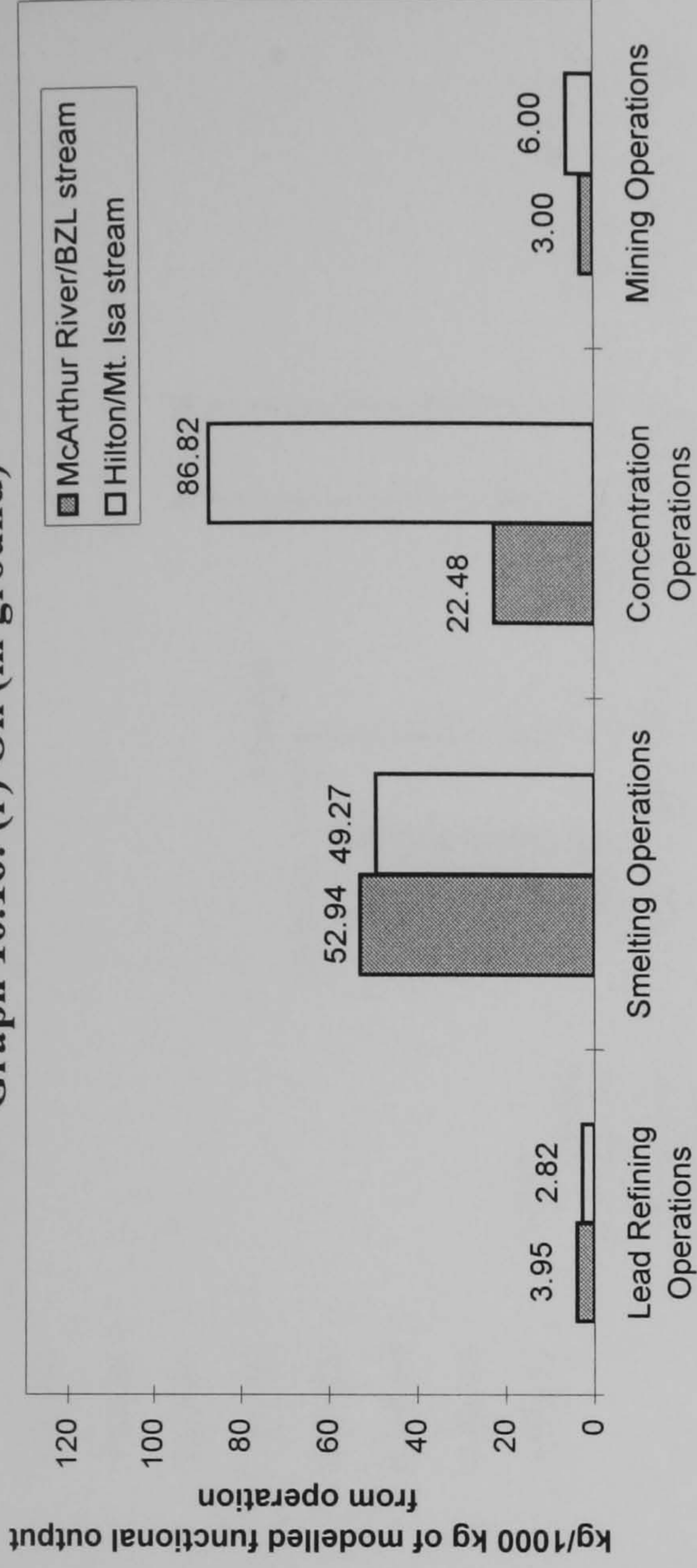


MIM Pb LCA (allocated)

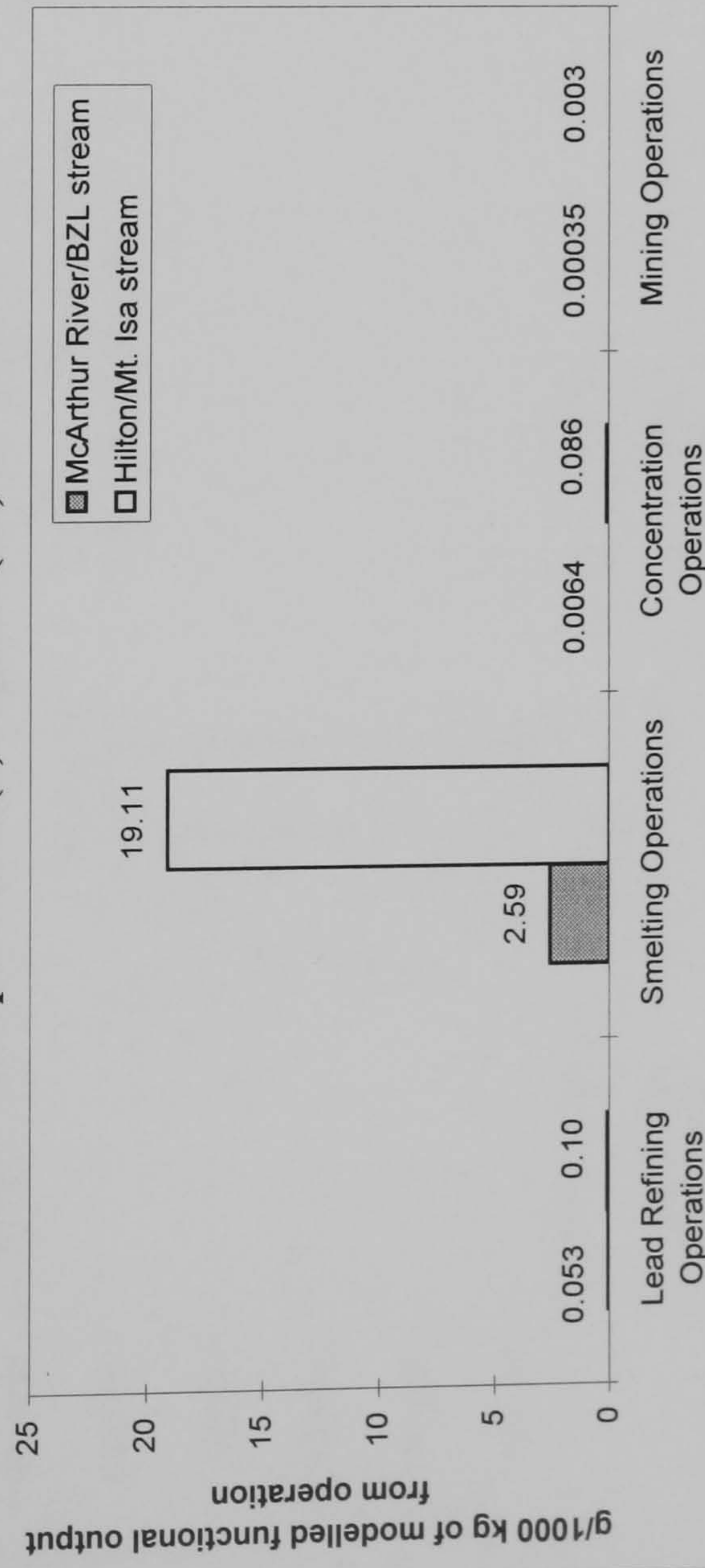
Graph 10.15: (r) Natural gas (in ground)



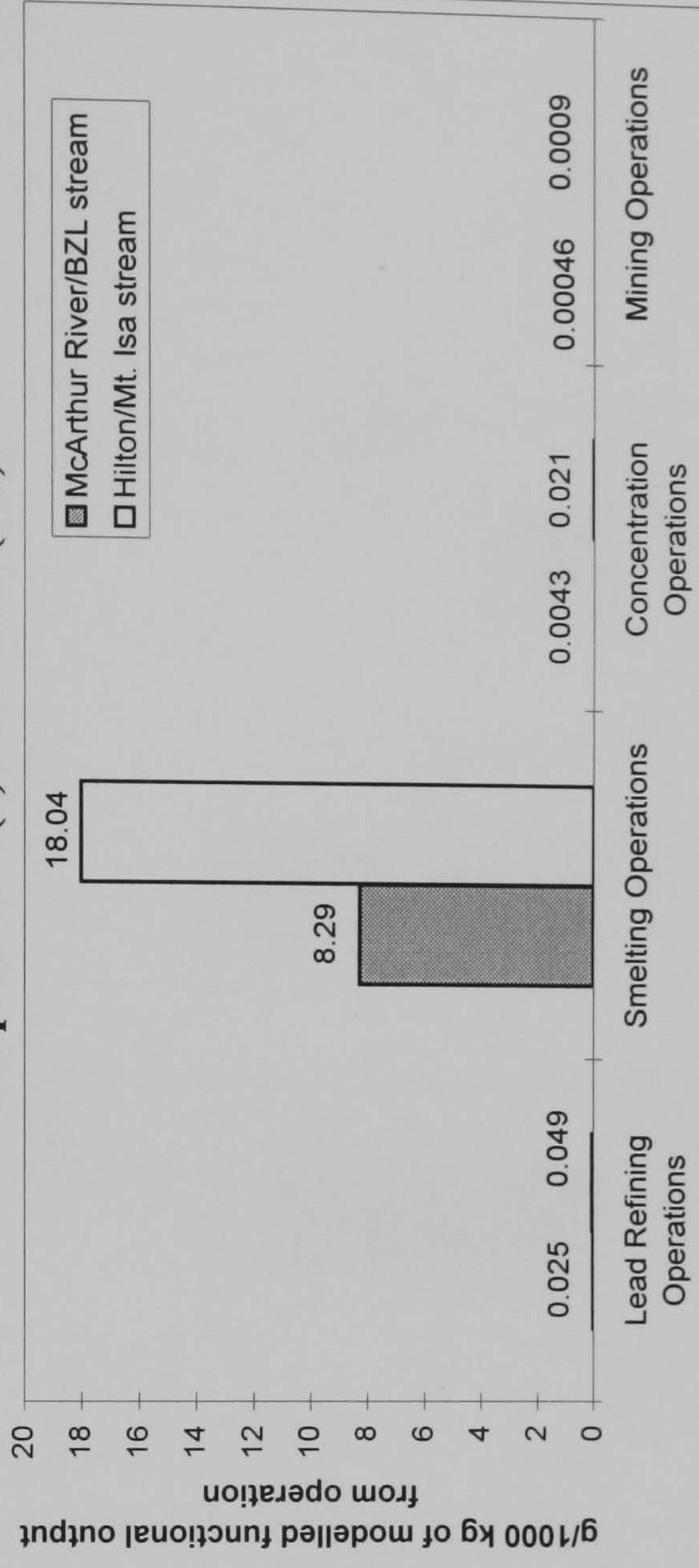
Graph 10.16: (r) Oil (in ground)



Graph 10.17: (a) Arsenic (As)

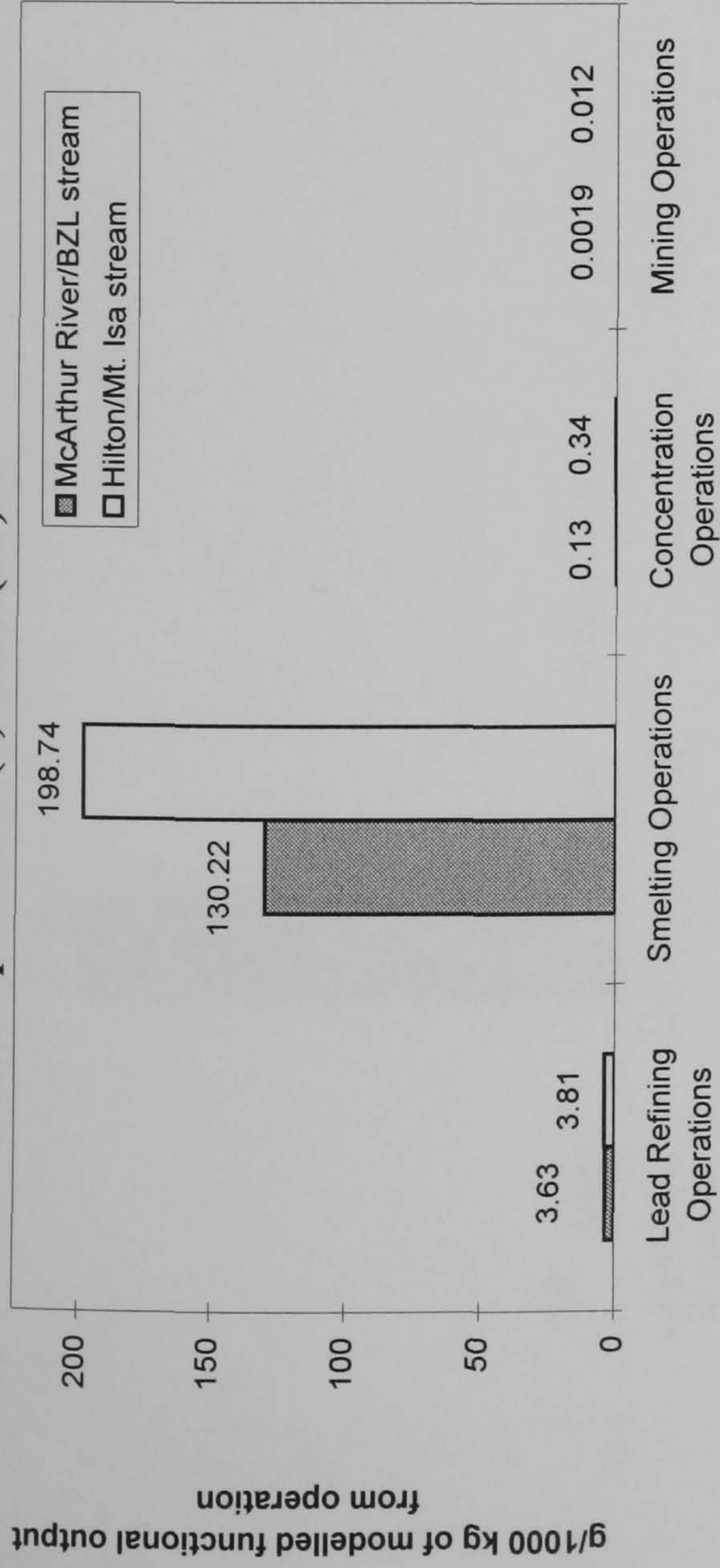


Graph 10.18: (a) Cadmium (Cd)

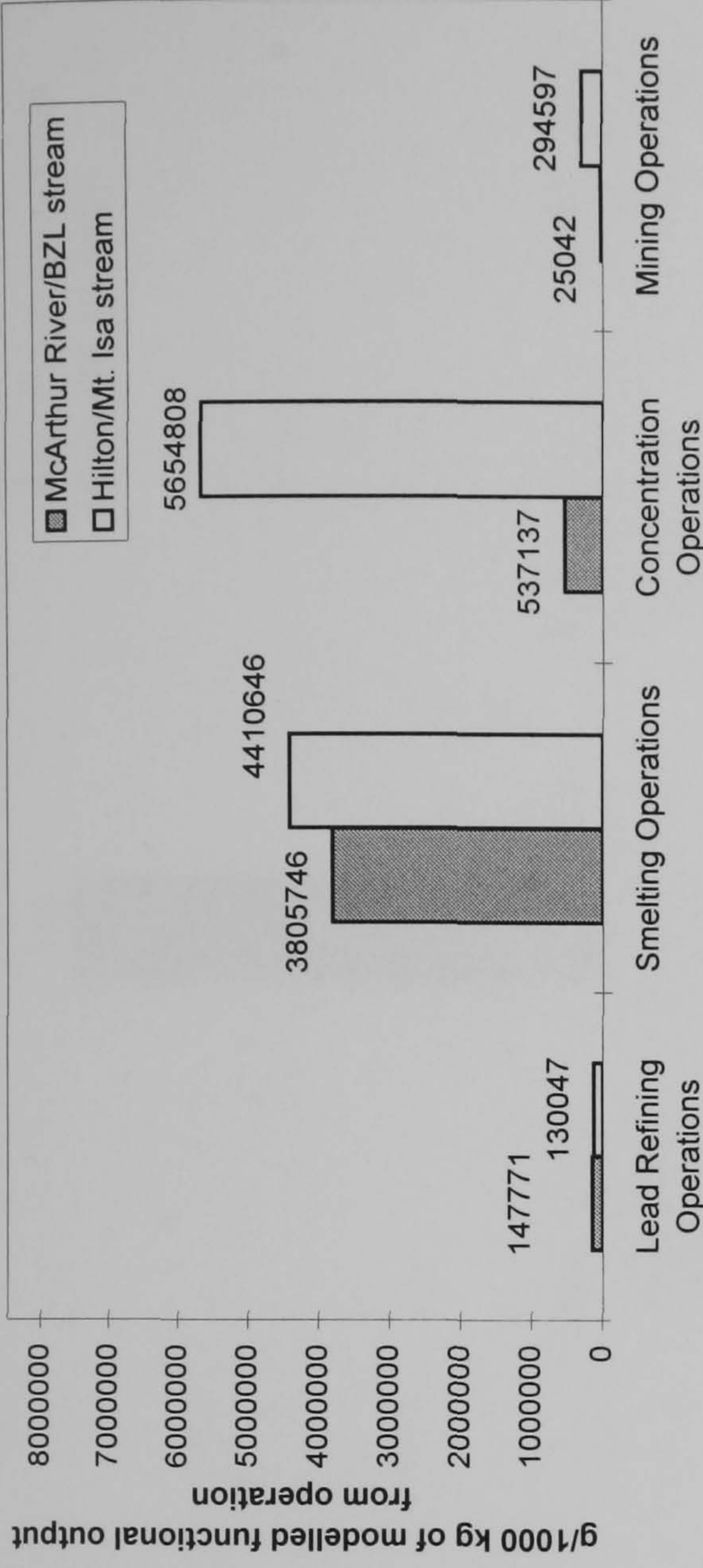


MIM Pb LCA (allocated)

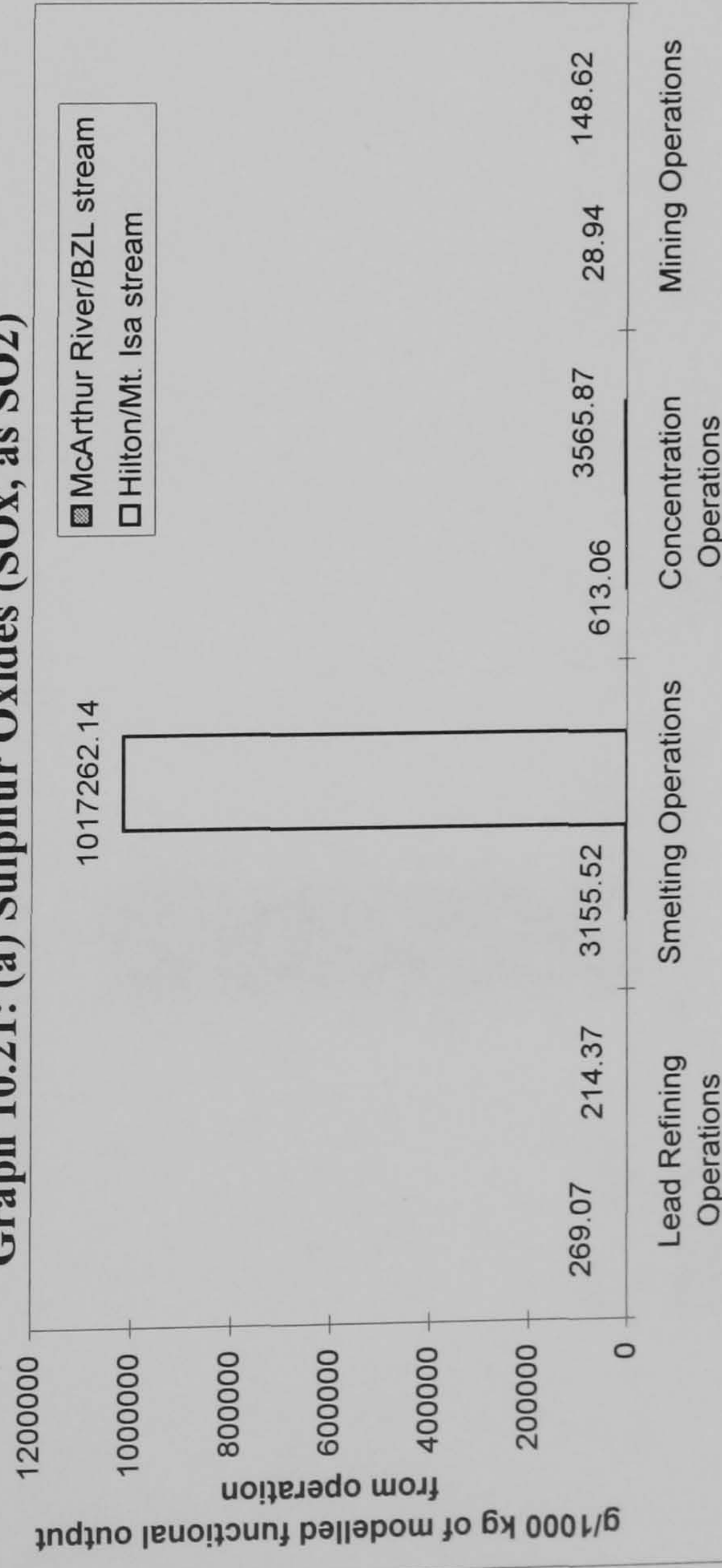
Graph 10.19: (a) Lead (Pb)



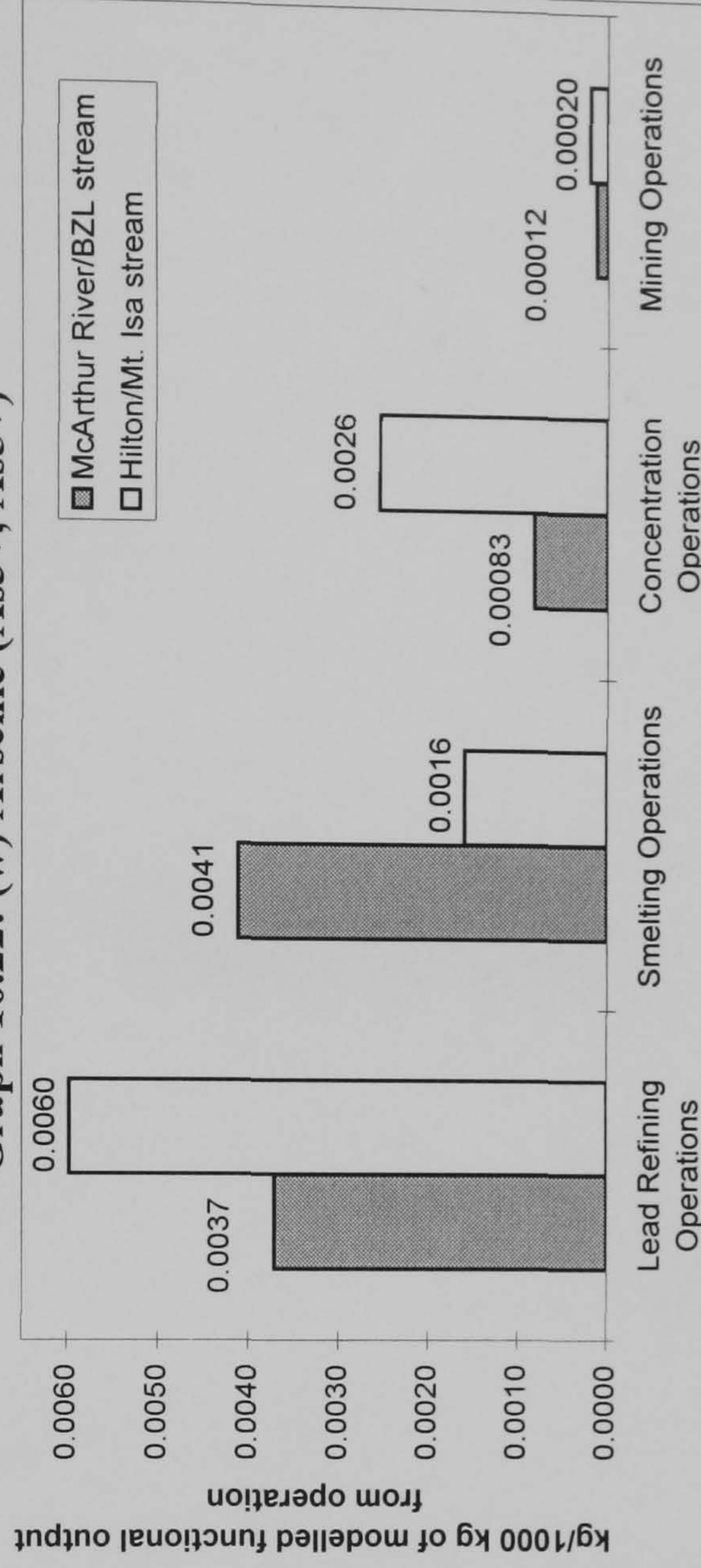
Graph 10.20: (a) Carbon Dioxide (CO₂, fossil)



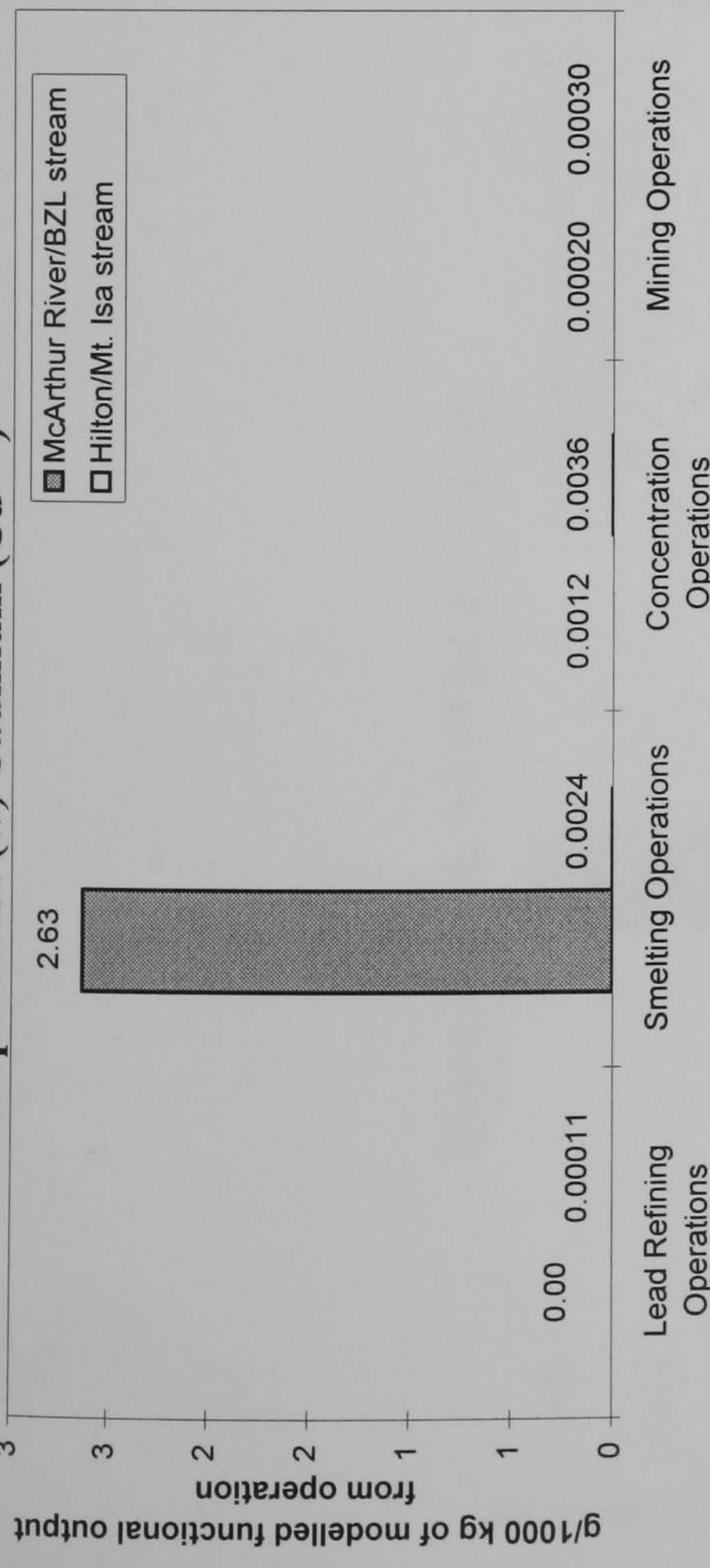
Graph 10.21: (a) Sulphur Oxides (SO_x, as SO₂)



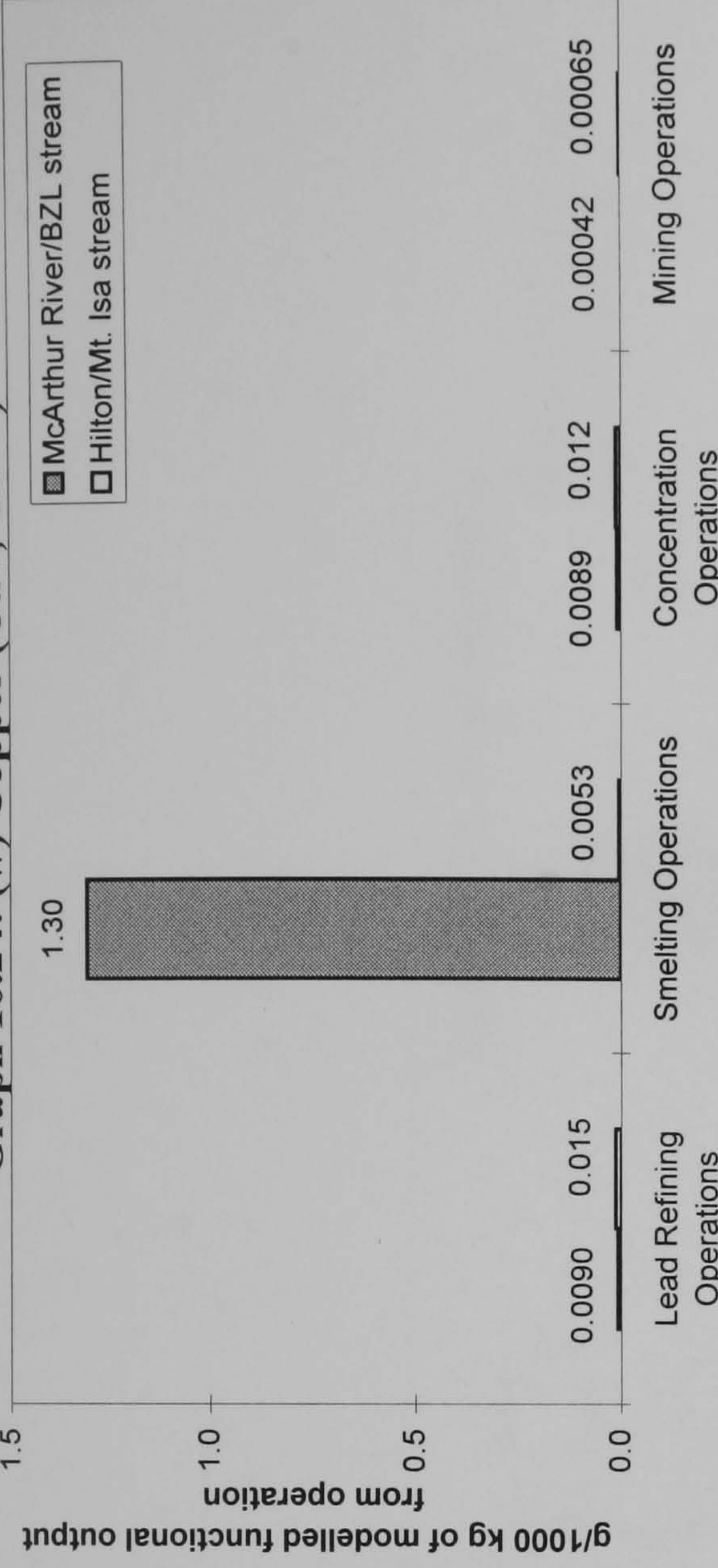
Graph 10.22: (w) Arsenic (As₃₊, As₅₊)



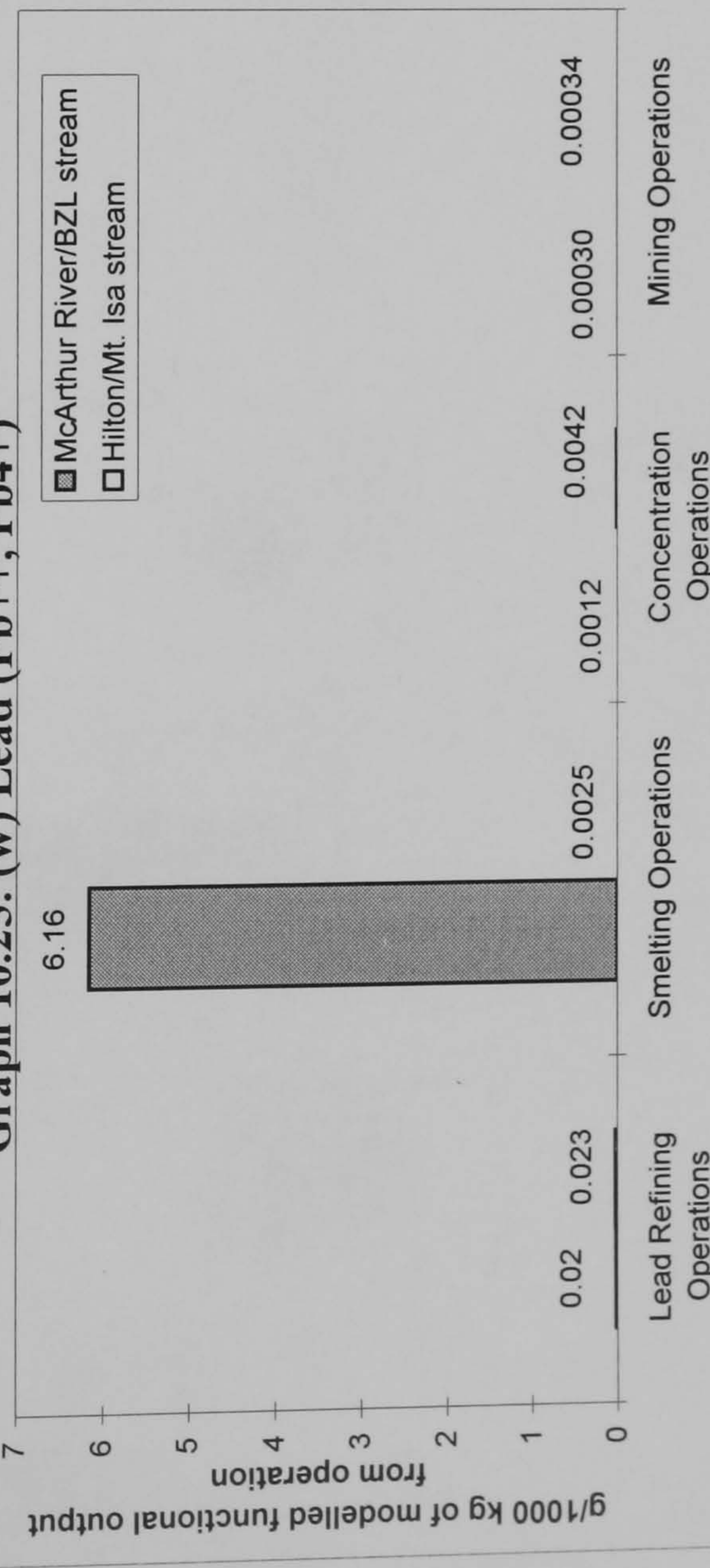
Graph 10.23: (w) Cadmium (Cd++)



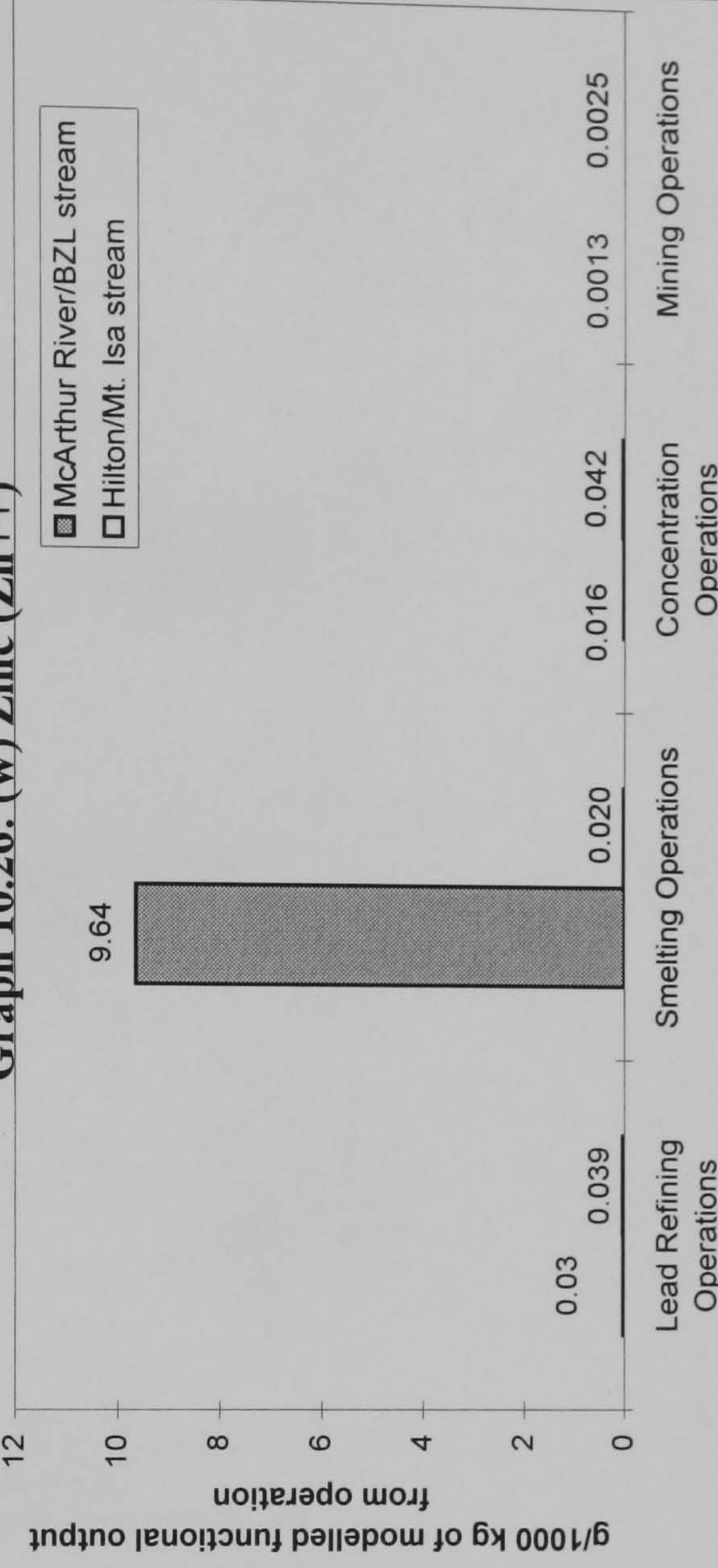
Graph 10.24: (w) Copper (Cu+, Cu++)



Graph 10.25: (w) Lead (Pb++, Pb4+)

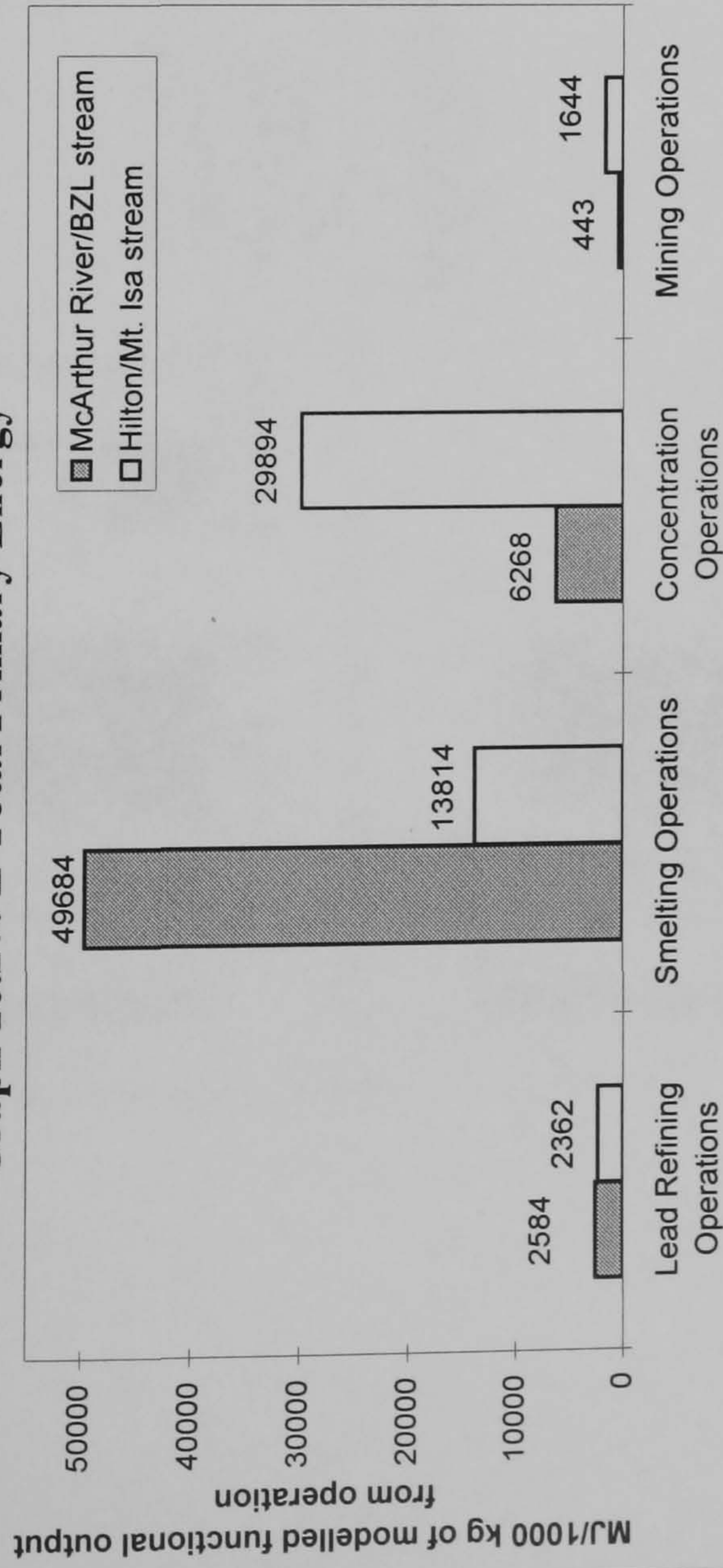


Graph 10.26: (w) Zinc (Zn++)

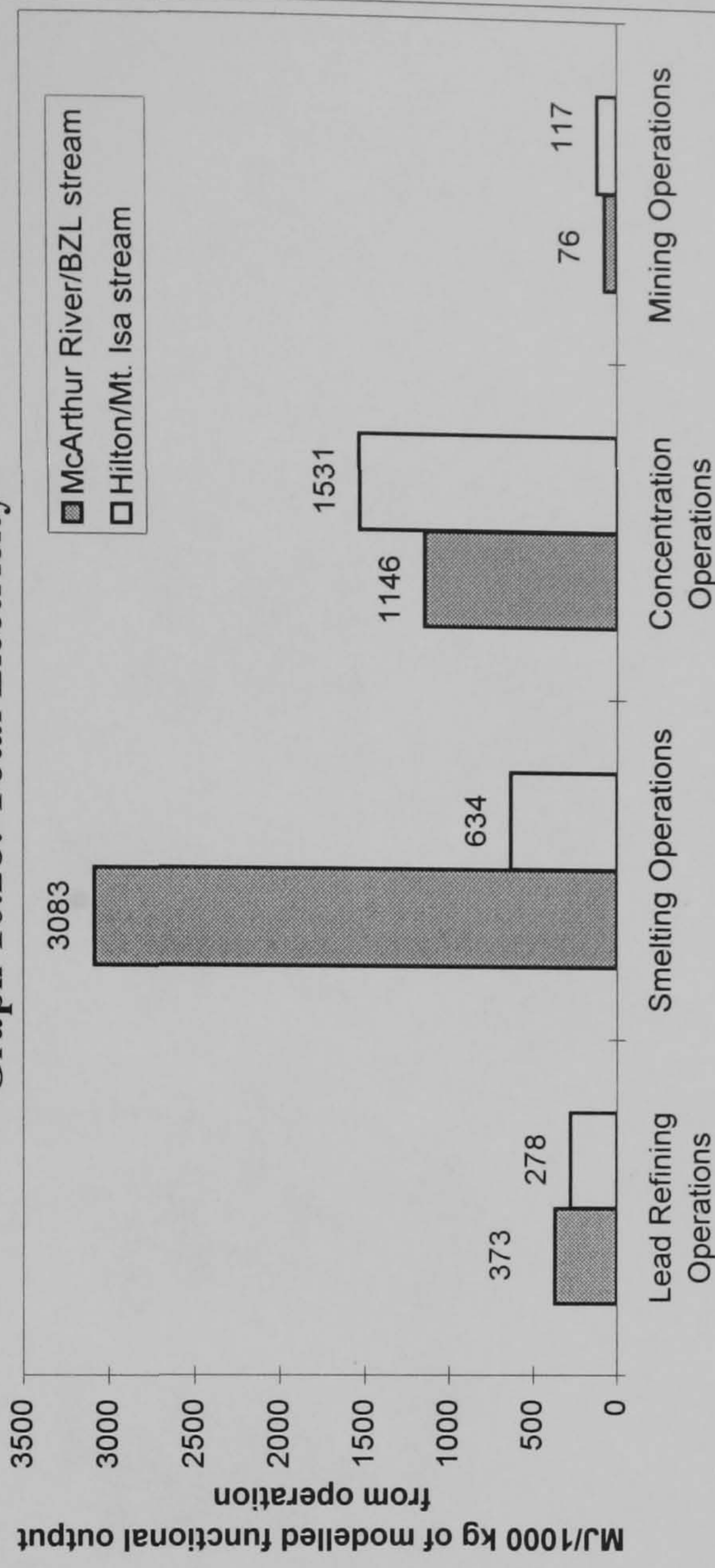


MIM Pb LCA (allocated)

Graph 10.27: E Total Primary Energy

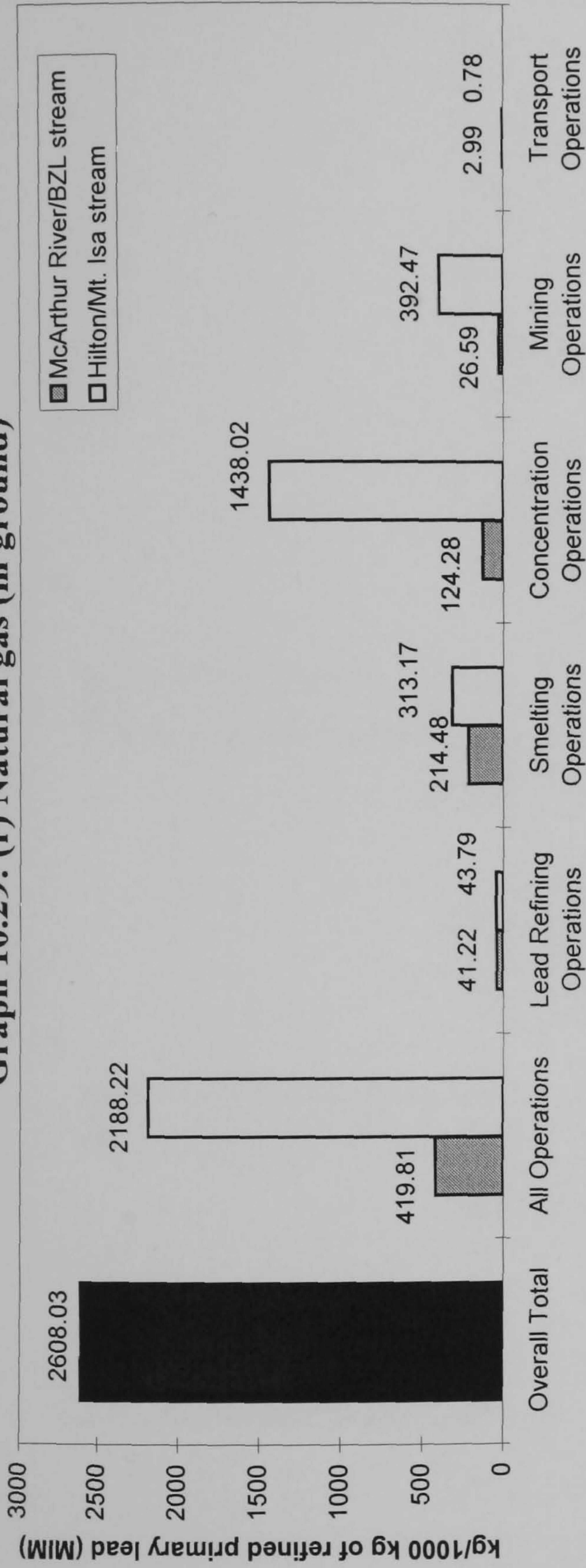


Graph 10.28: Total Electricity

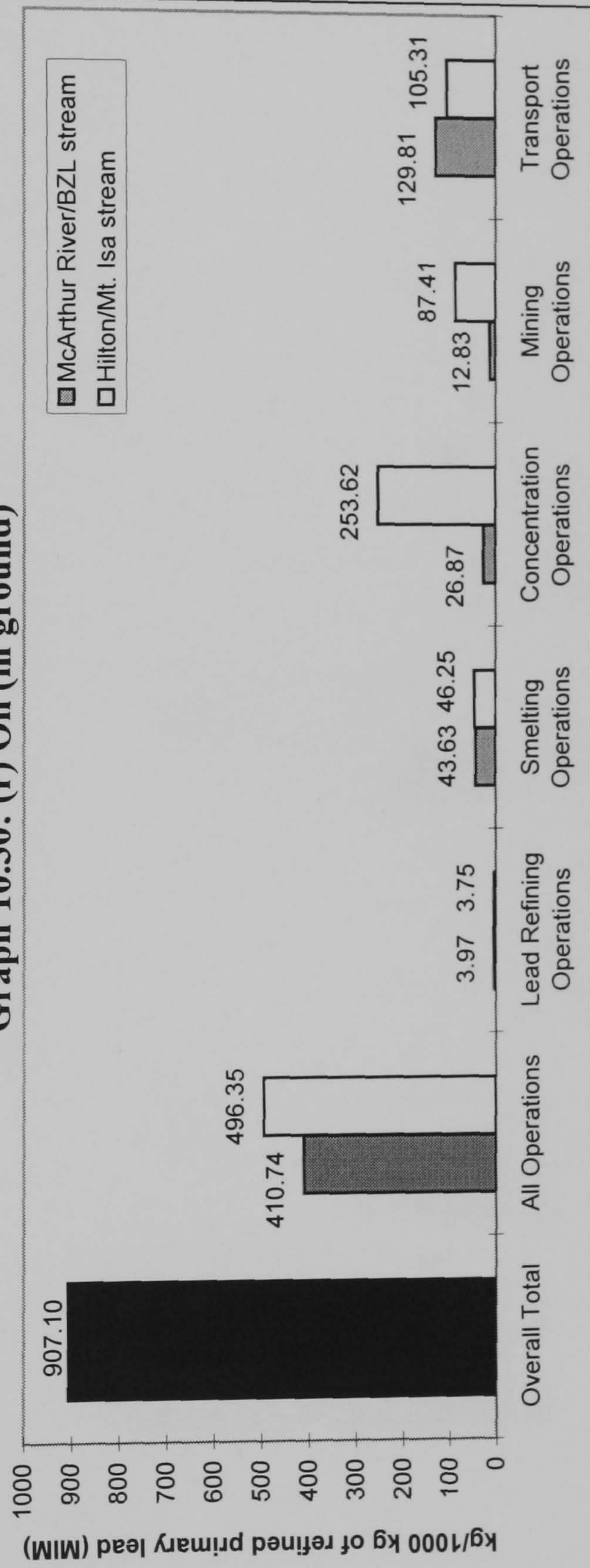


MIM Pb LCA (allocated)

Graph 10.29: (r) Natural gas (in ground)

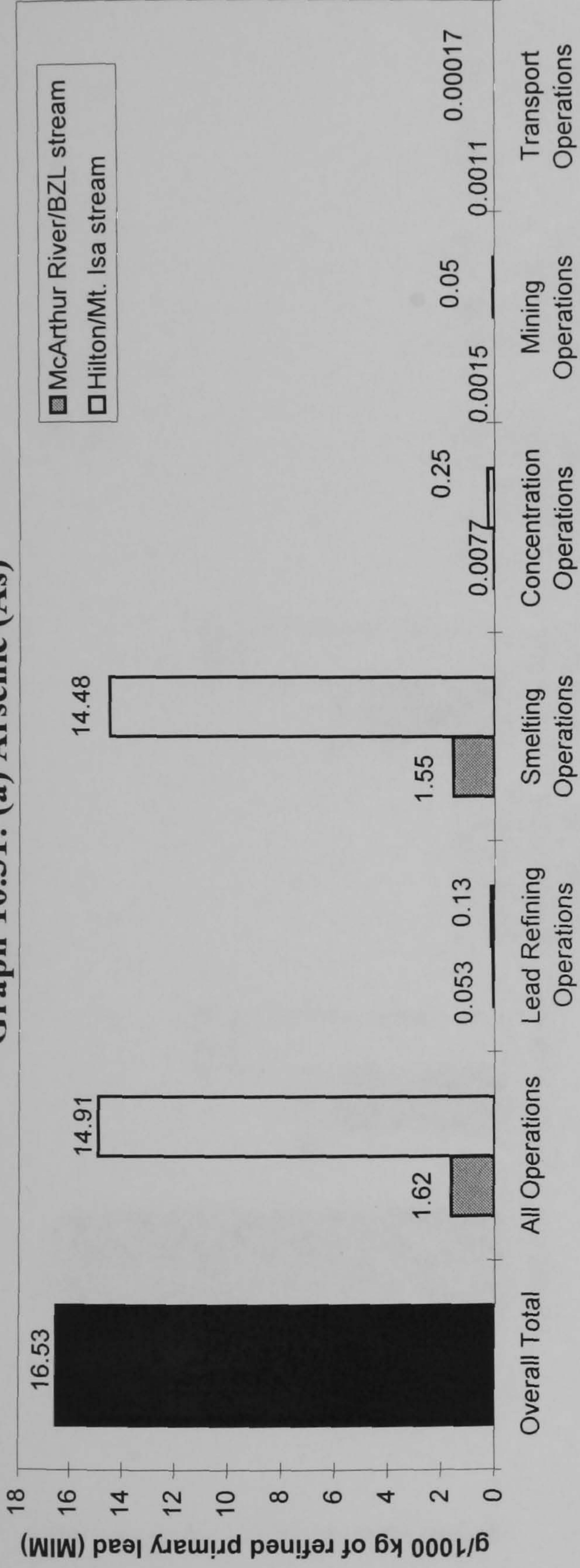


Graph 10.30: (r) Oil (in ground)

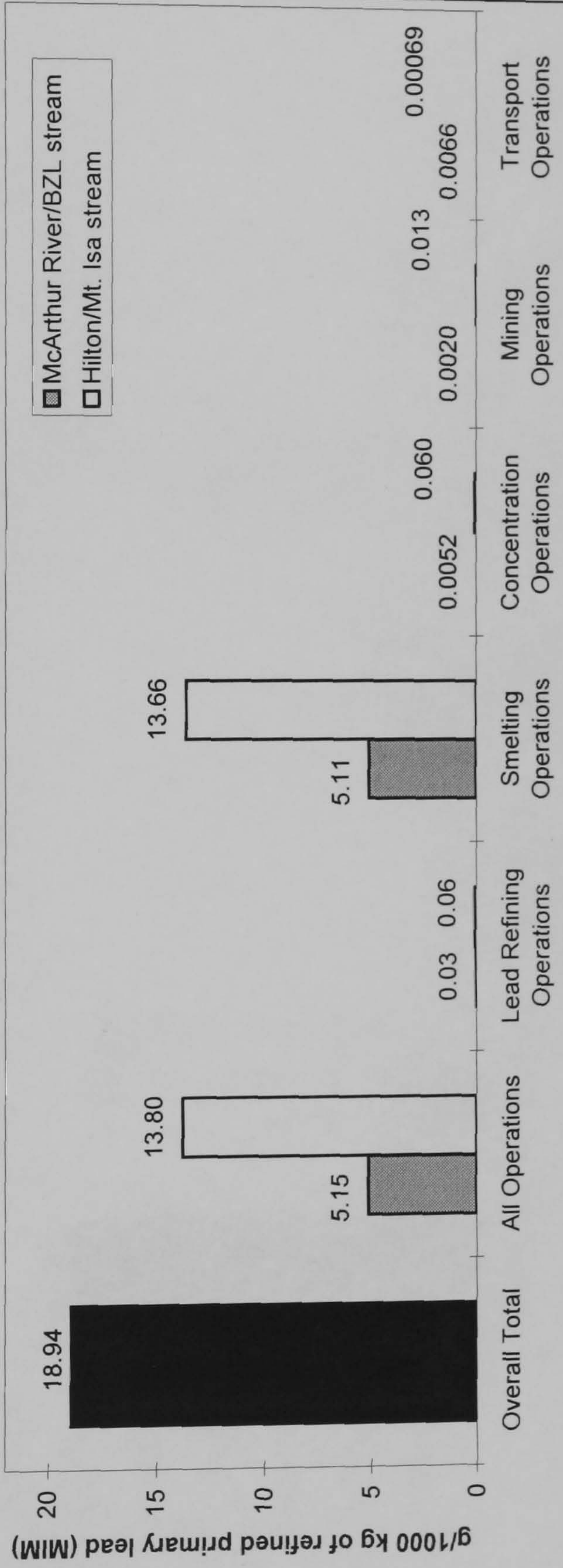


MIM Pb LCA (unallocated)

Graph 10.31: (a) Arsenic (As)

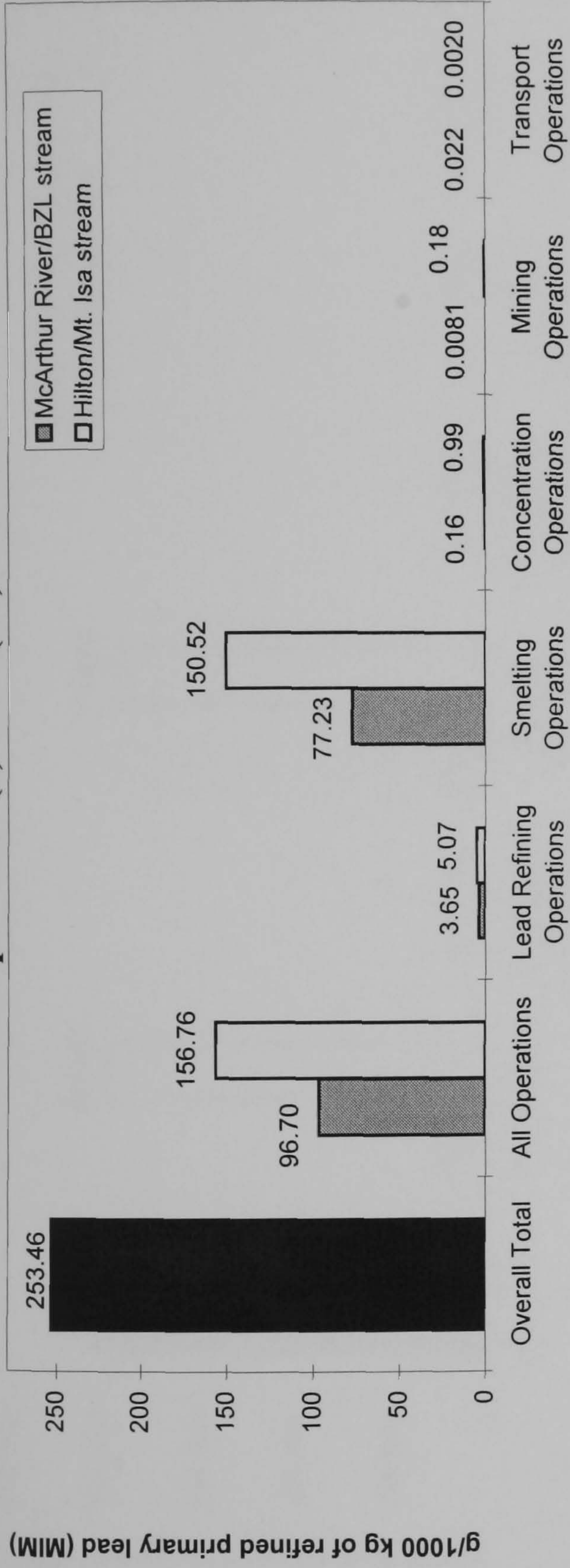


Graph 10.32: (a) Cadmium (Cd)

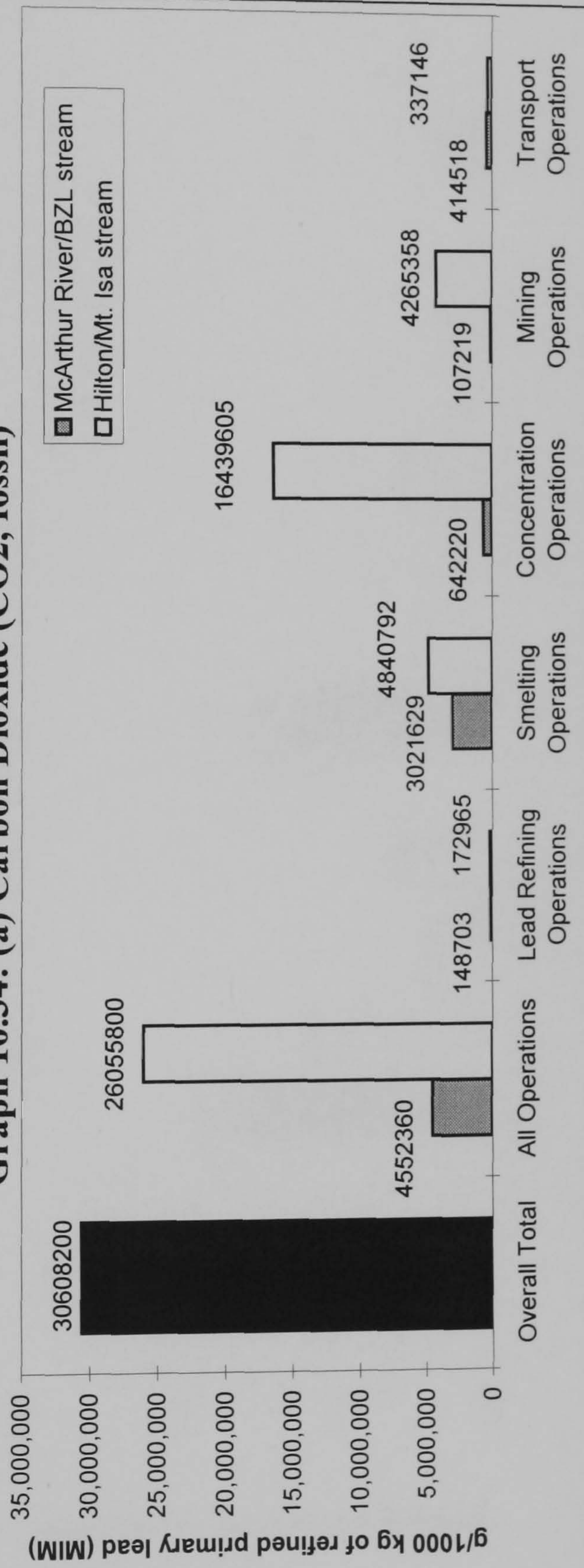


MIM Pb LCA (unallocated)

Graph 10.33: (a) Lead (Pb)

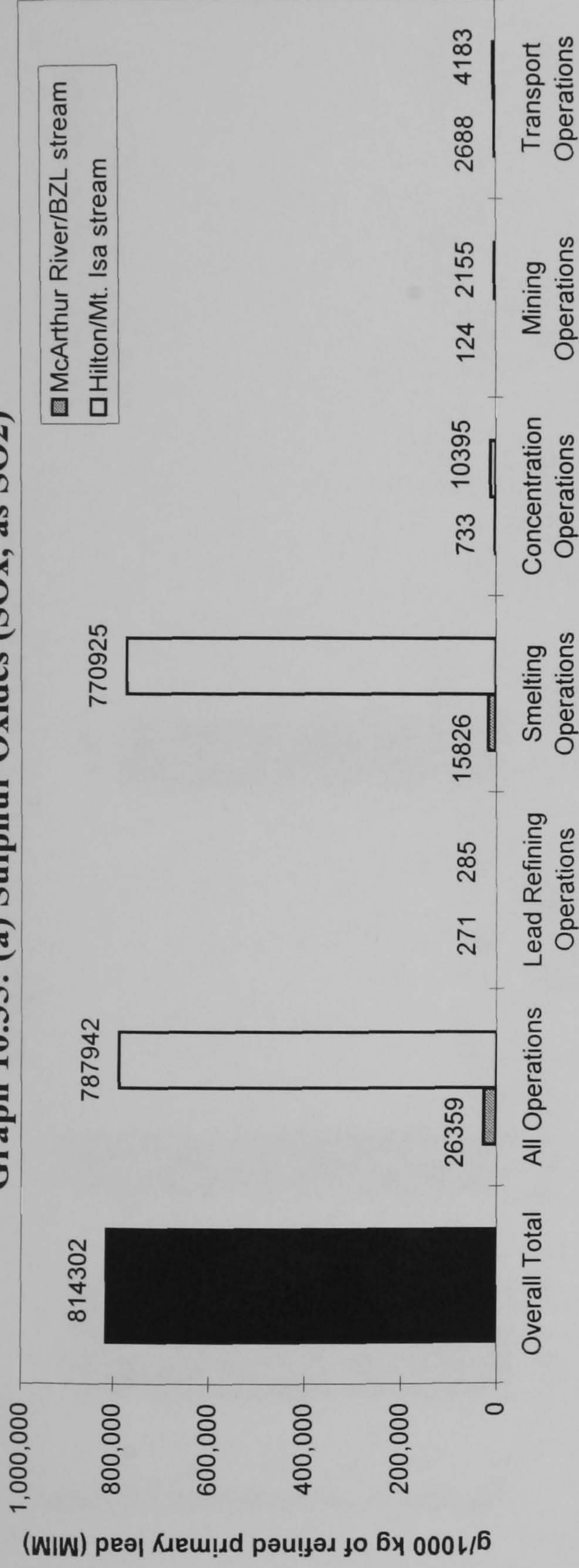


Graph 10.34: (a) Carbon Dioxide (CO2, fossil)

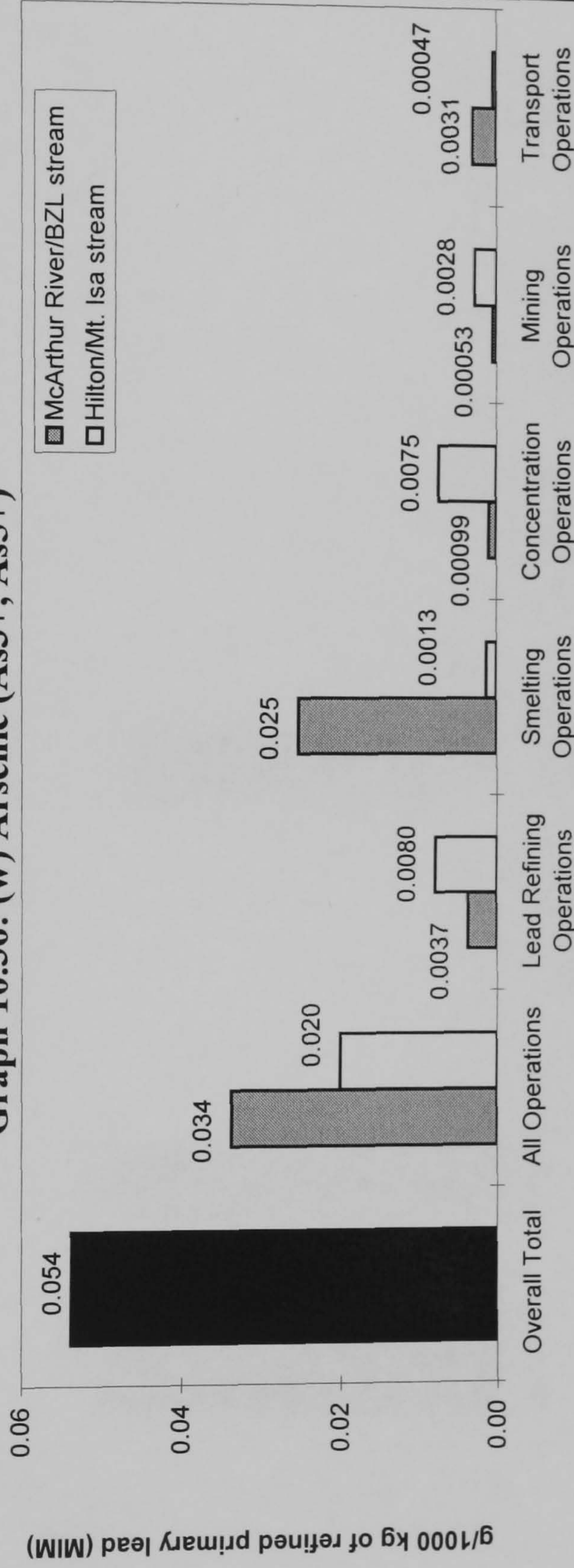


MIM Pb LCA (unallocated)

Graph 10.35: (a) Sulphur Oxides (SO_x, as SO₂)

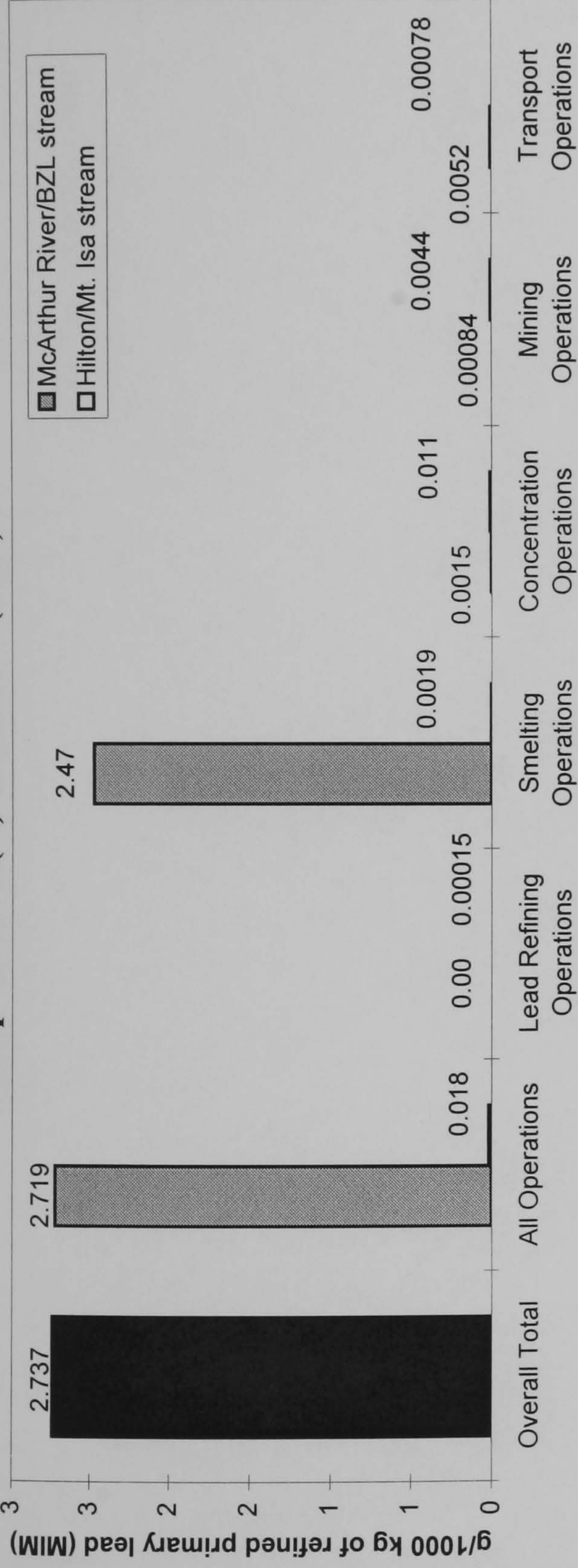


Graph 10.36: (w) Arsenic (As₃₊, As₅₊)

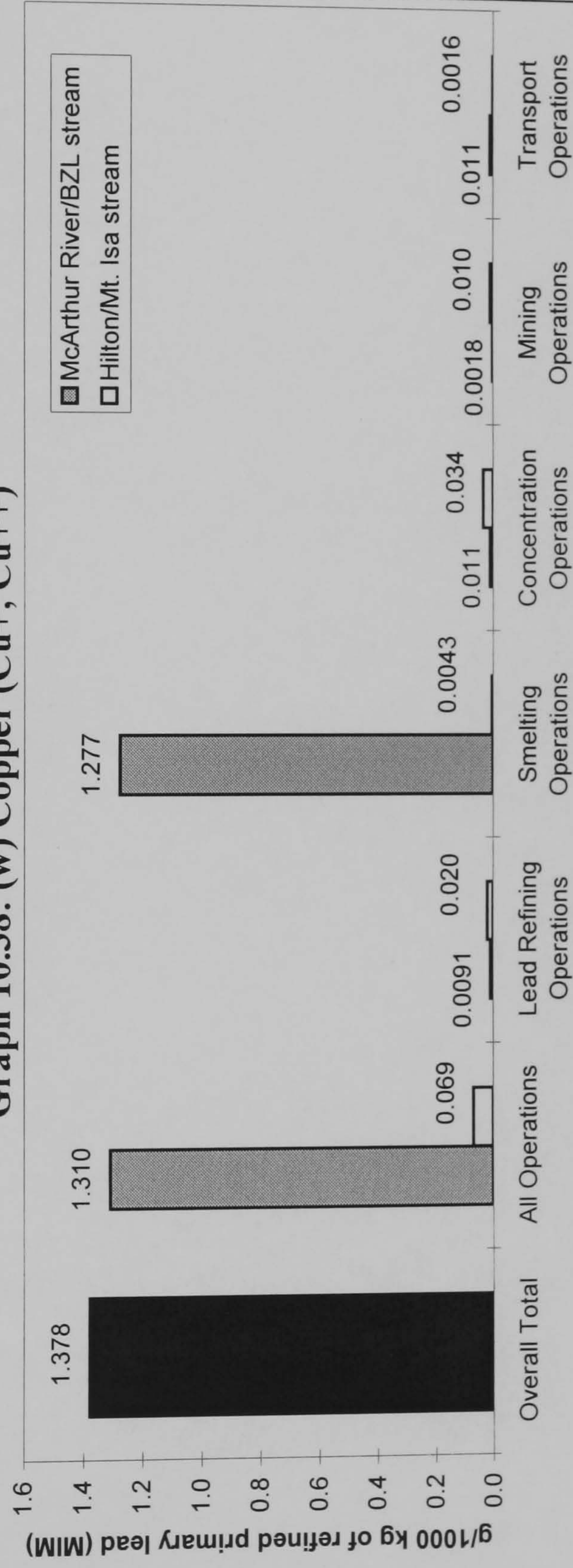


MIM Pb LCA (unallocated)

Graph 10.37: (w) Cadmium (Cd+)

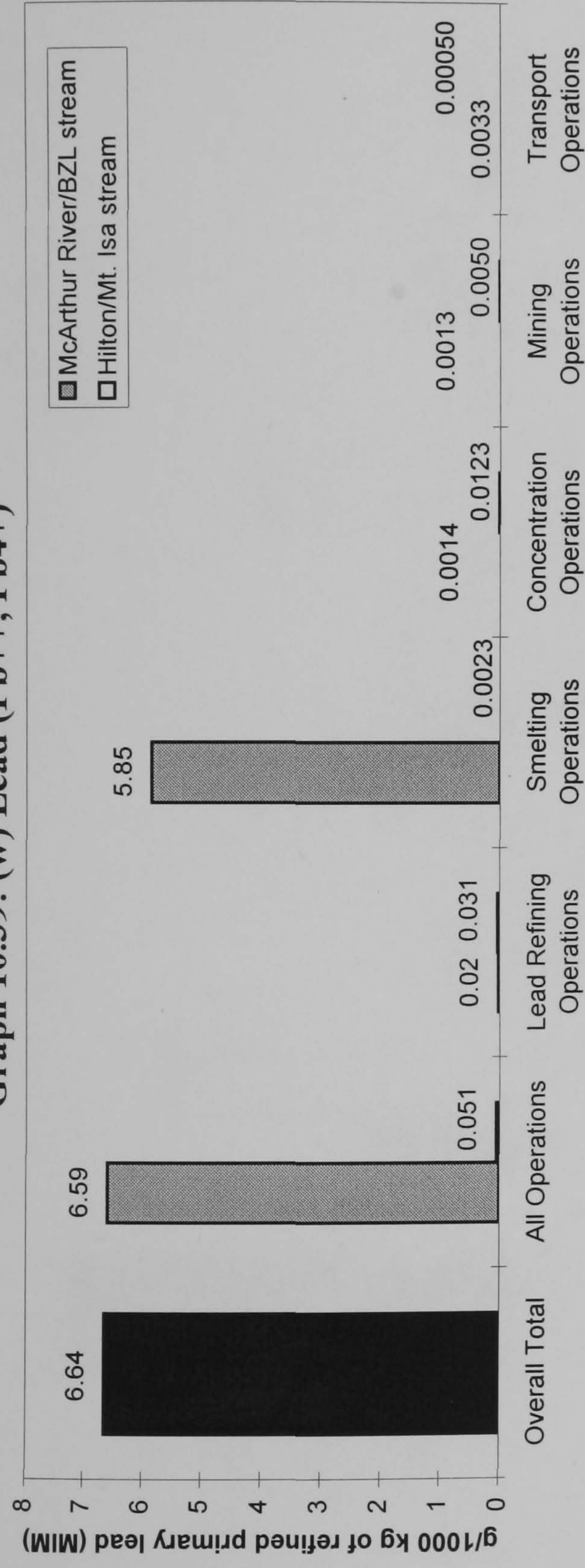


Graph 10.38: (w) Copper (Cu+, Cu++)

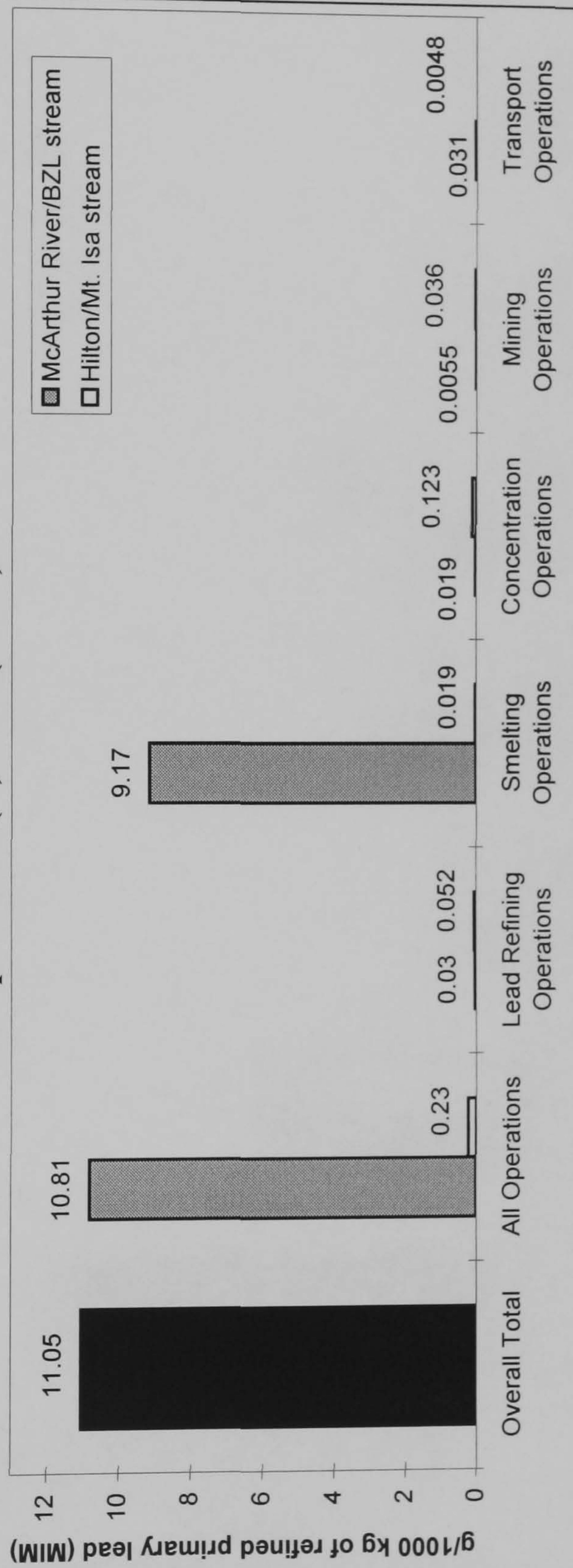


MIM Pb LCA (unallocated)

Graph 10.39: (w) Lead (Pb⁺⁺, Pb⁴⁺)

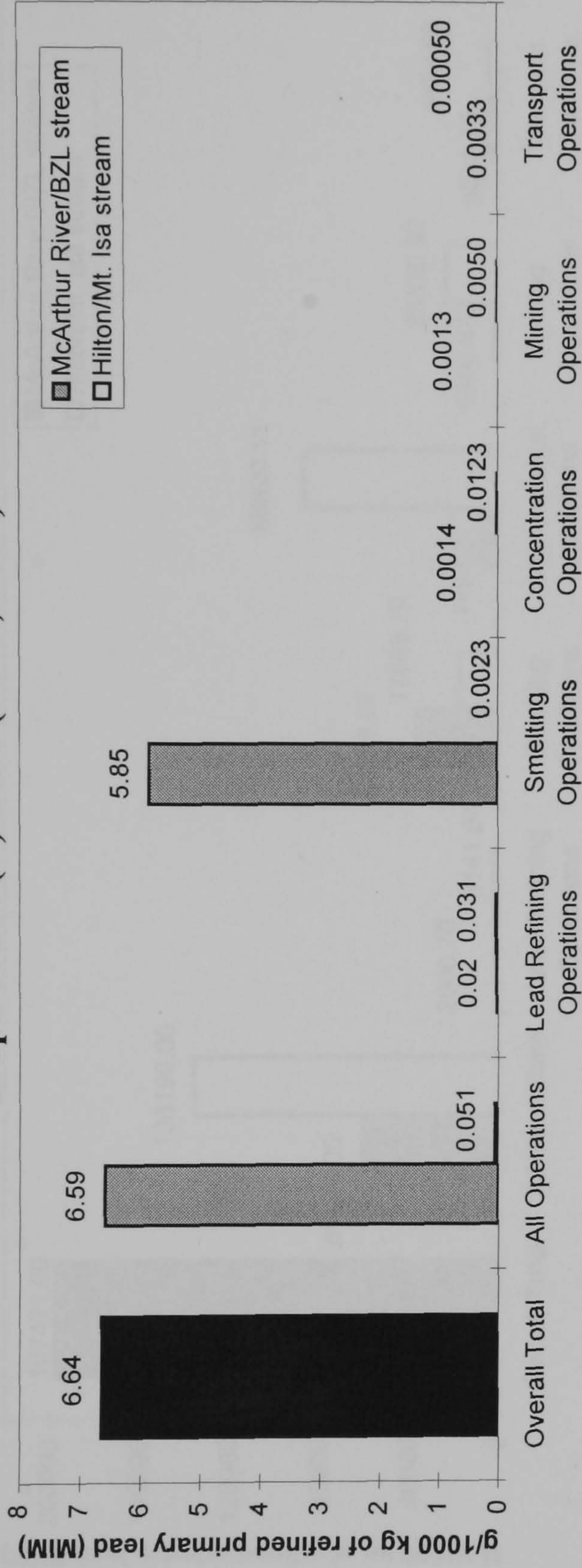


Graph 10.40: (w) Zinc (Zn⁺⁺)

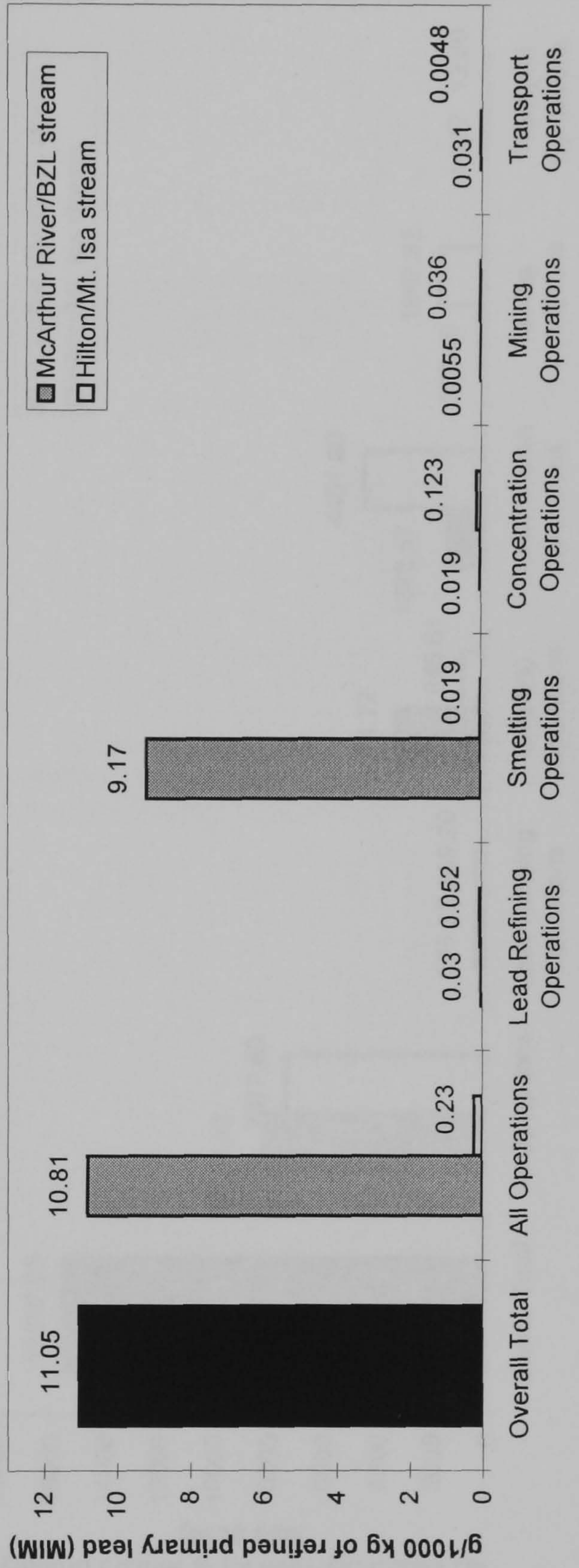


MIM Pb LCA (unallocated)

Graph 10.39: (w) Lead (Pb⁺⁺, Pb⁴⁺)

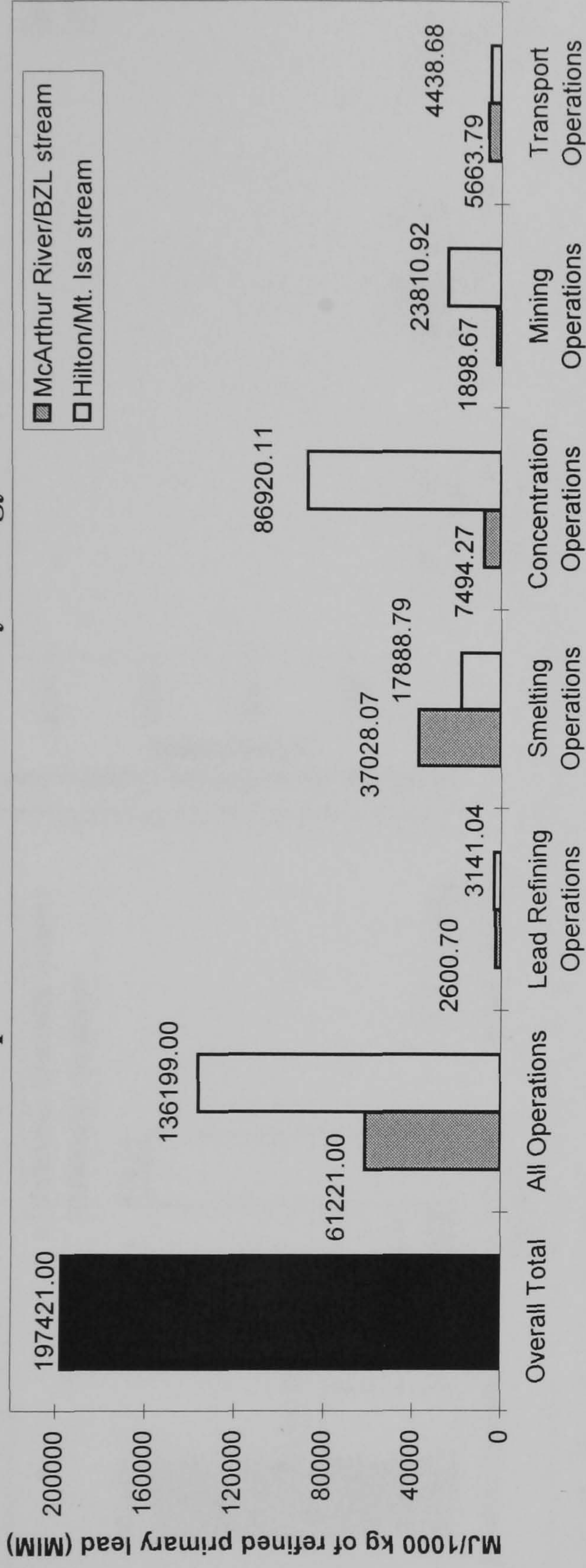


Graph 10.40: (w) Zinc (Zn⁺⁺)

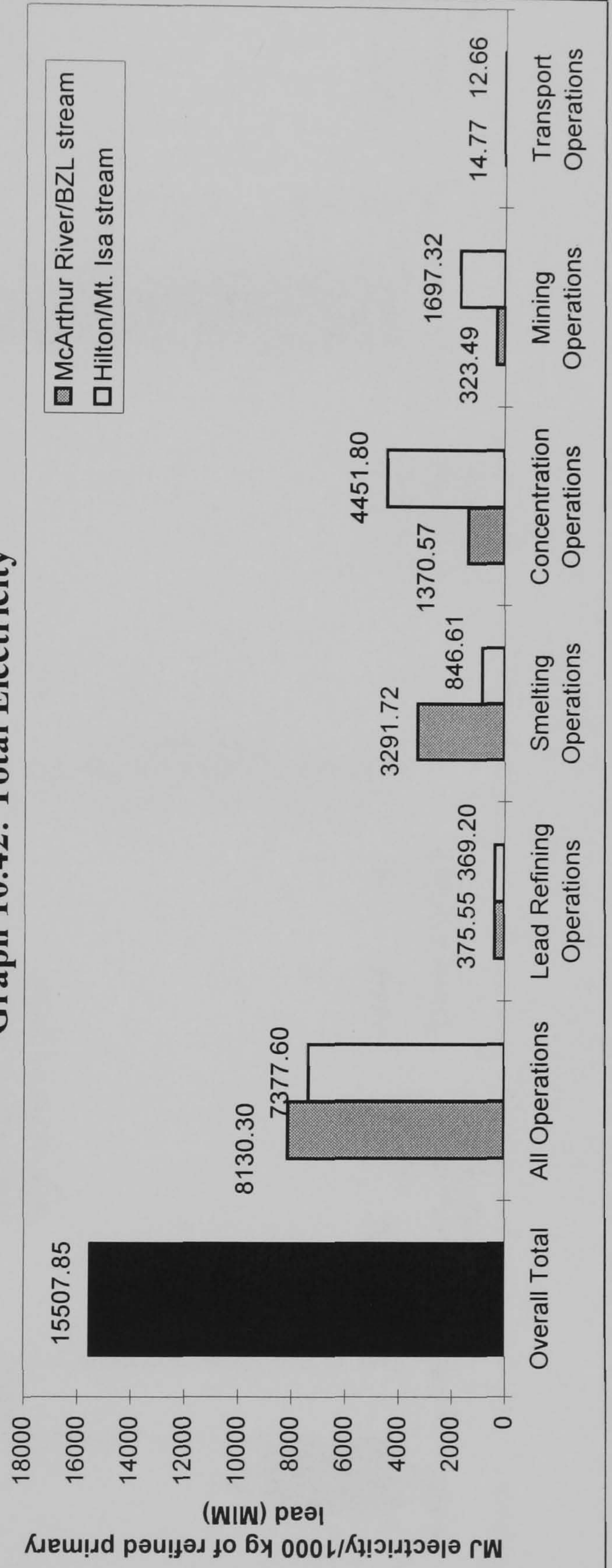


MIM Pb LCA (unallocated)

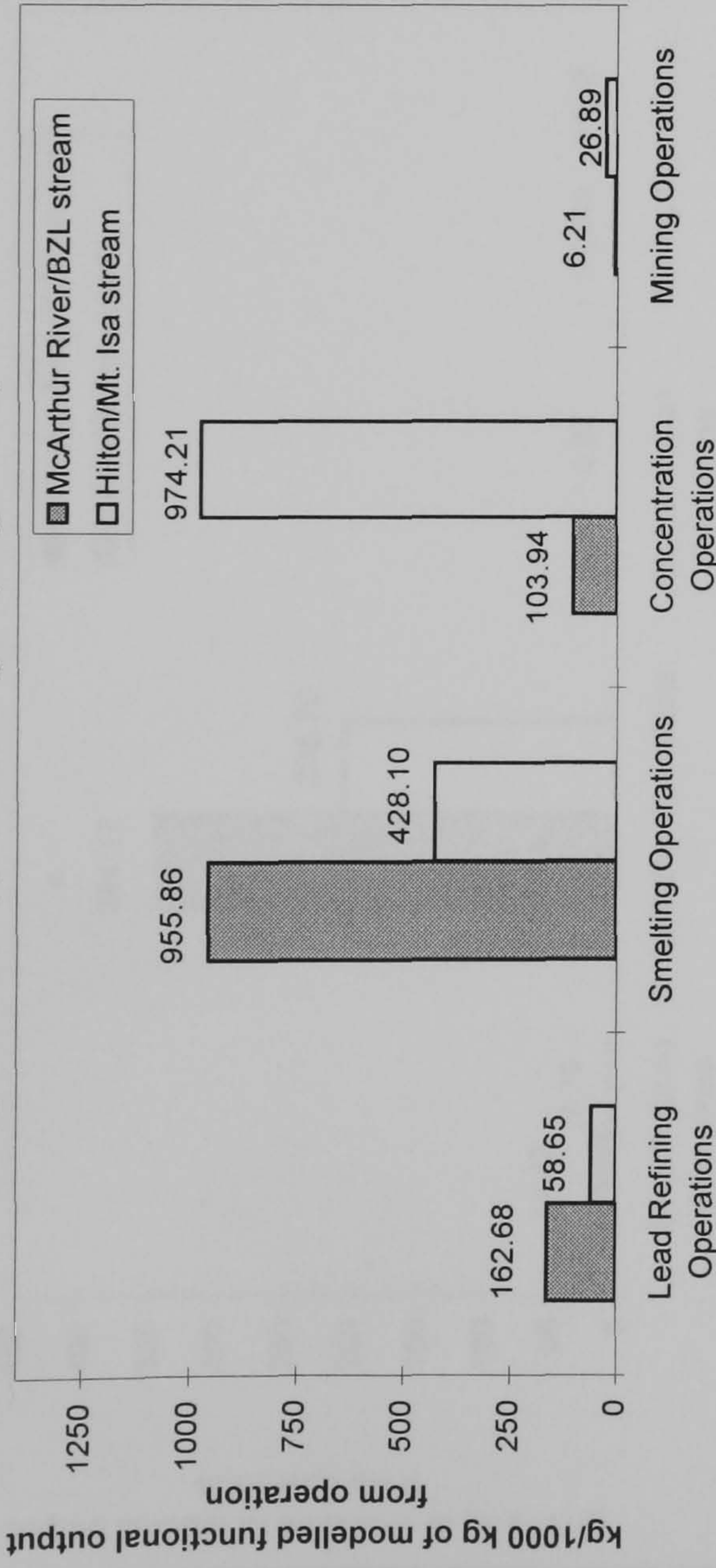
Graph 10.41: E Total Primary Energy



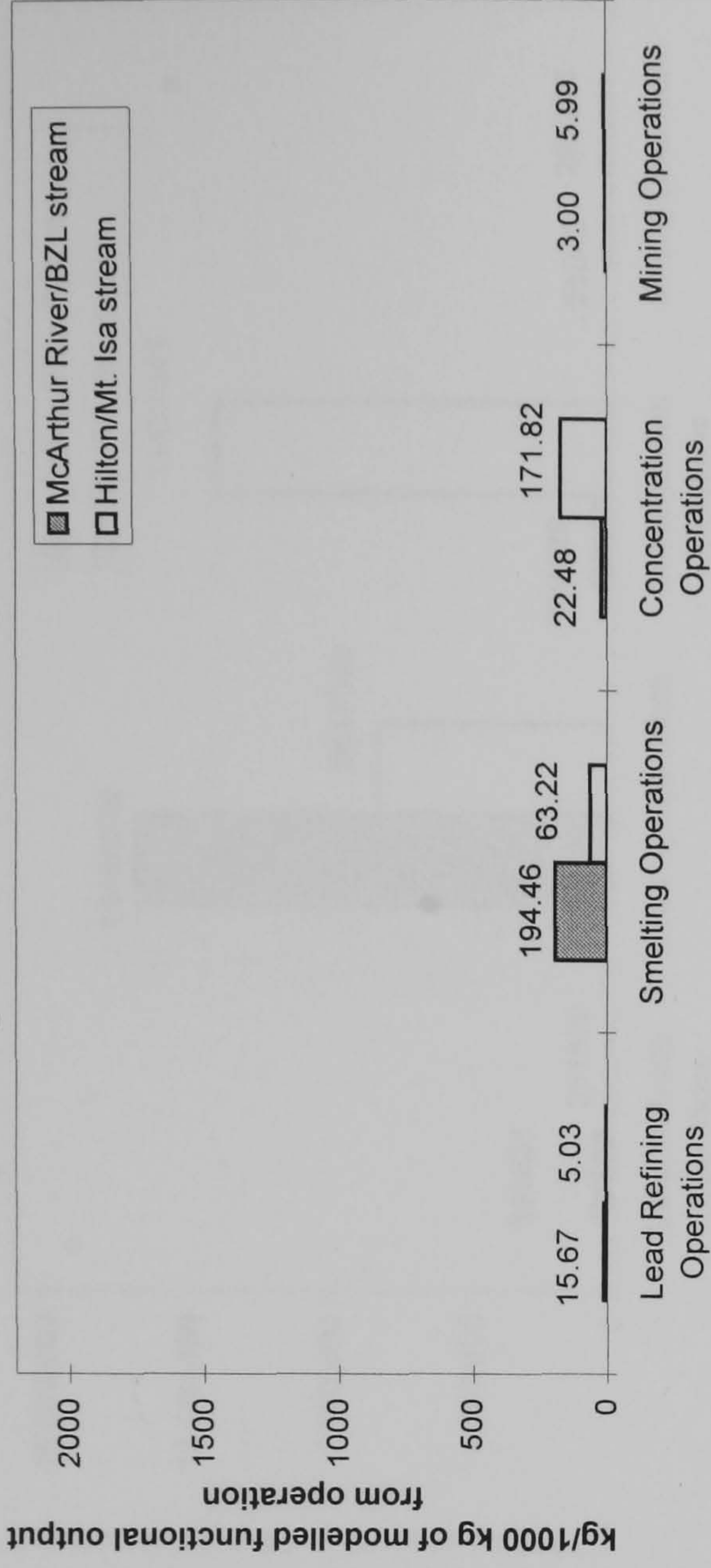
Graph 10.42: Total Electricity



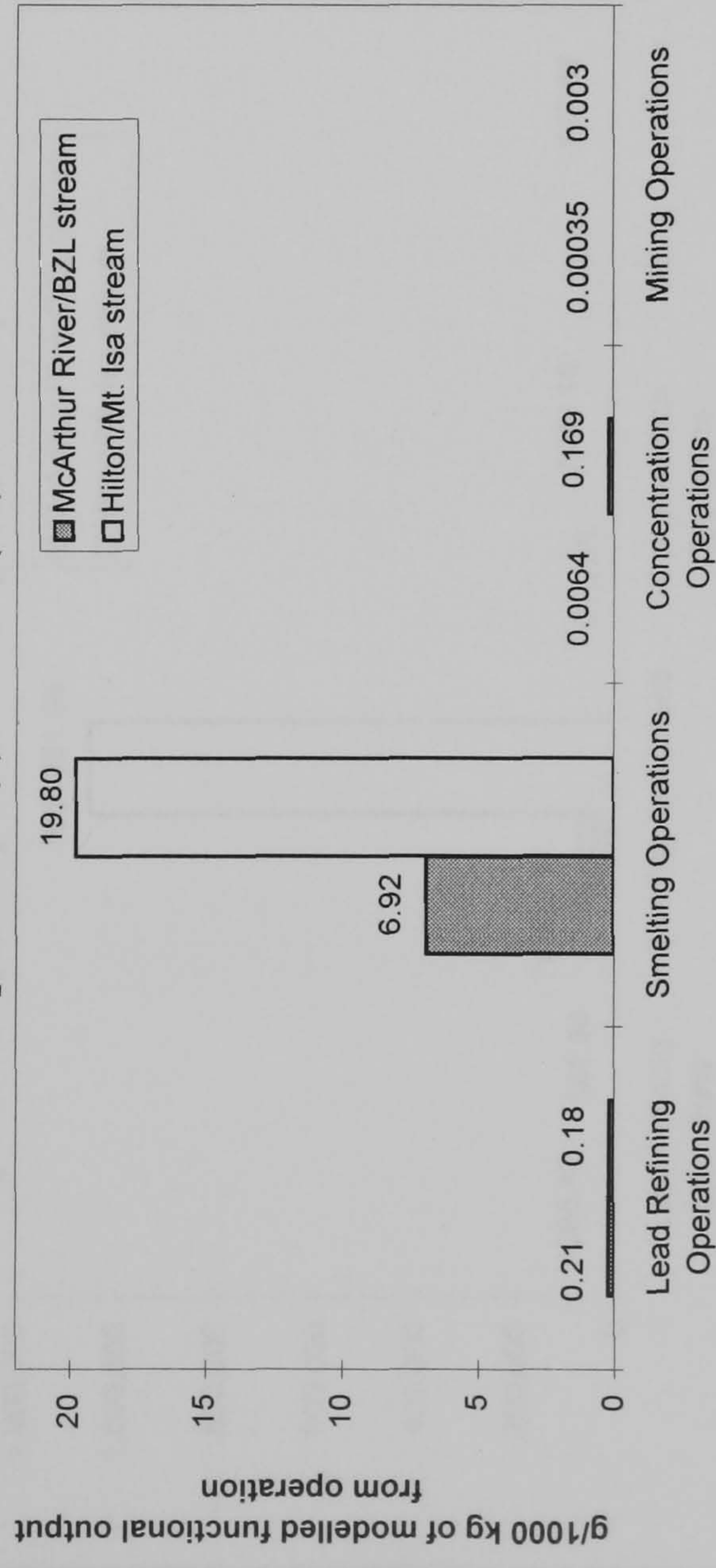
Graph 10.43: (r) Natural gas (in ground)



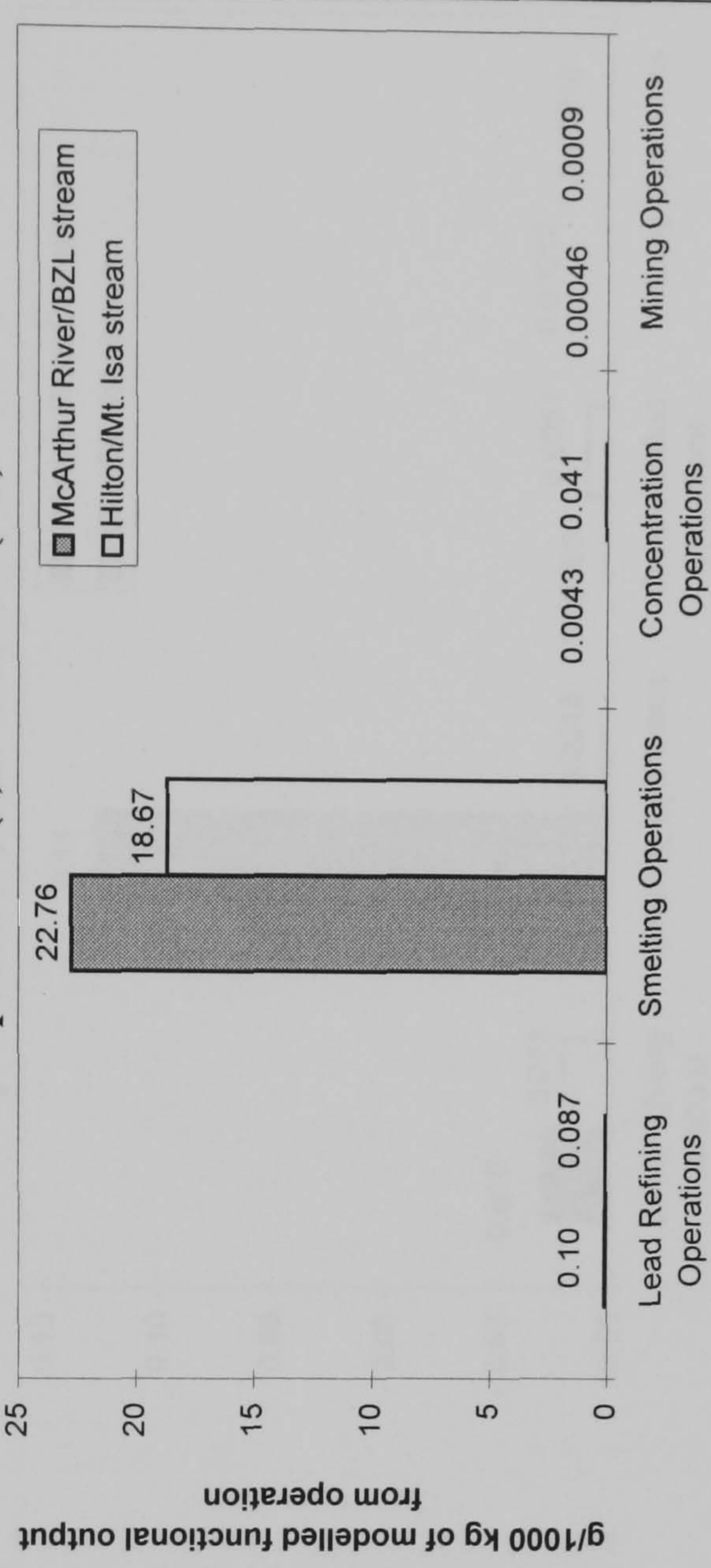
Graph 10.44: (r) Oil (in ground)



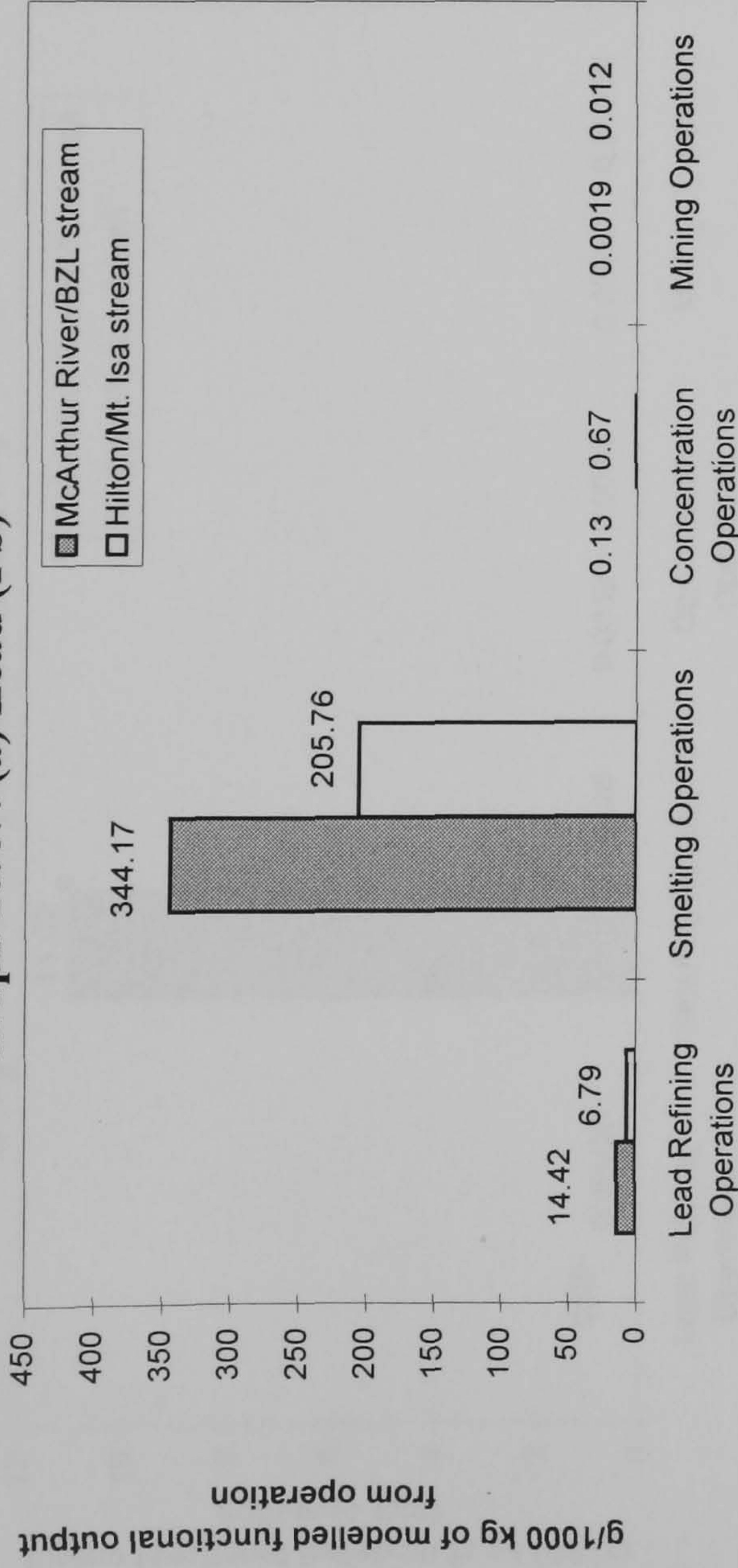
Graph 10.45: (a) Arsenic (As)



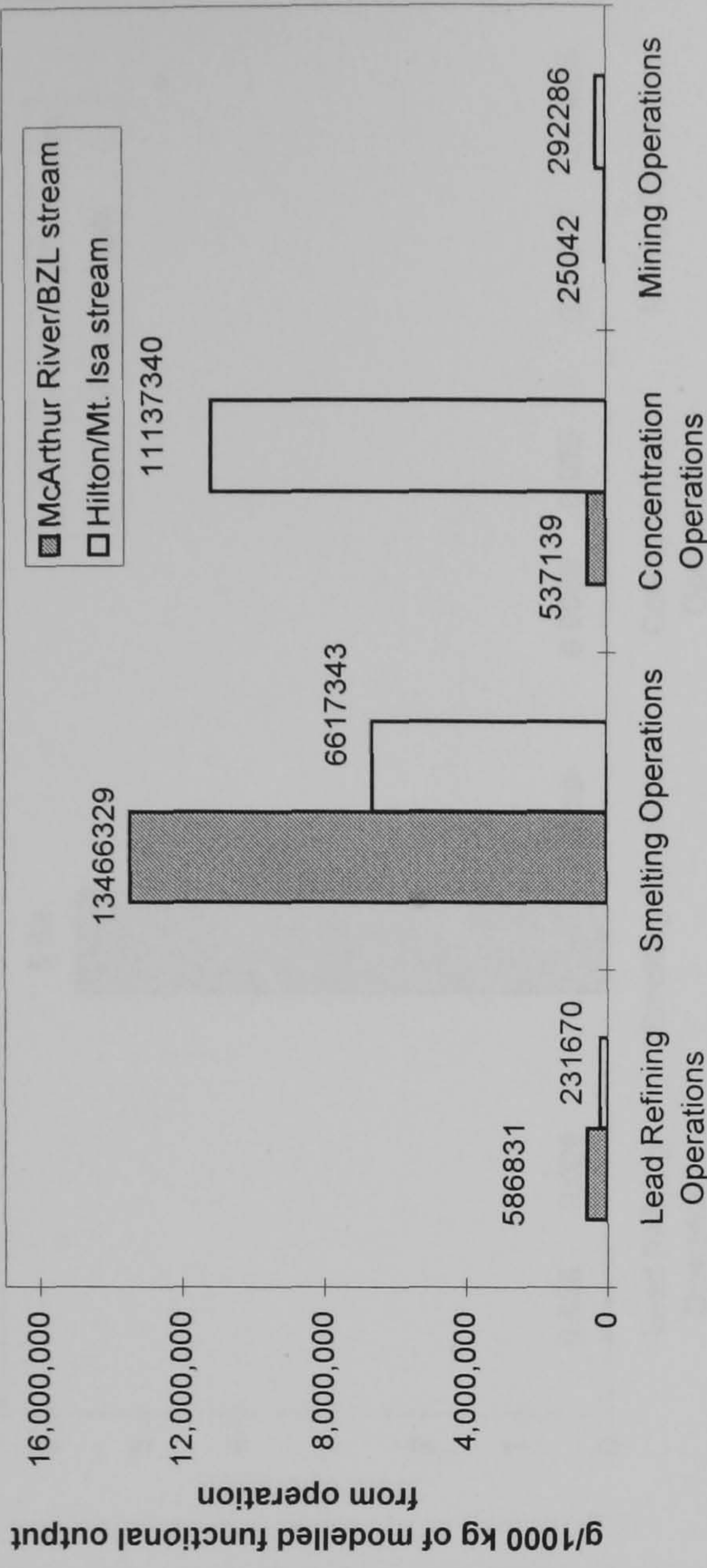
Graph 10.46: (a) Cadmium (Cd)



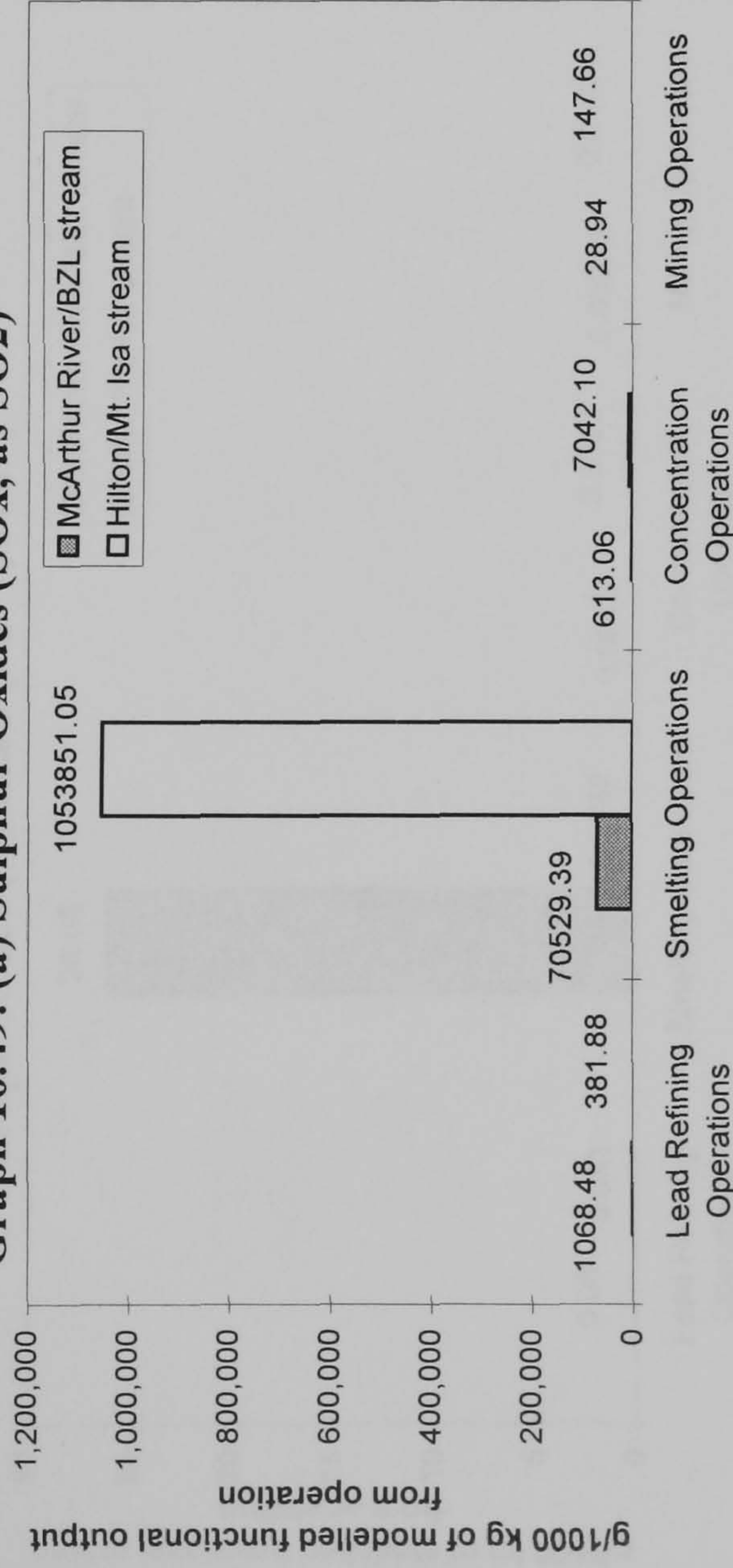
Graph 10.47: (a) Lead (Pb)



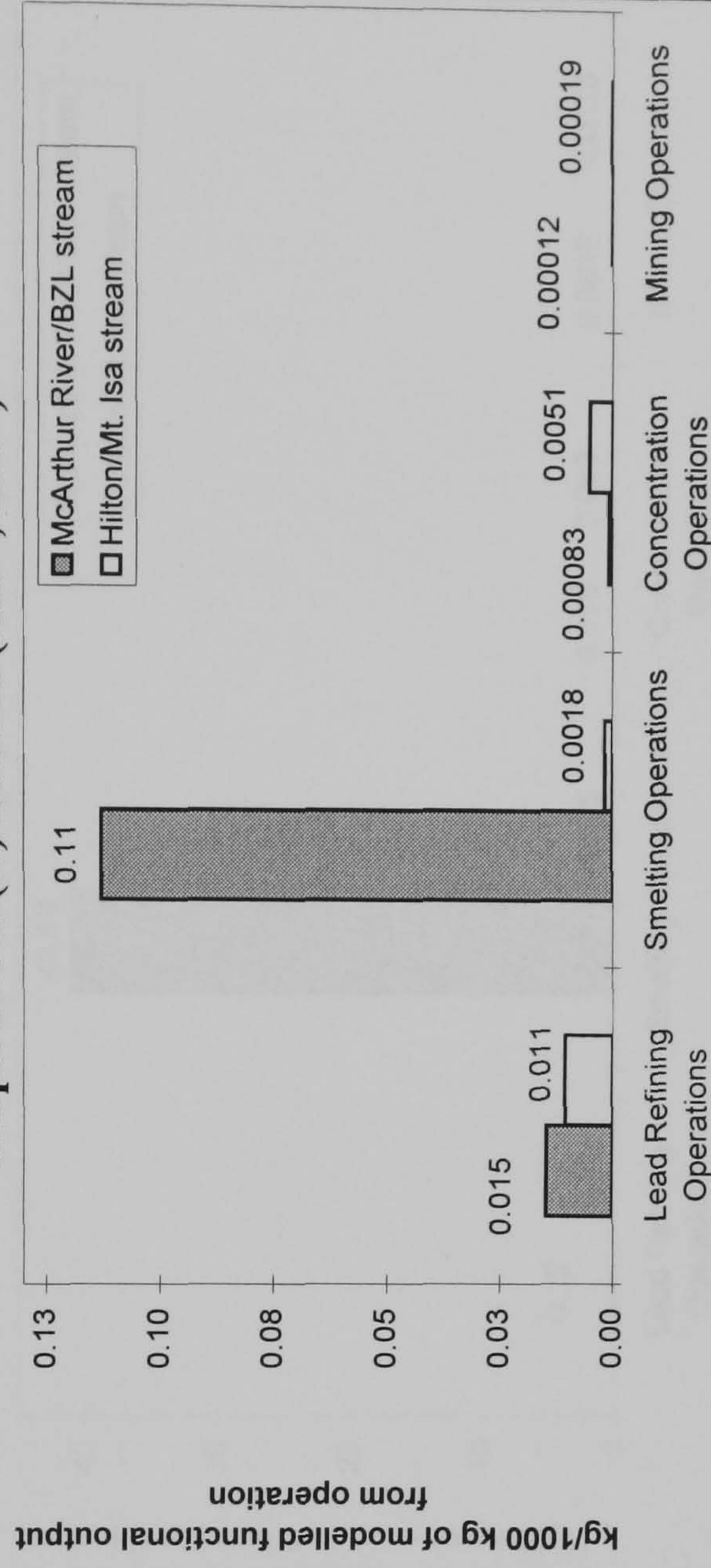
Graph 10.48: (a) Carbon Dioxide (CO₂, fossil)



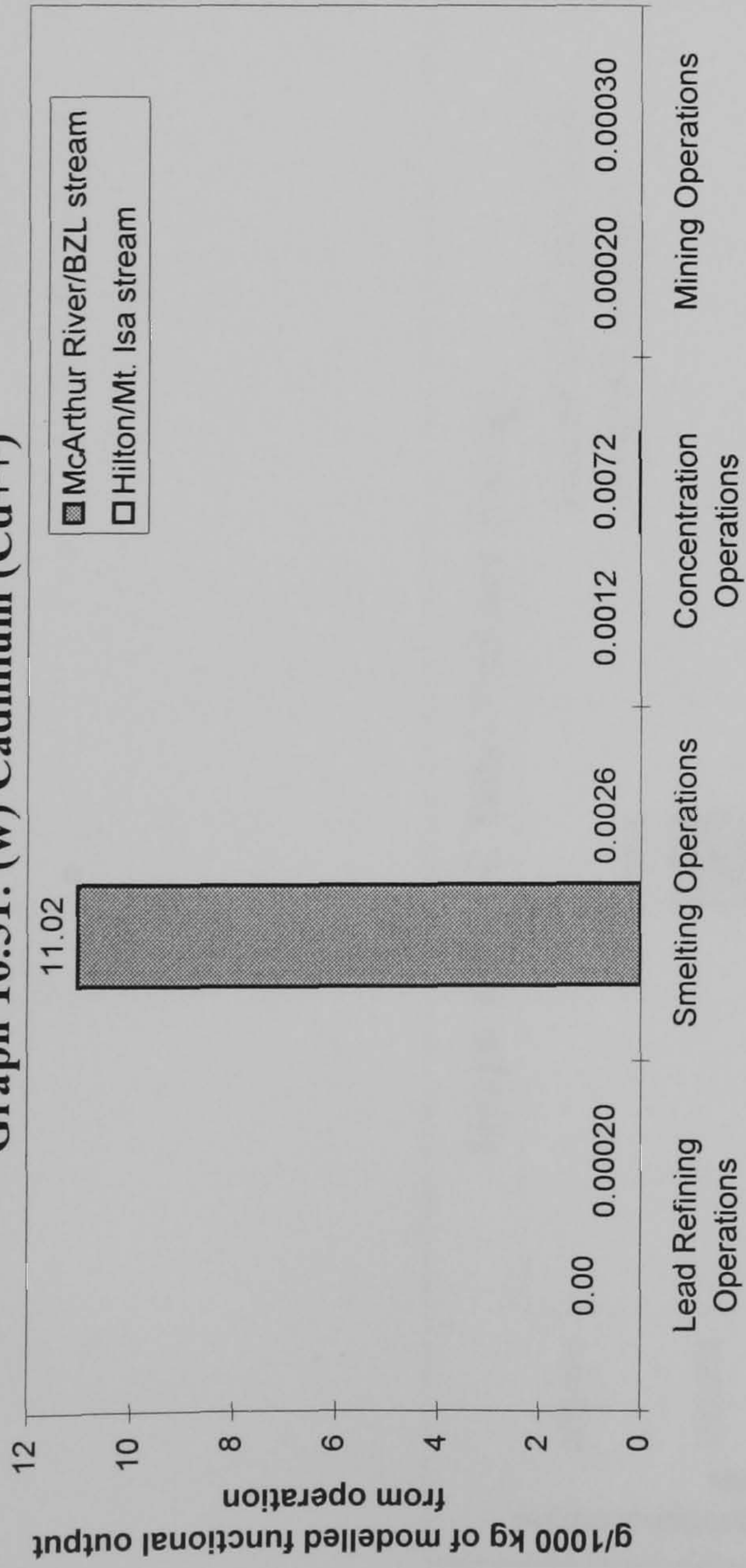
Graph 10.49: (a) Sulphur Oxides (SO_x, as SO₂)



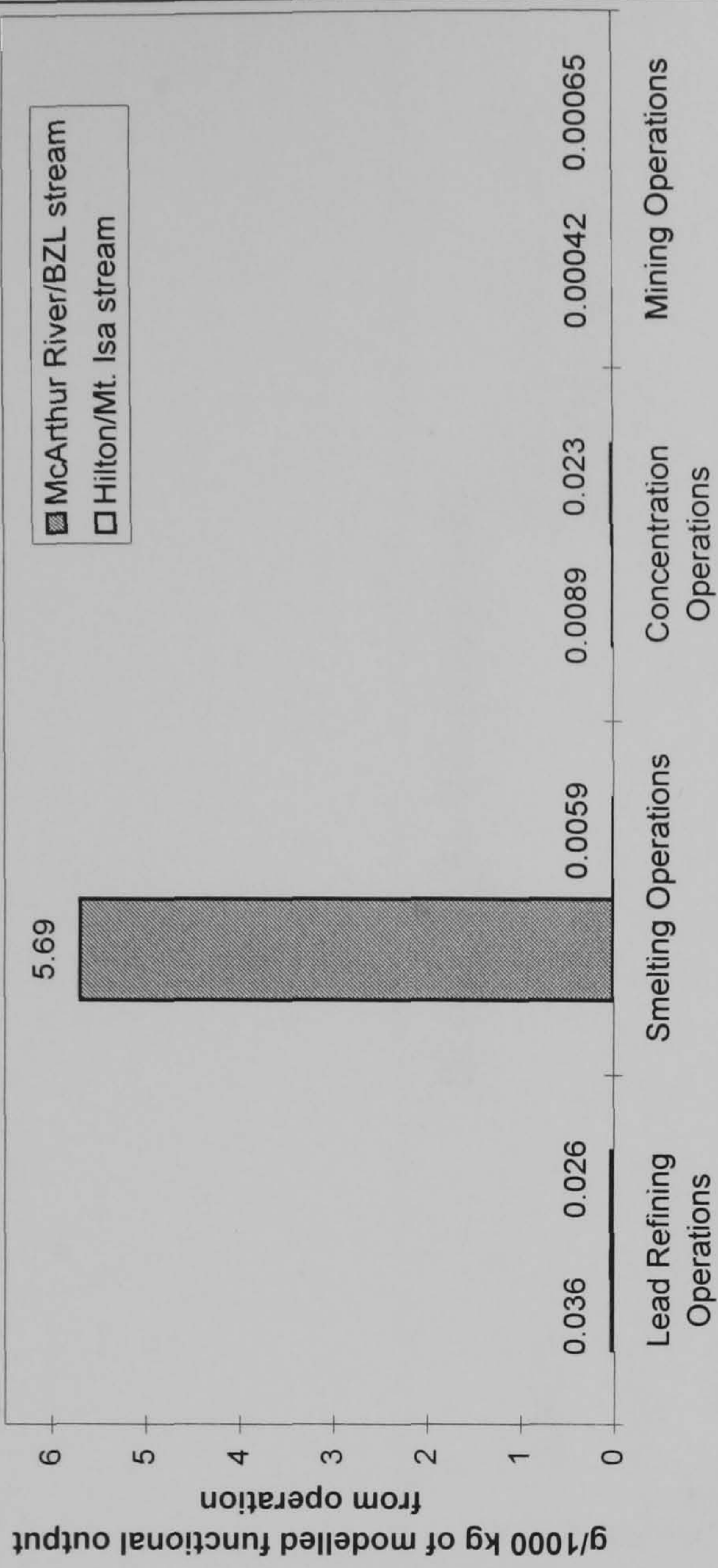
Graph 10.50: (w) Arsenic (As₃₊, As₅₊)



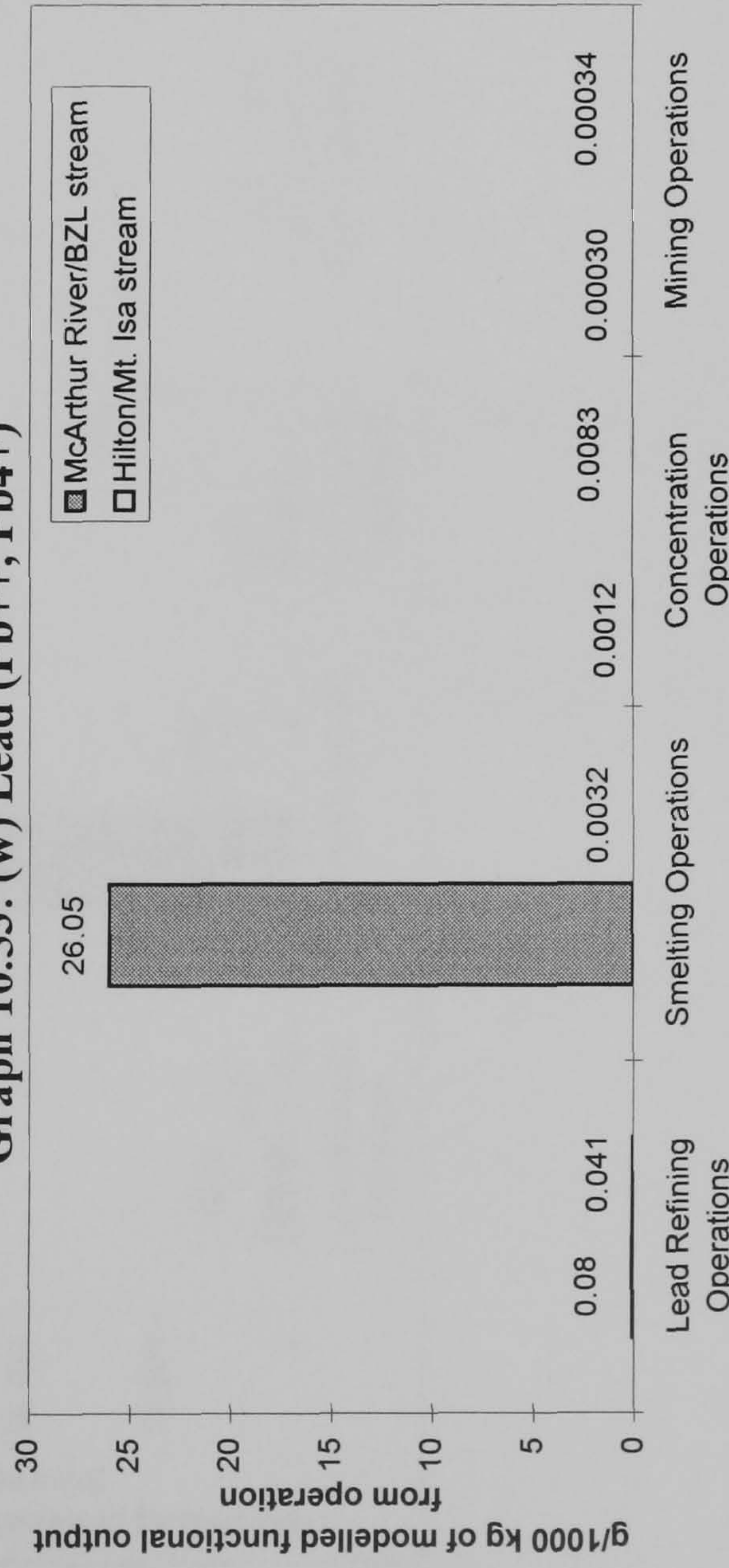
Graph 10.51: (w) Cadmium (Cd++)



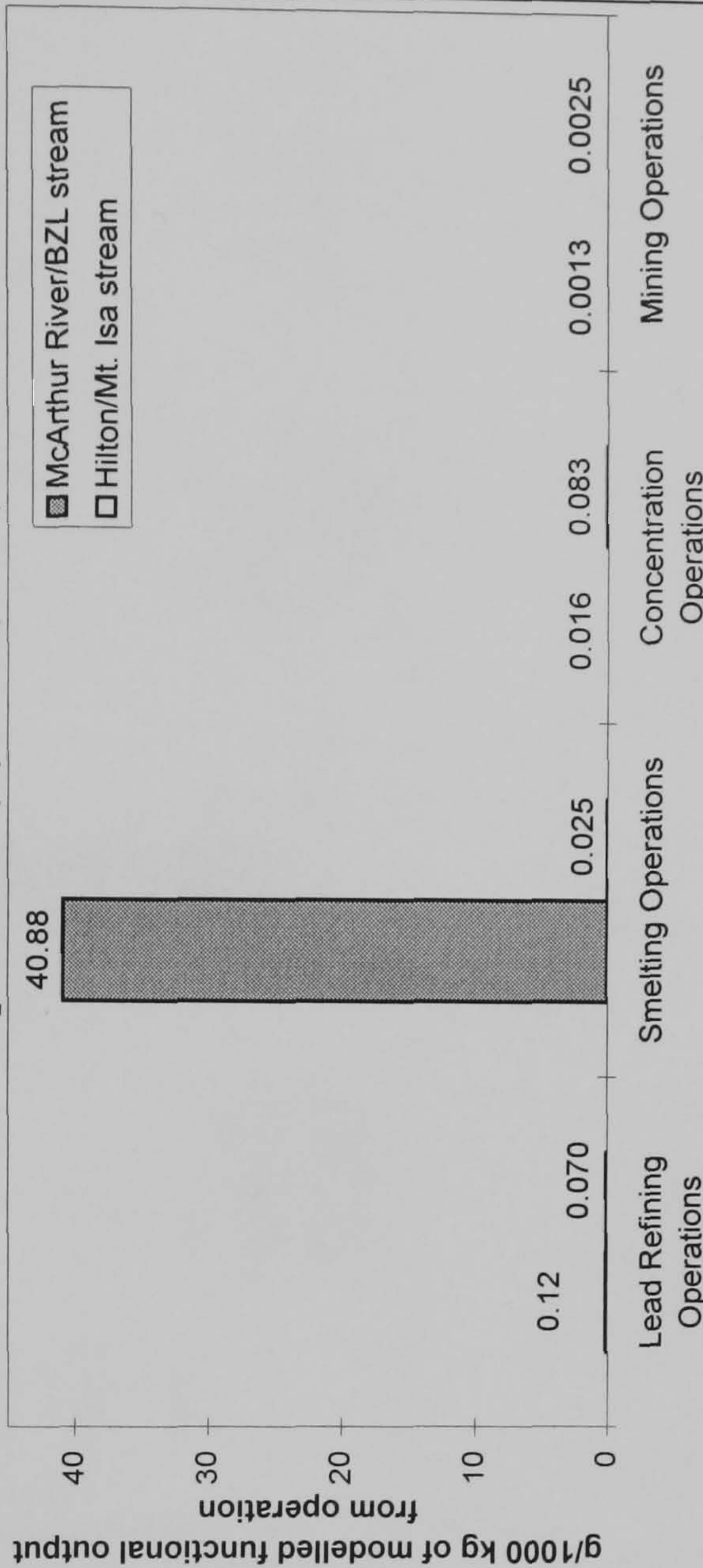
Graph 10.52: (w) Copper (Cu+, Cu++)



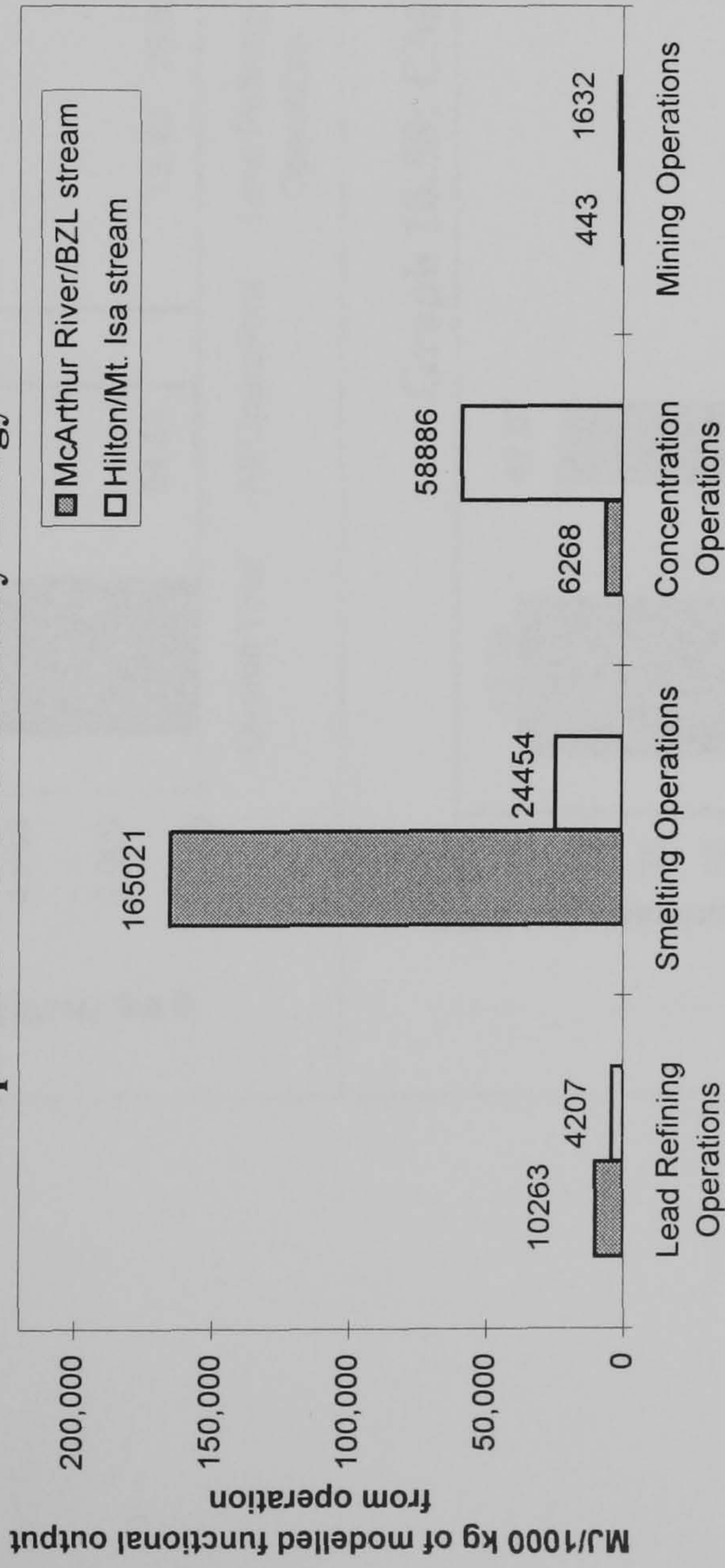
Graph 10.53: (w) Lead (Pb++, Pb4+)



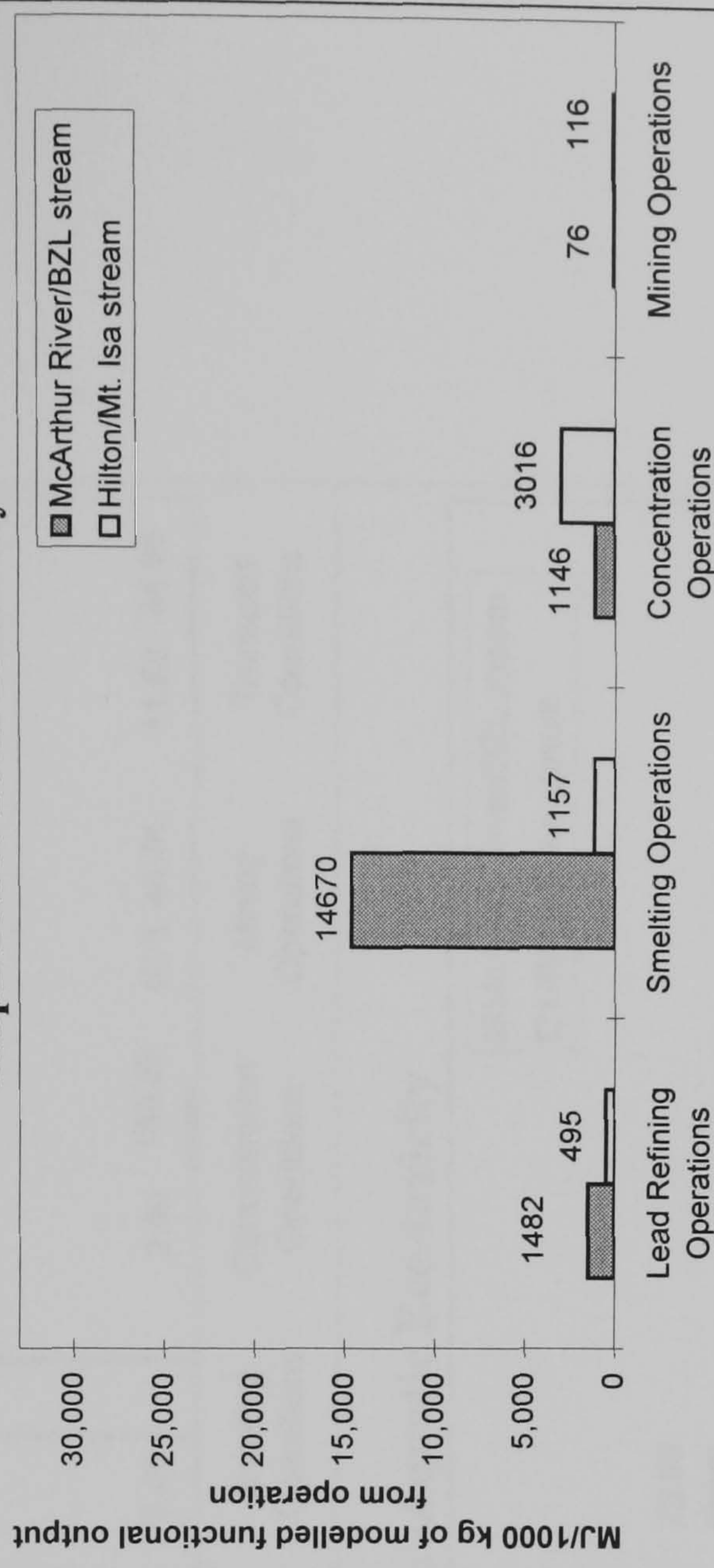
Graph 10.54: (w) Zinc (Zn++)



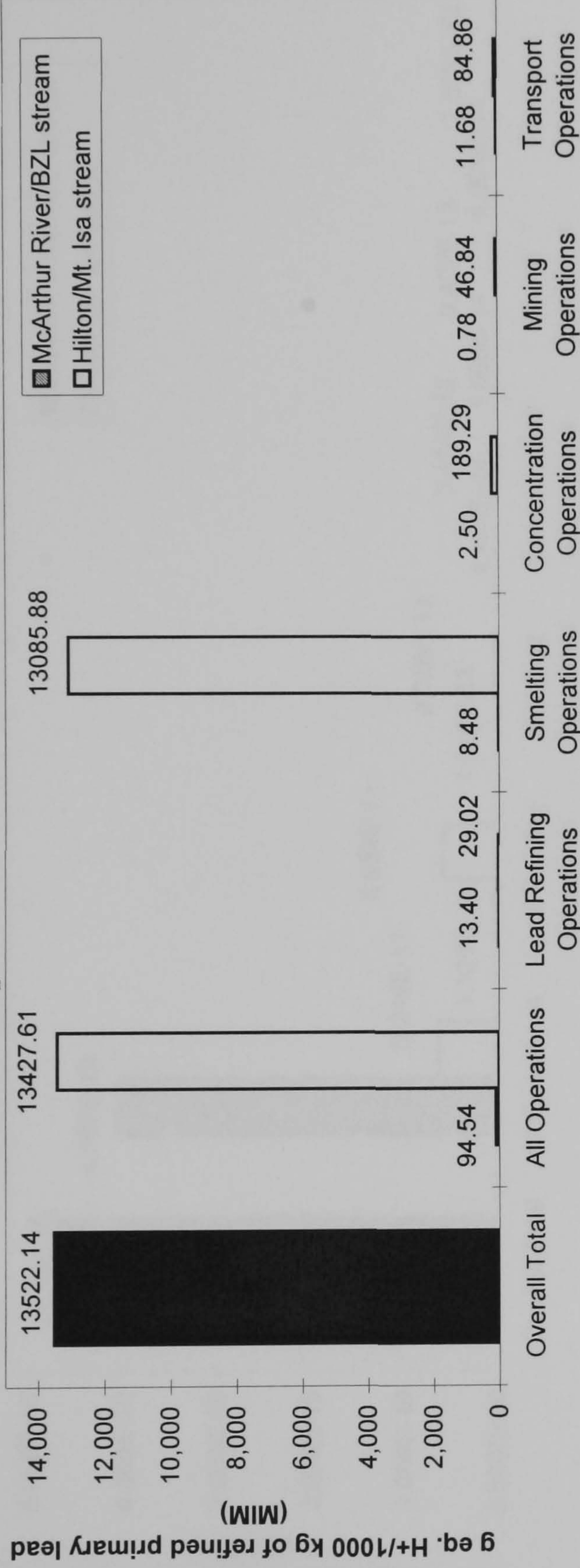
Graph 10.55: E Total Primary Energy



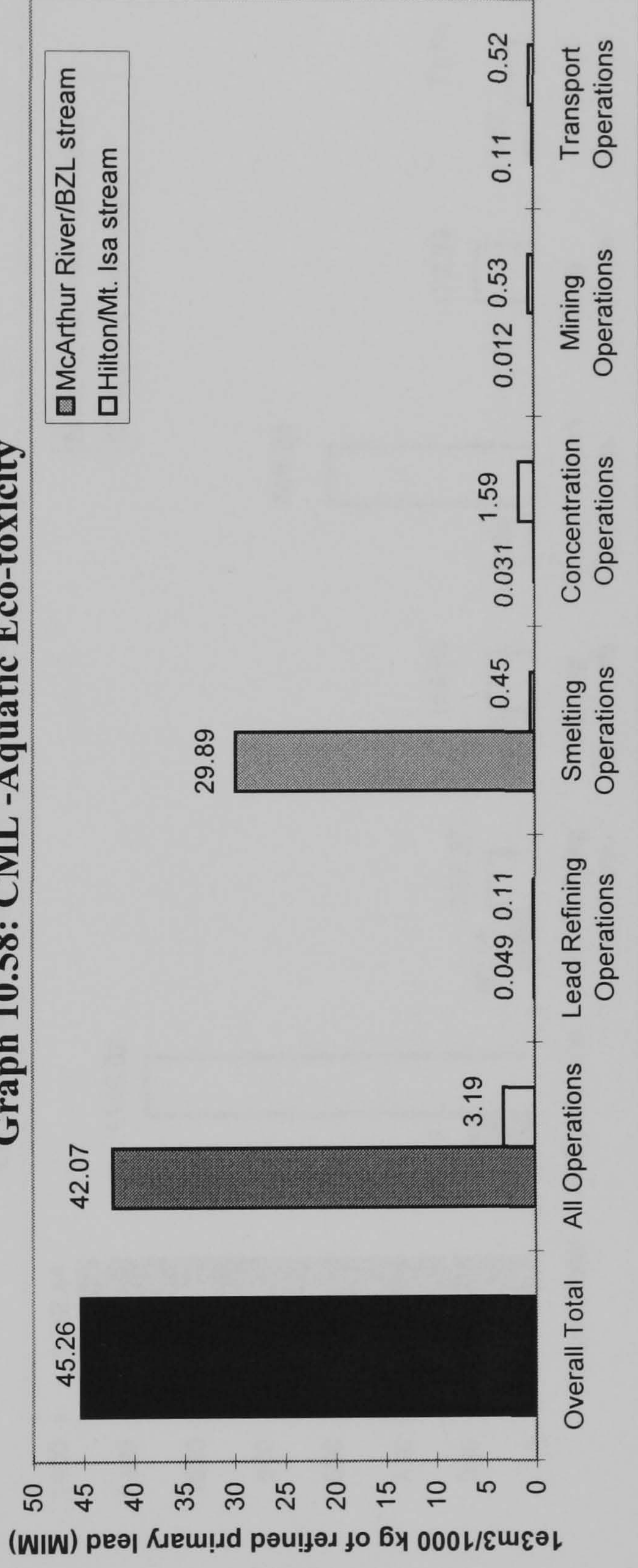
Graph 10.56: Total Electricity



Graph 10.57: CML -Air Acidification

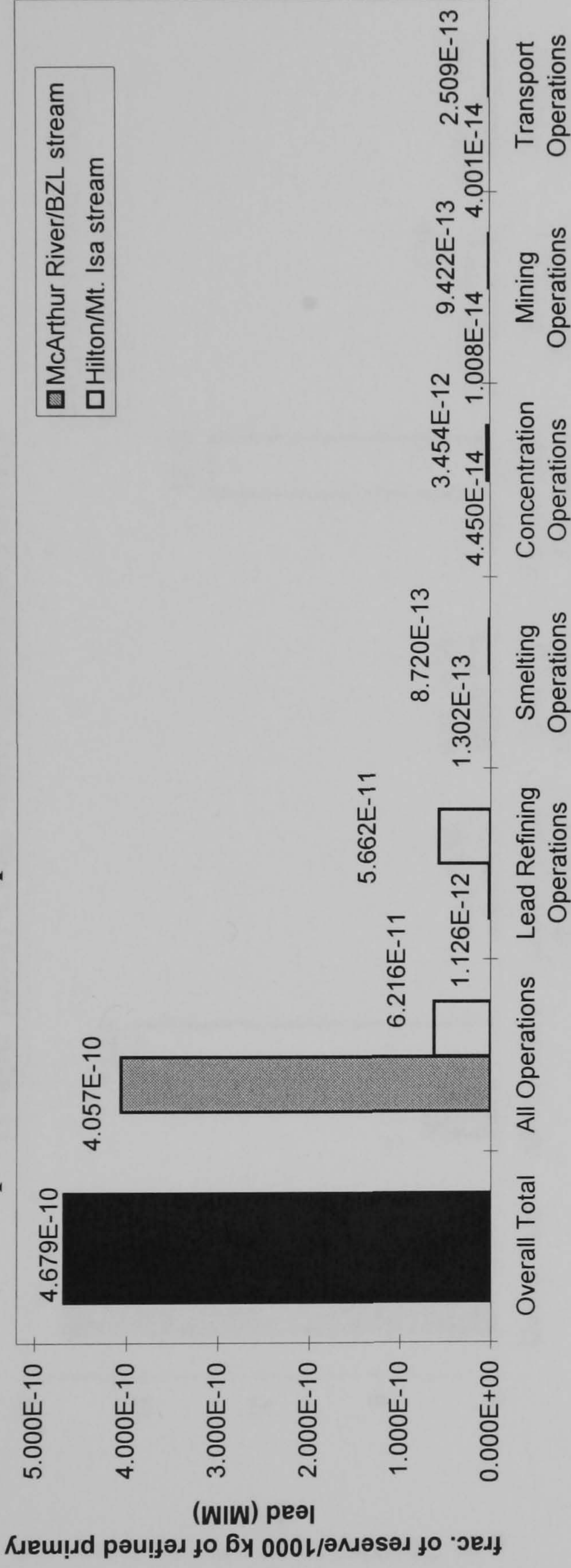


Graph 10.58: CML -Aquatic Eco-toxicity

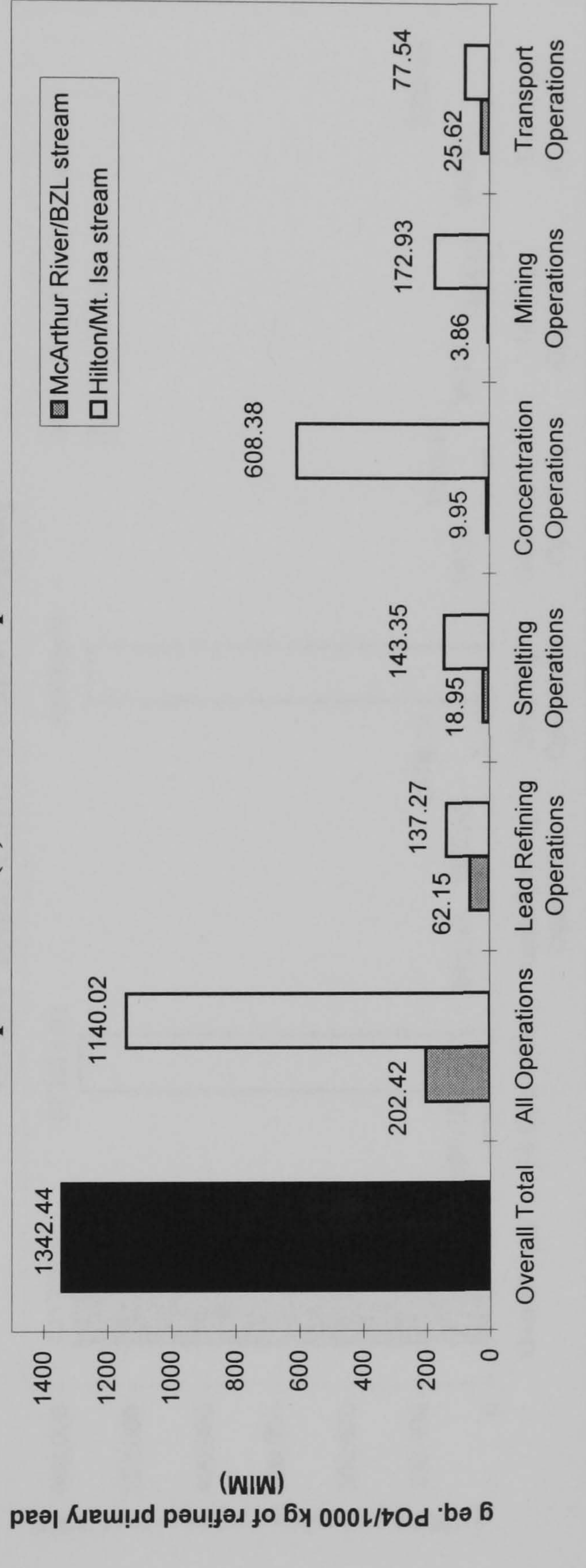


MIM Pb LCA (allocated)

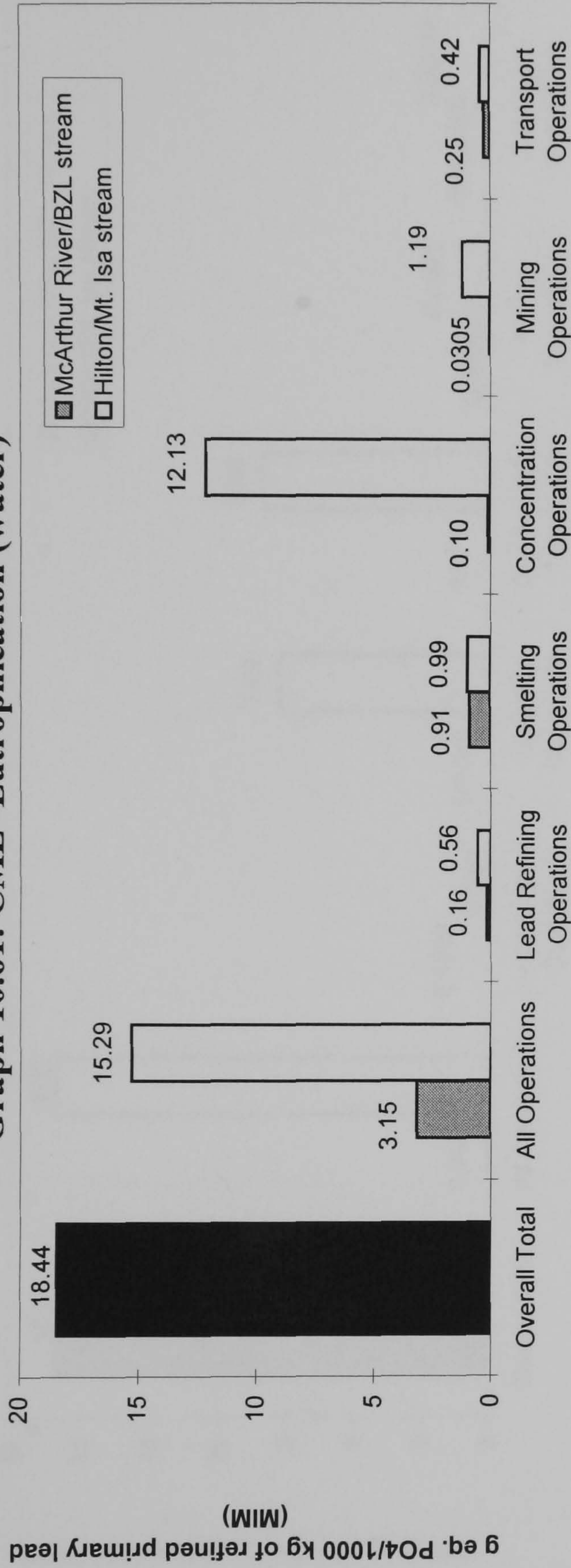
Graph 10.59: CML -Depletion of non-renewable resources



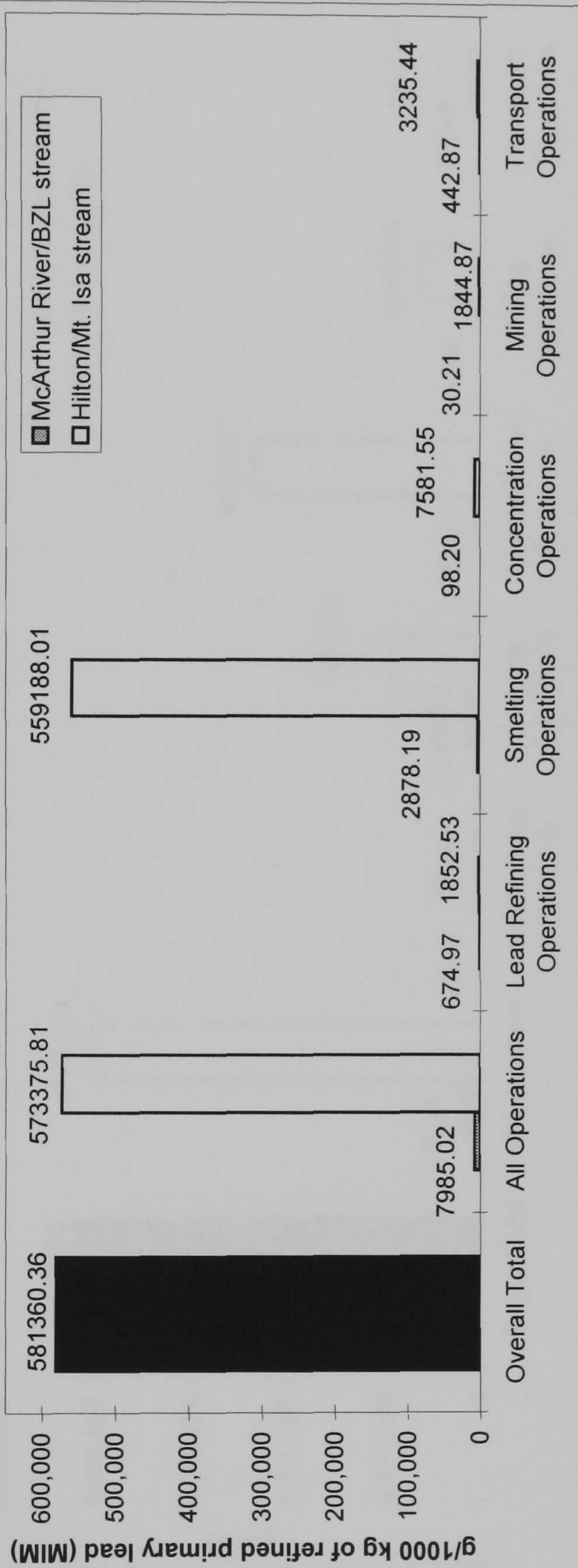
Graph 10.60: (a) CML -Eutrophication



Graph 10.61: CML -Eutrophication (water)

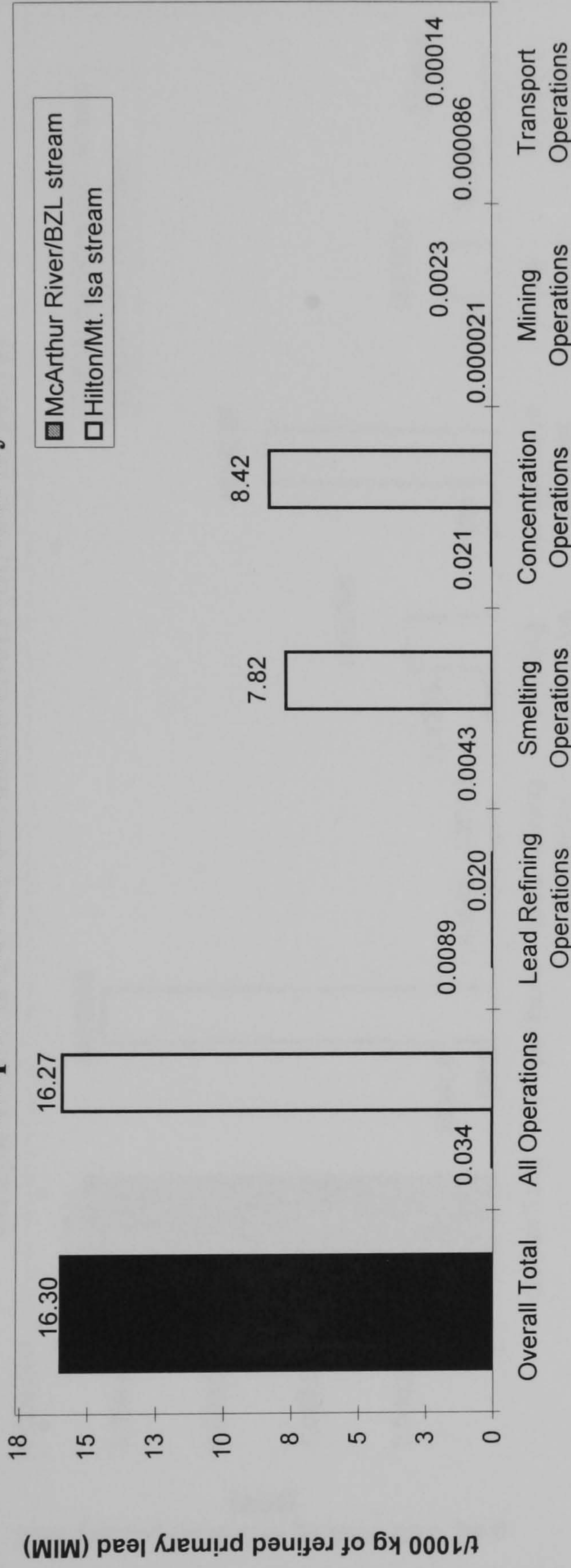


Graph 10.62: CML -Human Toxicity

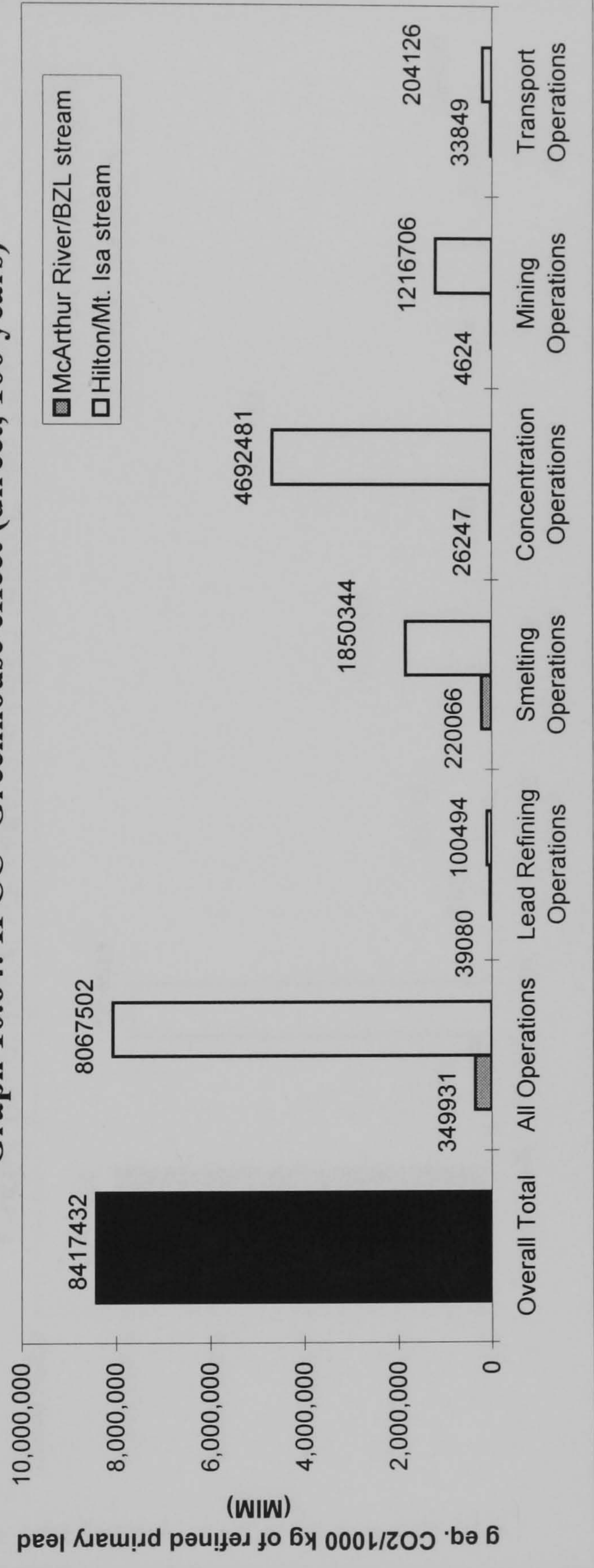


MIM Pb LCA (allocated)

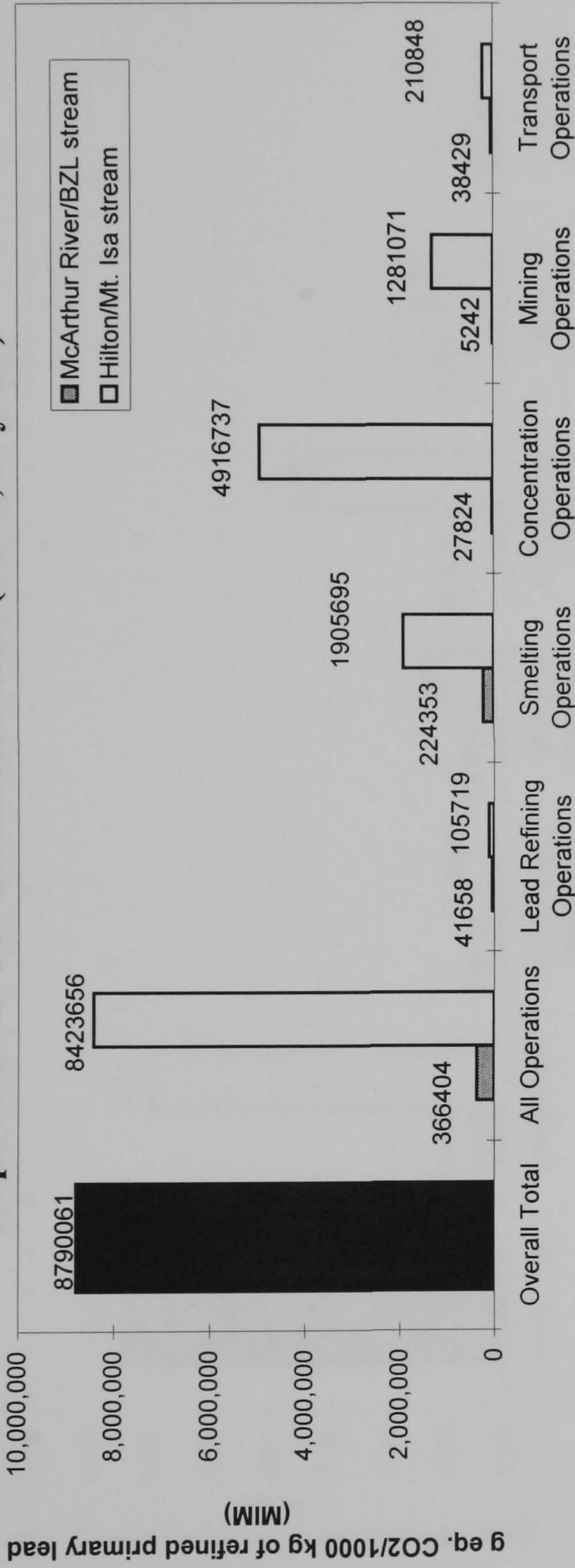
Graph 10.63: CML -Terrestrial Eco-toxicity



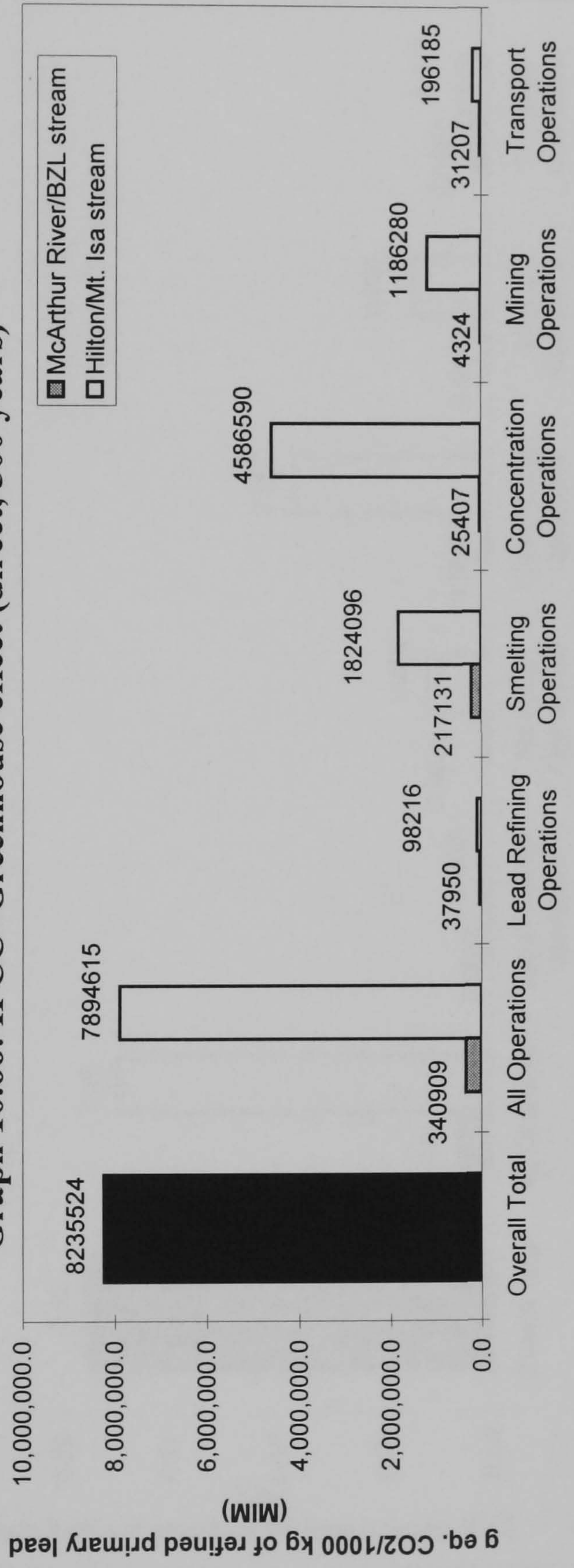
Graph 10.64: IPCC -Greenhouse effect (direct, 100 years)



Graph 10.65: IPCC -Greenhouse effect (direct, 20 years)

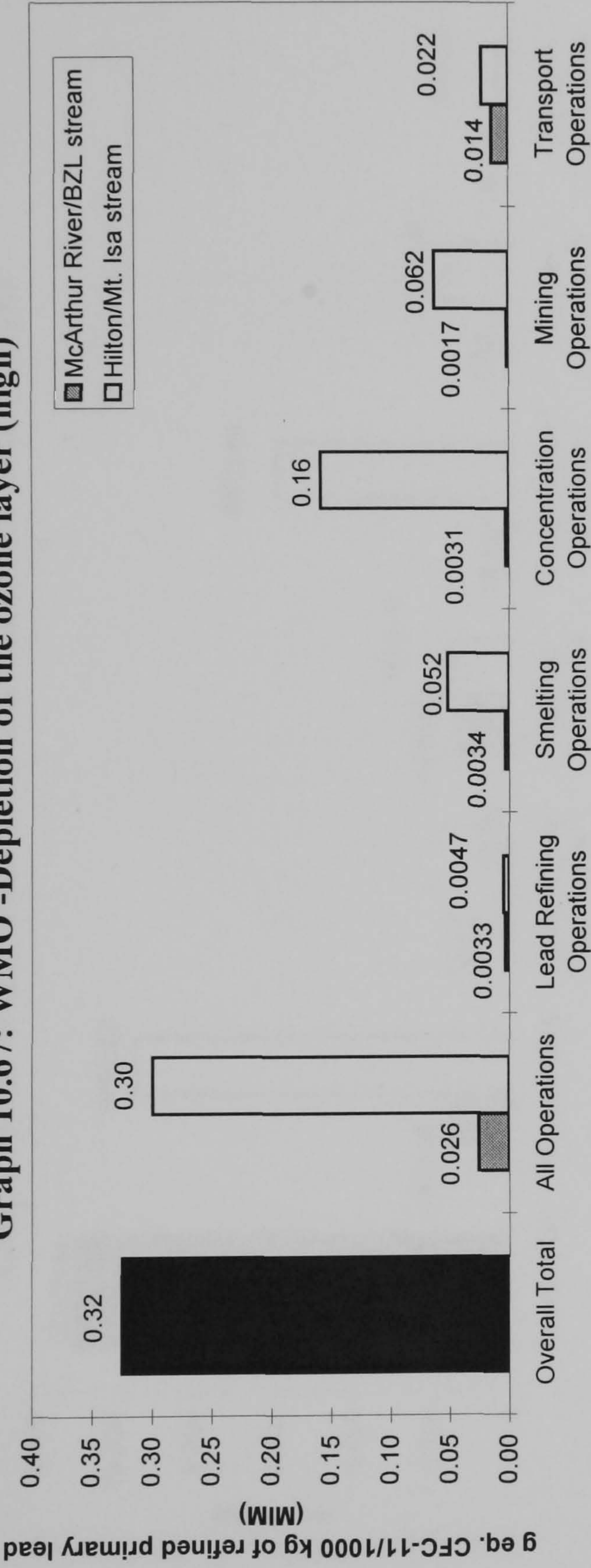


Graph 10.66: IPCC -Greenhouse effect (direct, 500 years)

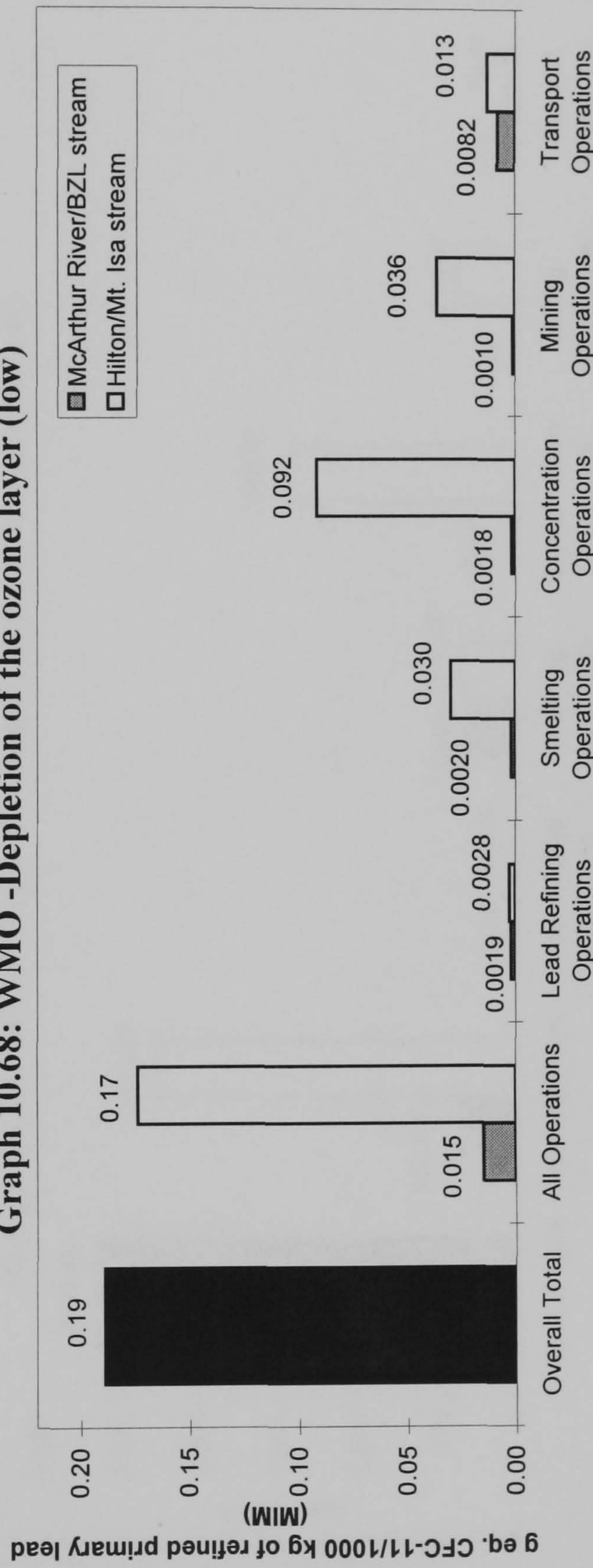


MIM Pb LCA (allocated)

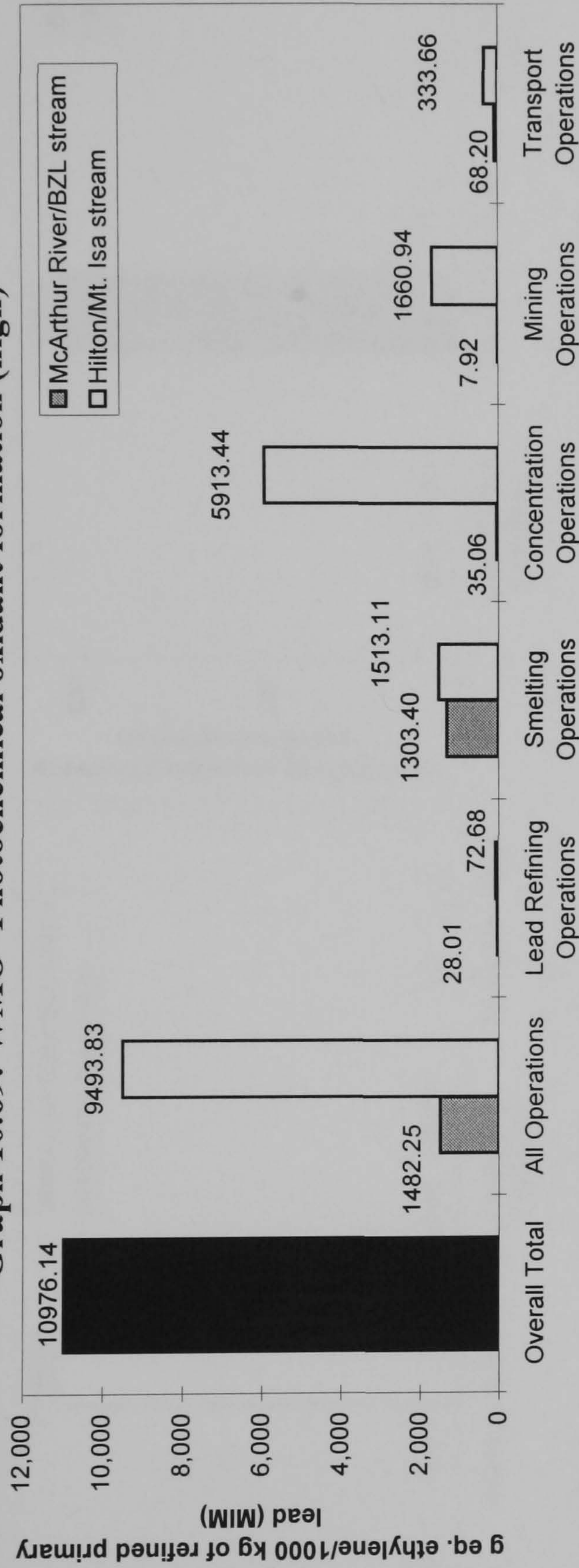
Graph 10.67: WMO - Depletion of the ozone layer (high)



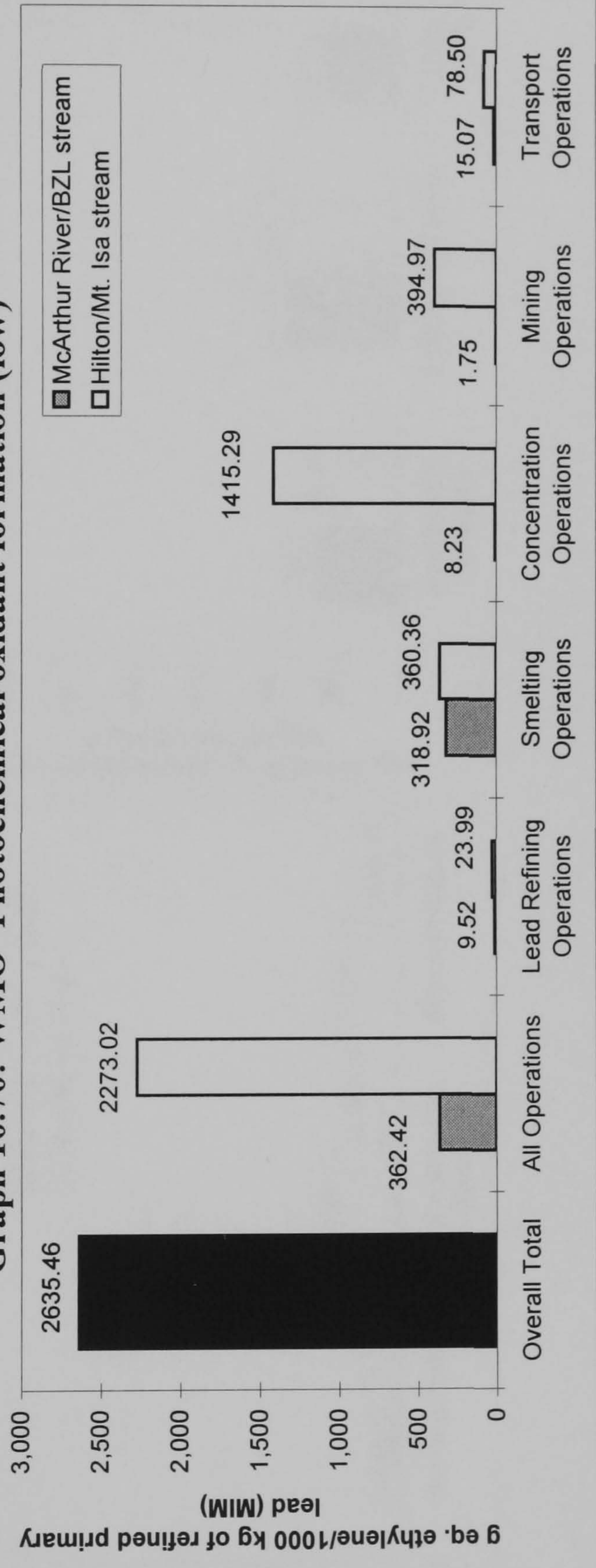
Graph 10.68: WMO - Depletion of the ozone layer (low)



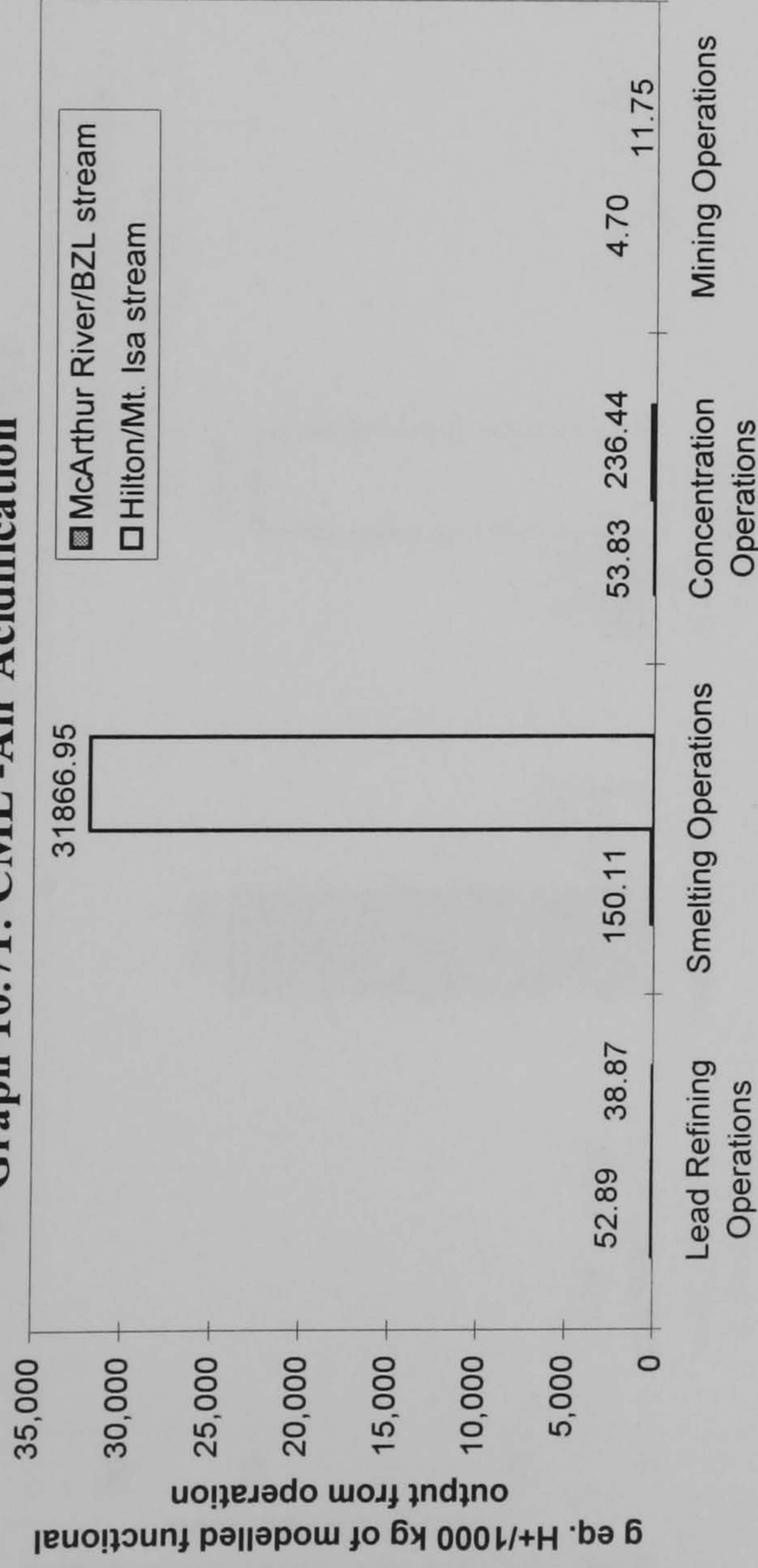
Graph 10.69: WMO -Photochemical oxidant formation (high)



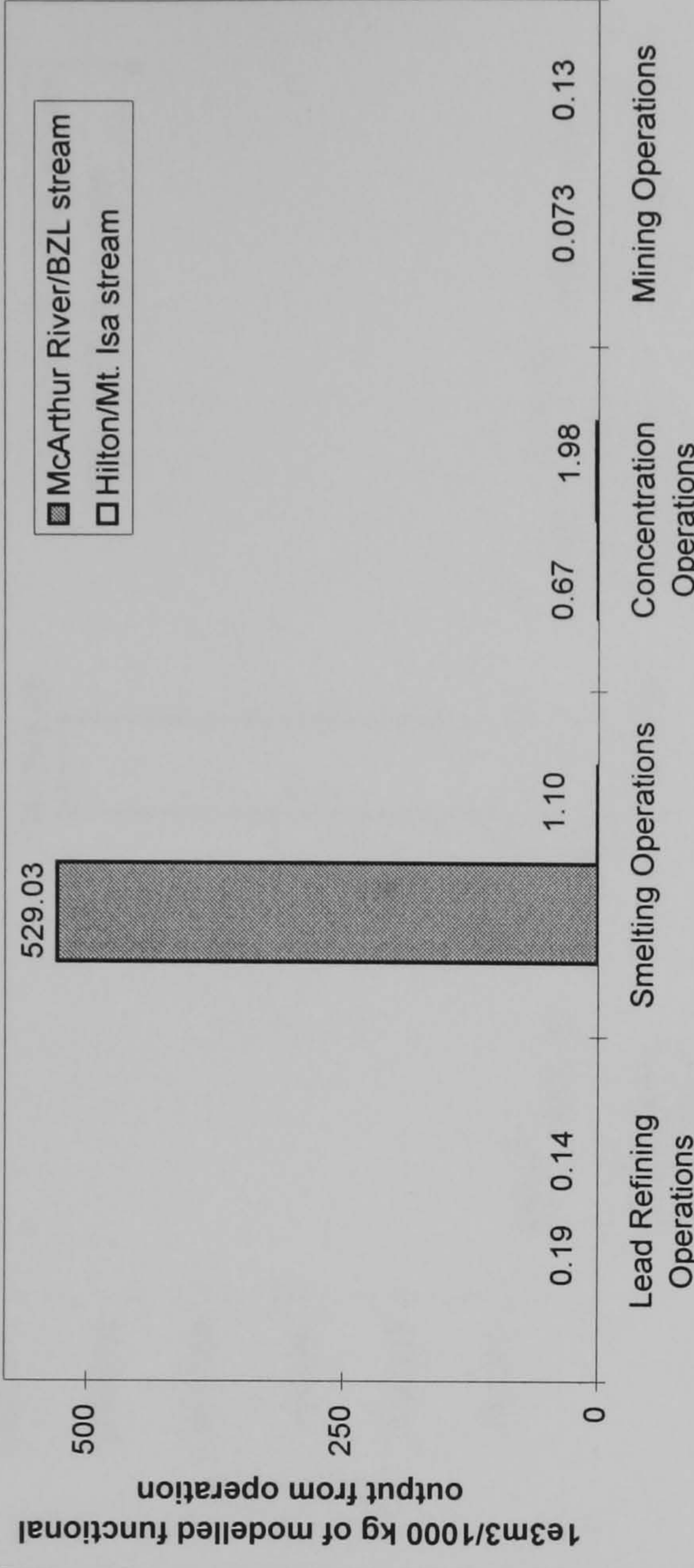
Graph 10.70: WMO -Photochemical oxidant formation (low)



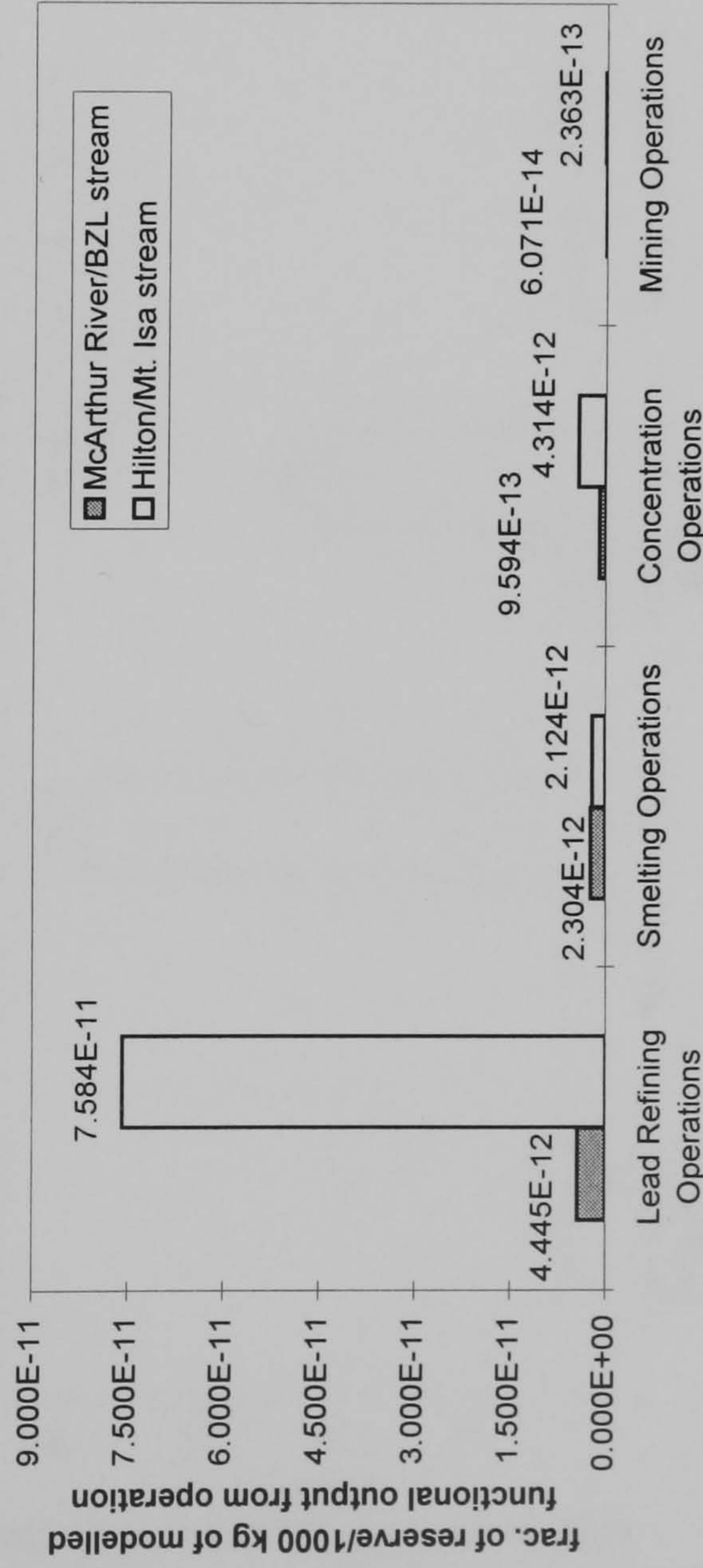
Graph 10.71: CML -Air Acidification



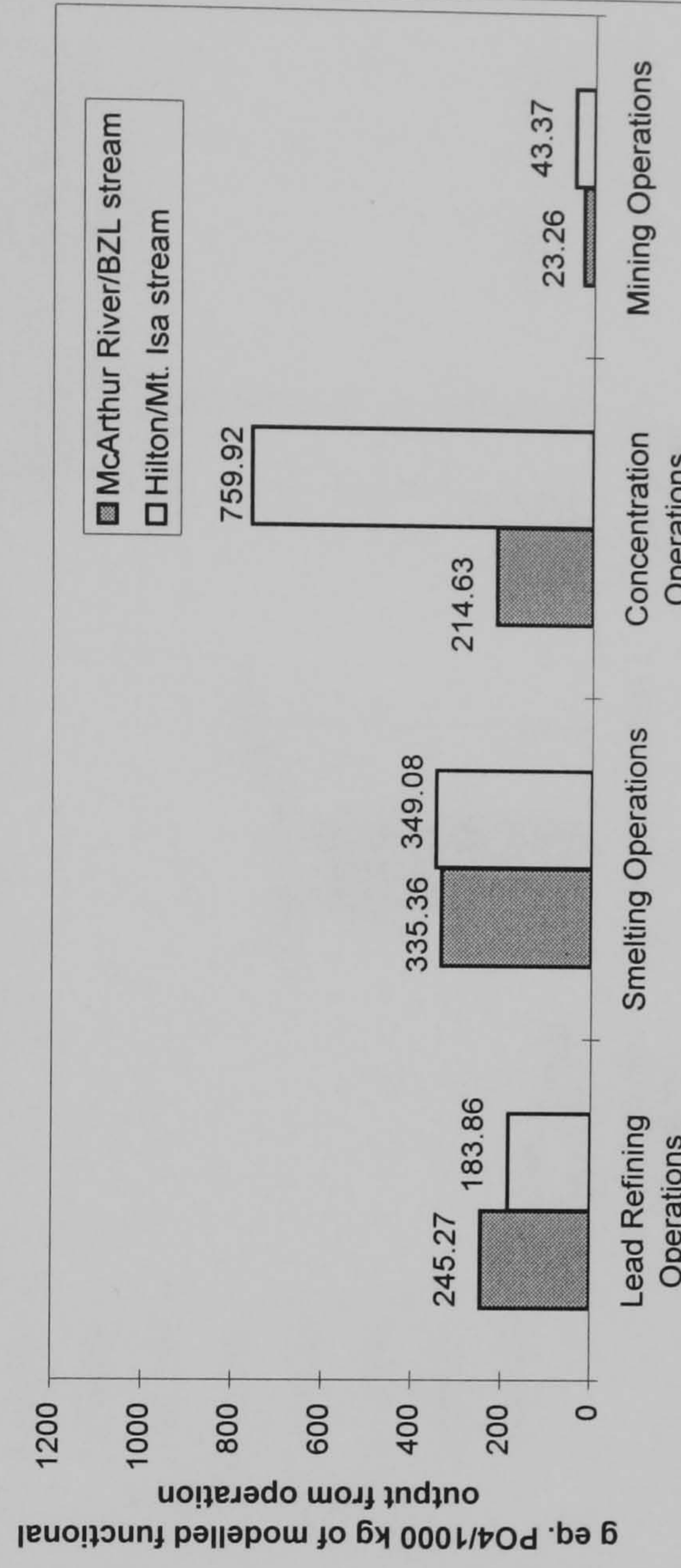
Graph 10.72: CML -Aquatic Eco-toxicity



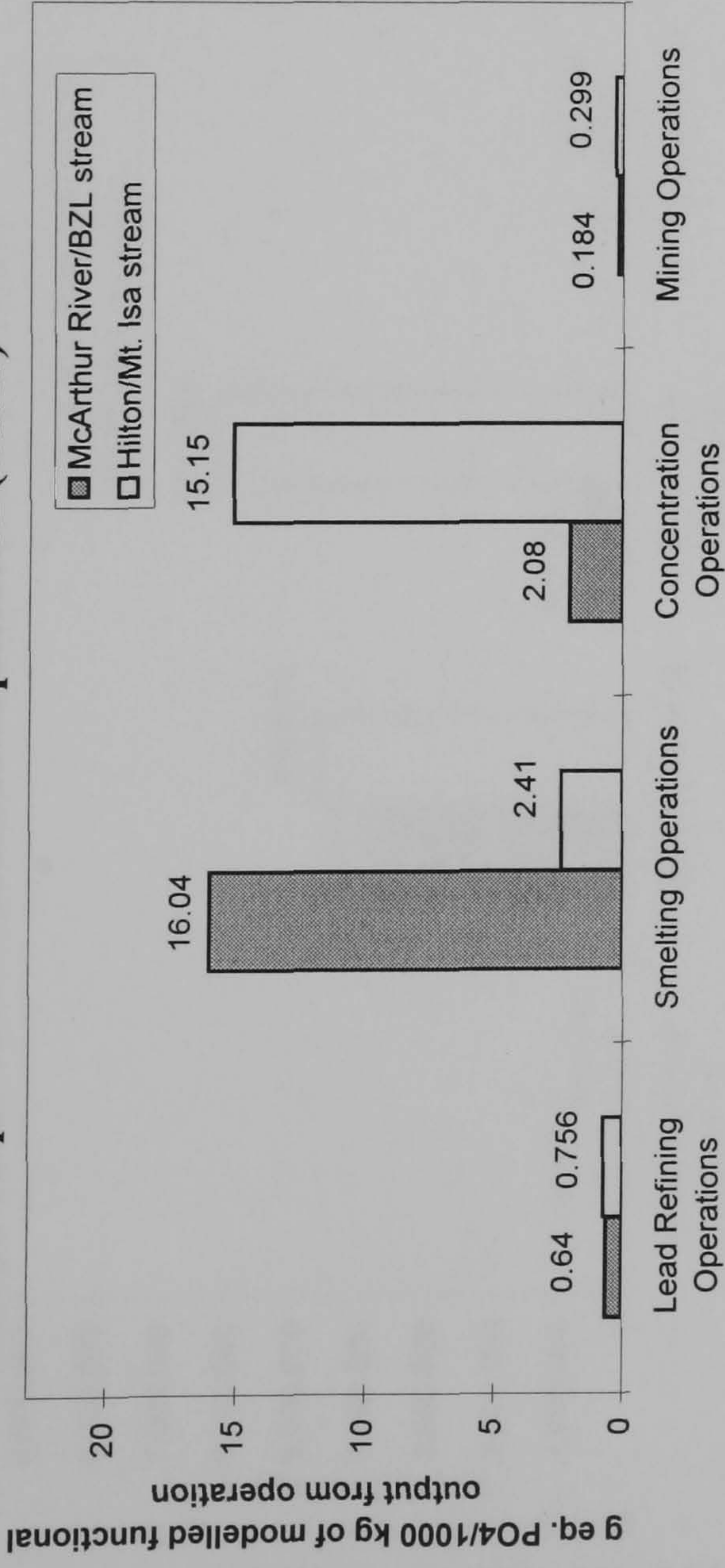
Graph 10.73: CML -Depletion on non-renewable resources



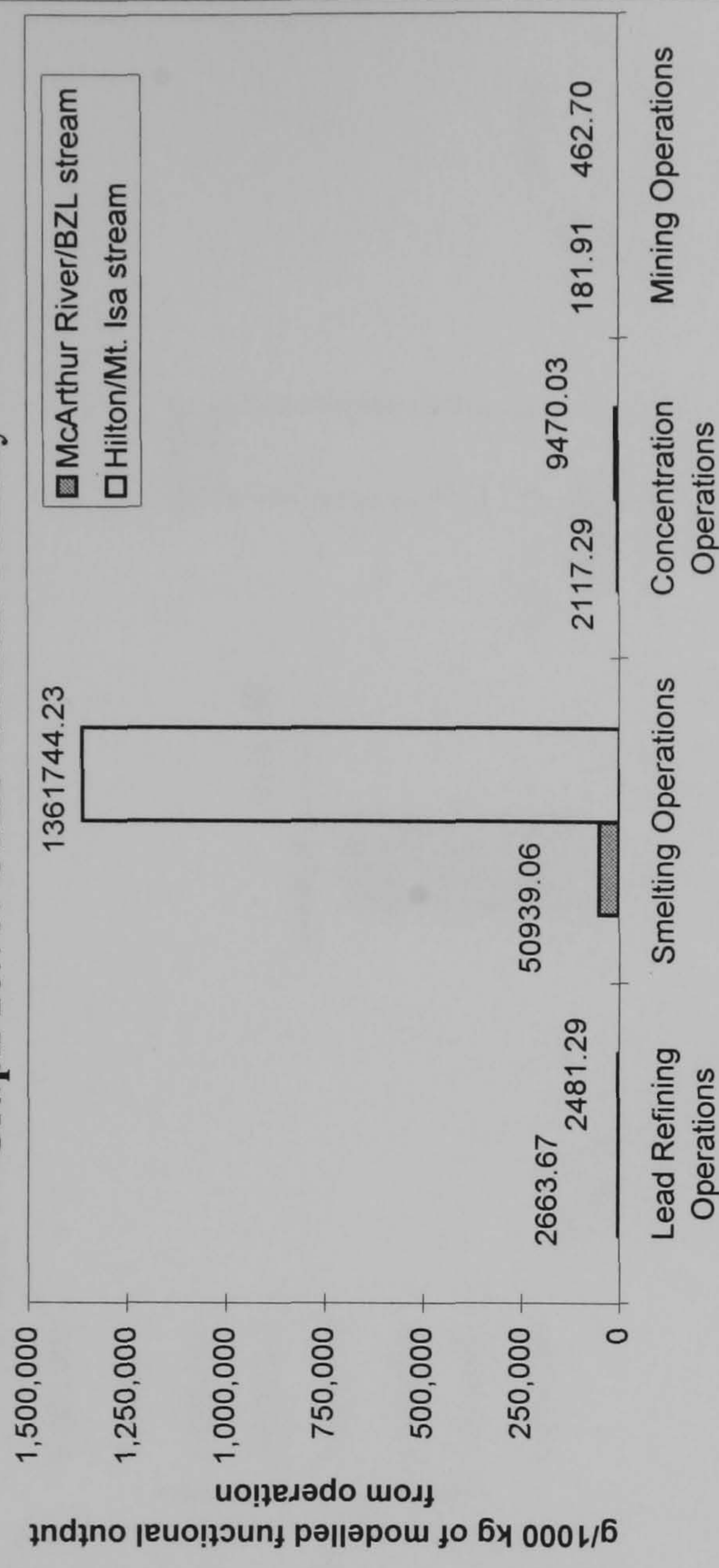
Graph 10.74: CML -Eutrophication



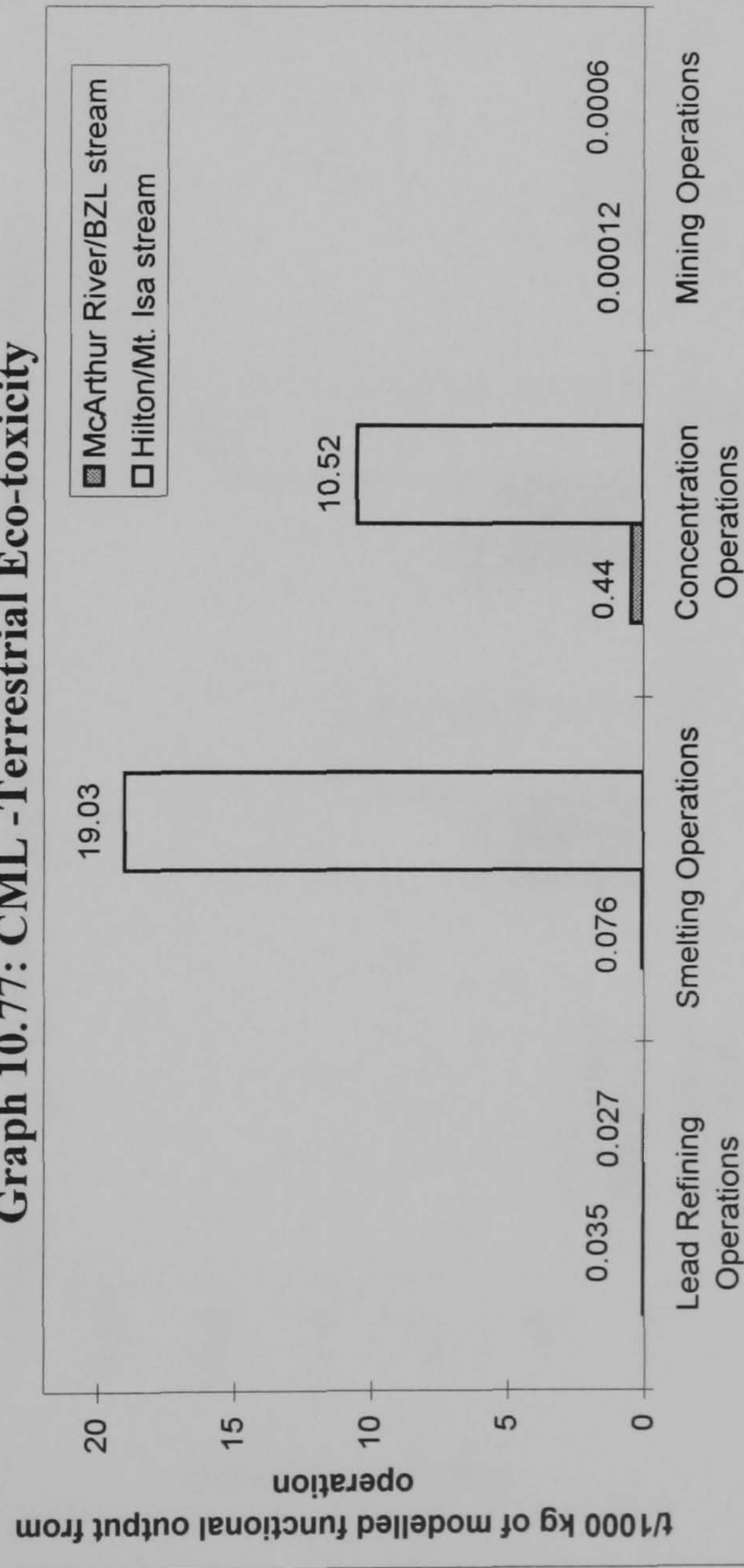
Graph 10.75: CML -Eutrophication (water)



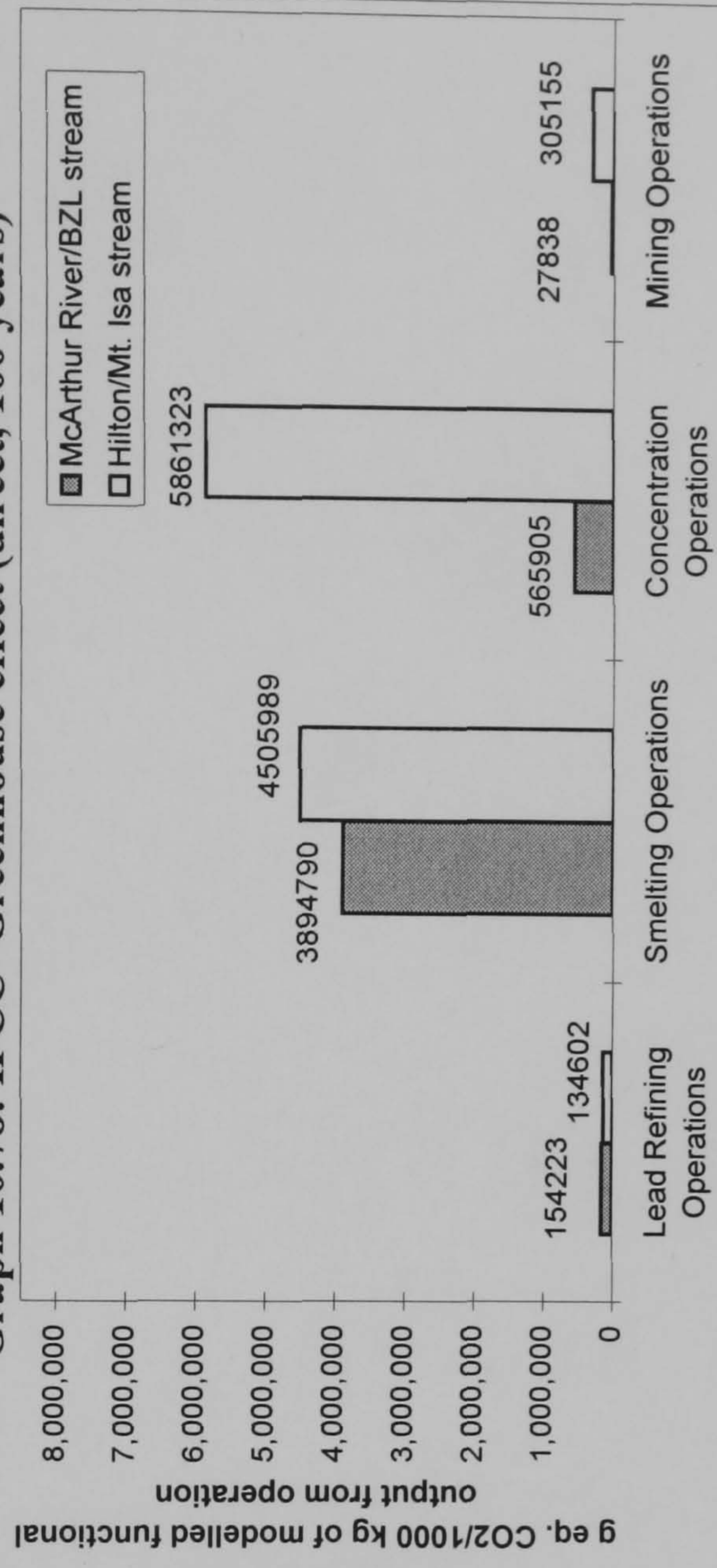
Graph 10.76: CML -Human Toxicity



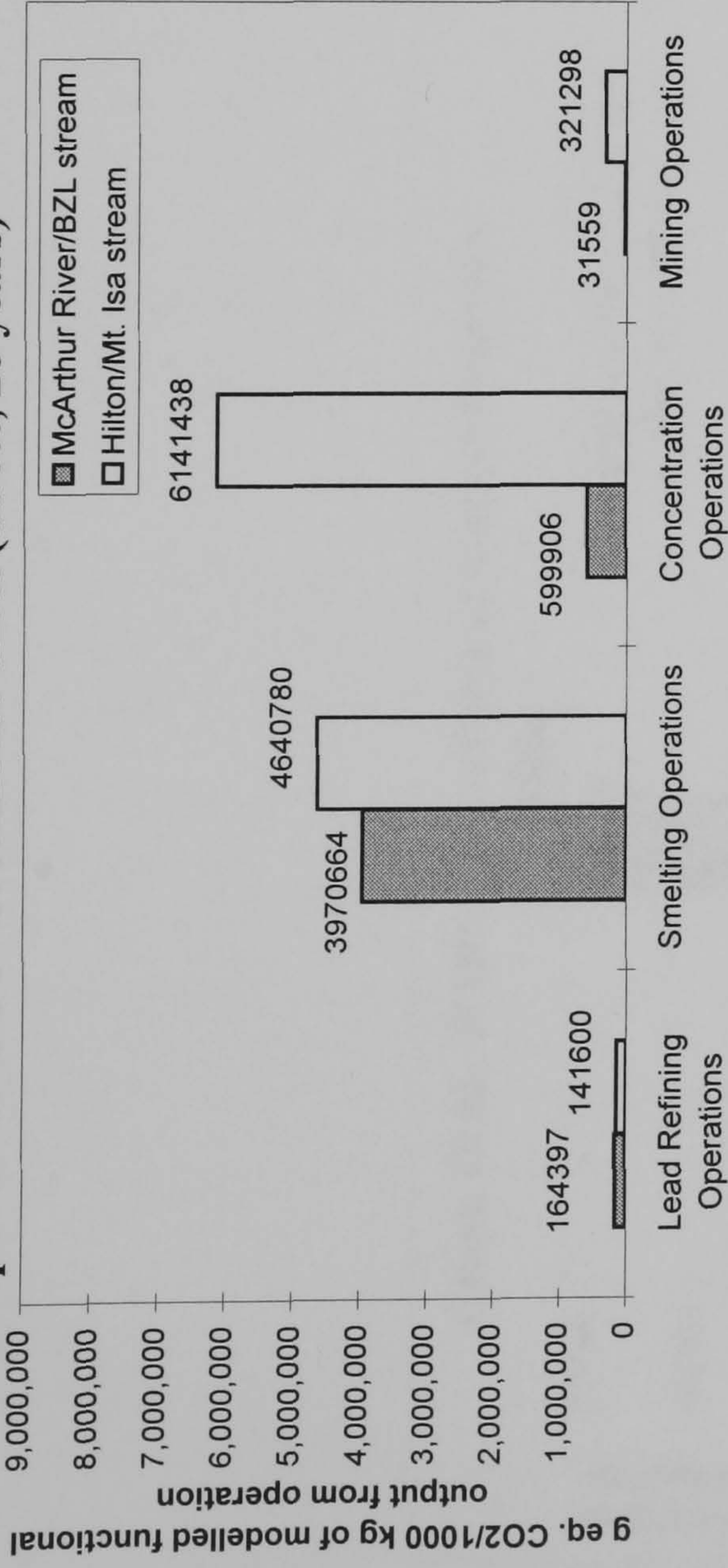
Graph 10.77: CML -Terrestrial Eco-toxicity



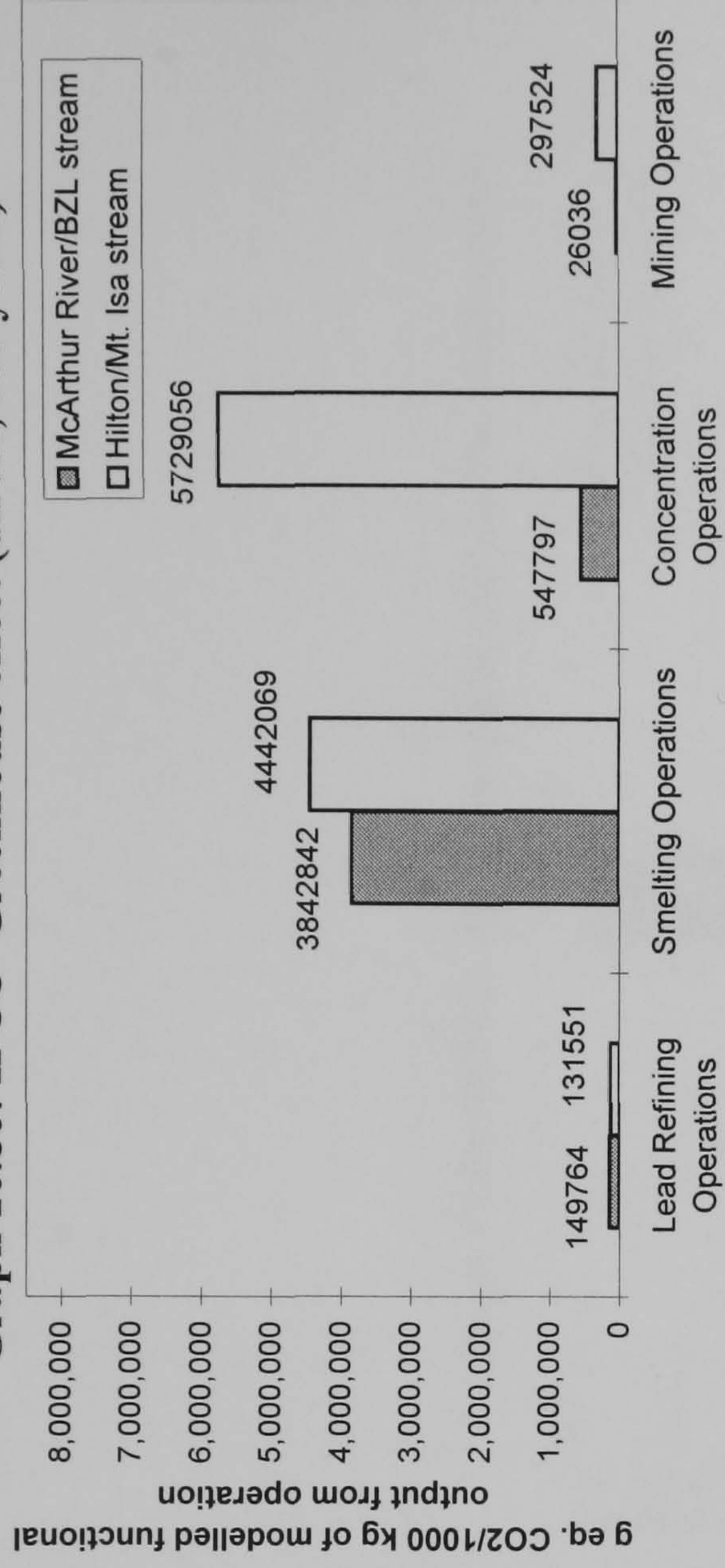
Graph 10.78: IPCC -Greenhouse effect (direct, 100 years)



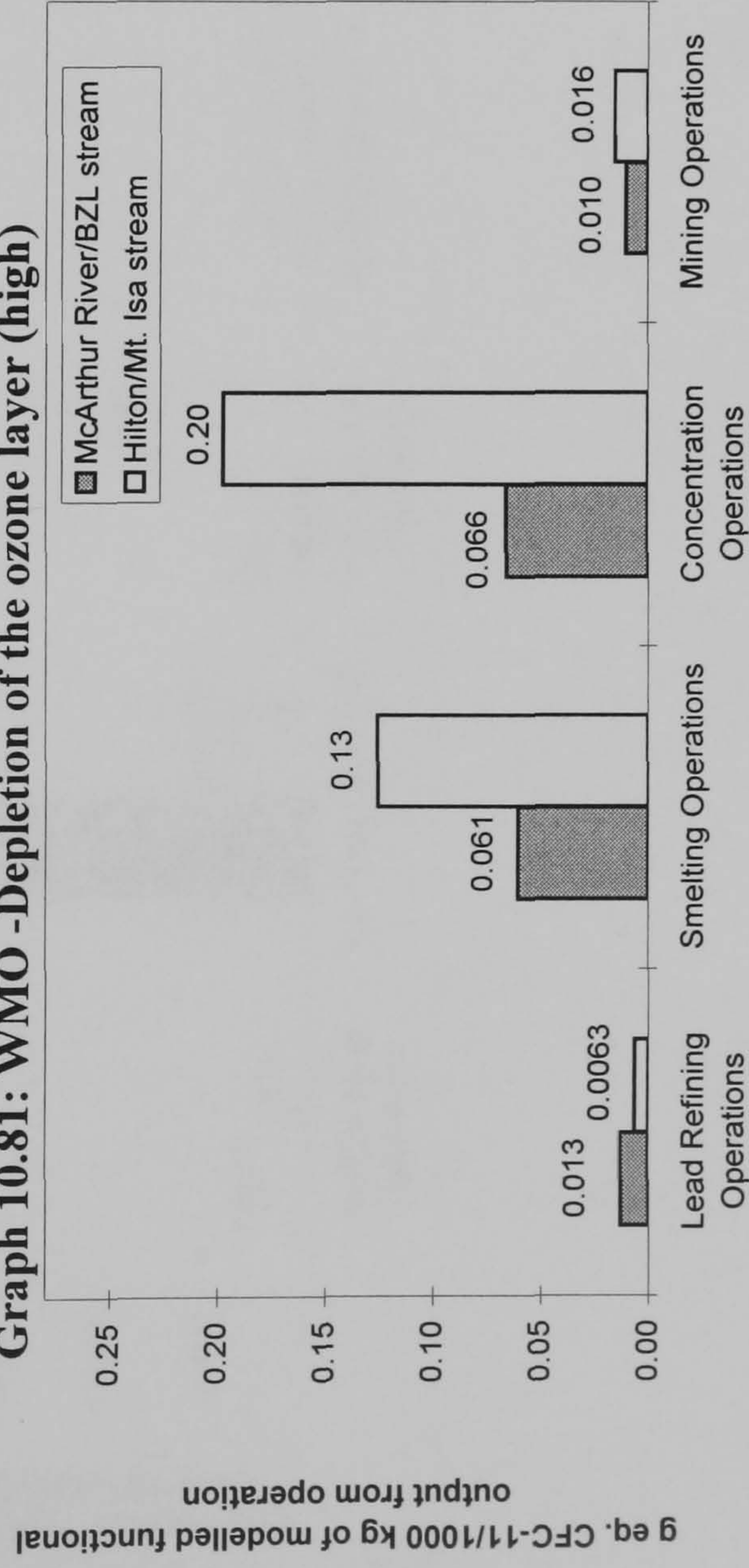
Graph 10.79: IPCC -Greenhouse effect (direct, 20 years)



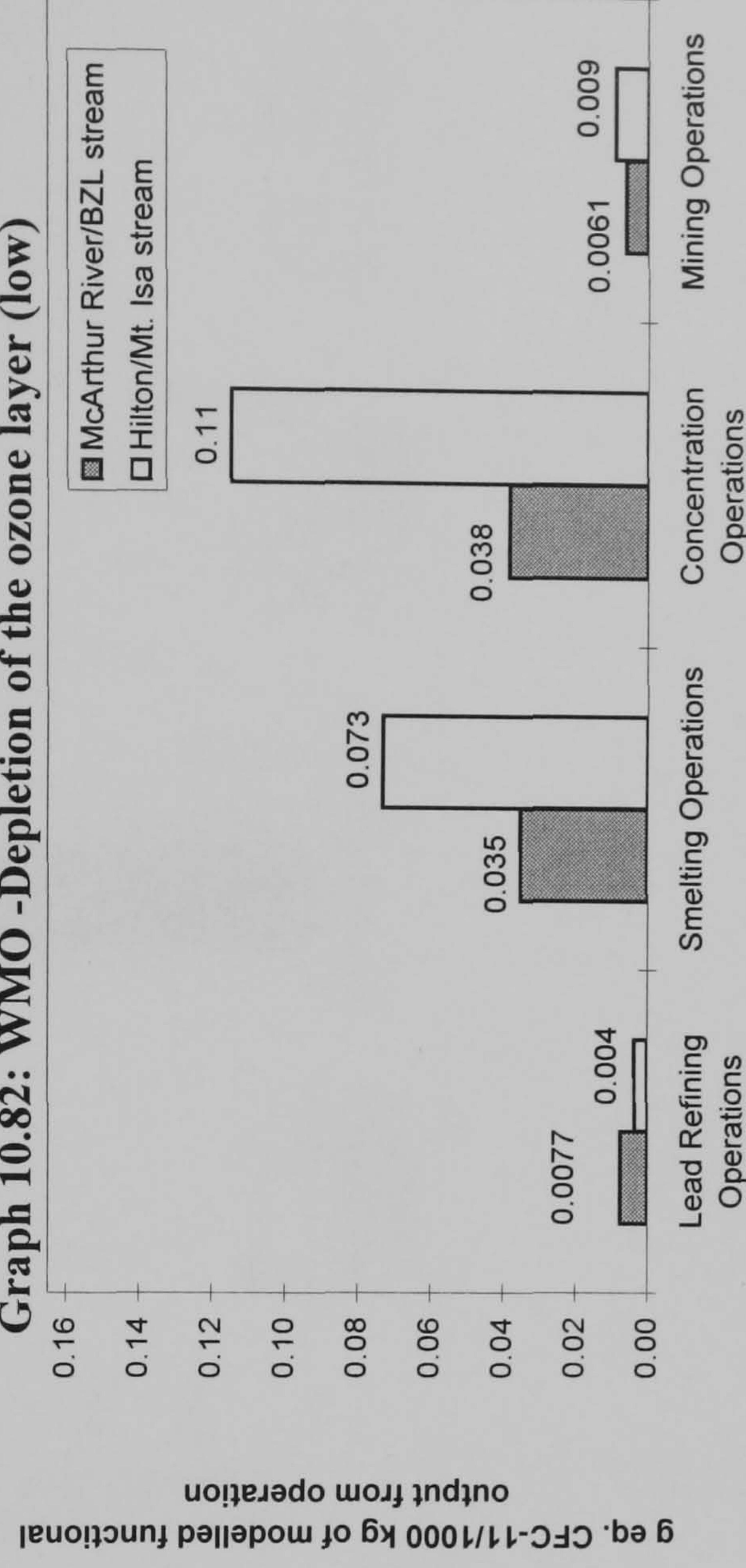
Graph 10.80: IPCC -Greenhouse effect (direct, 500 years)



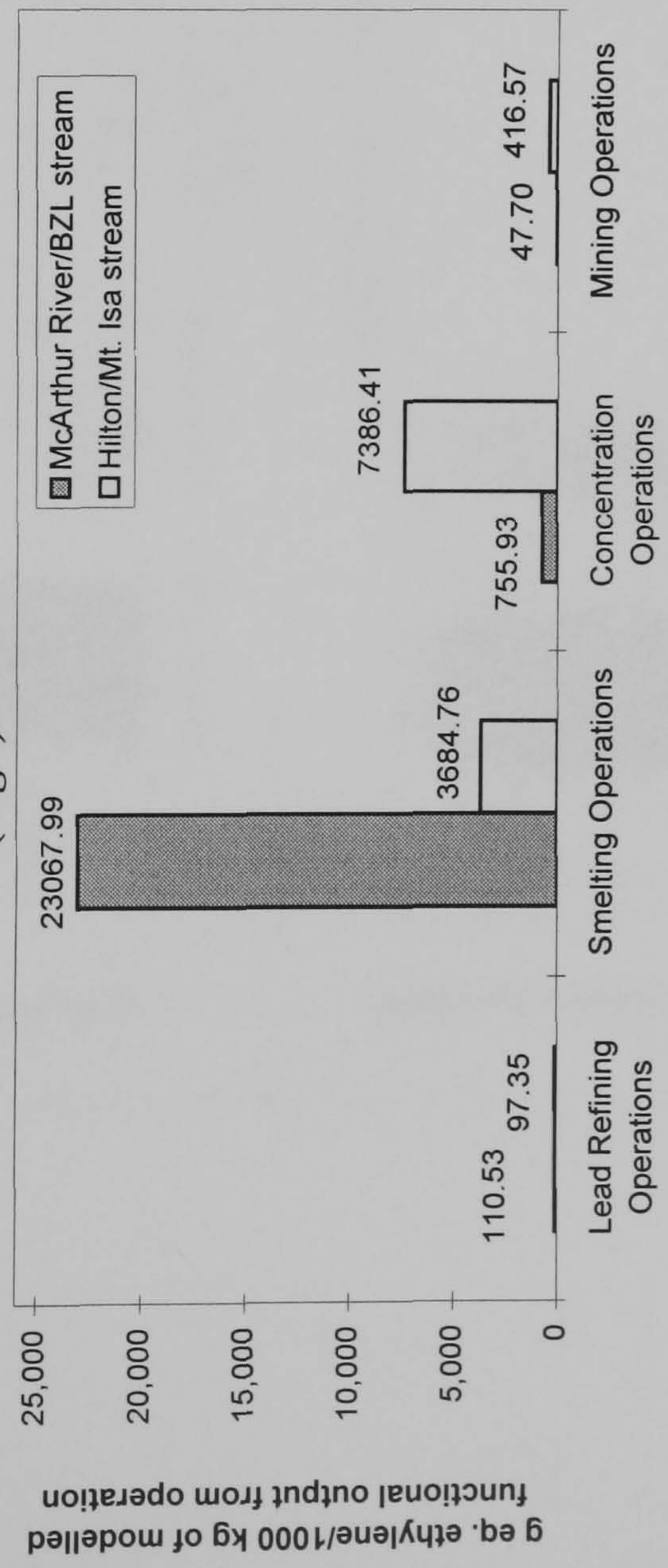
Graph 10.81: WMO -Depletion of the ozone layer (high)



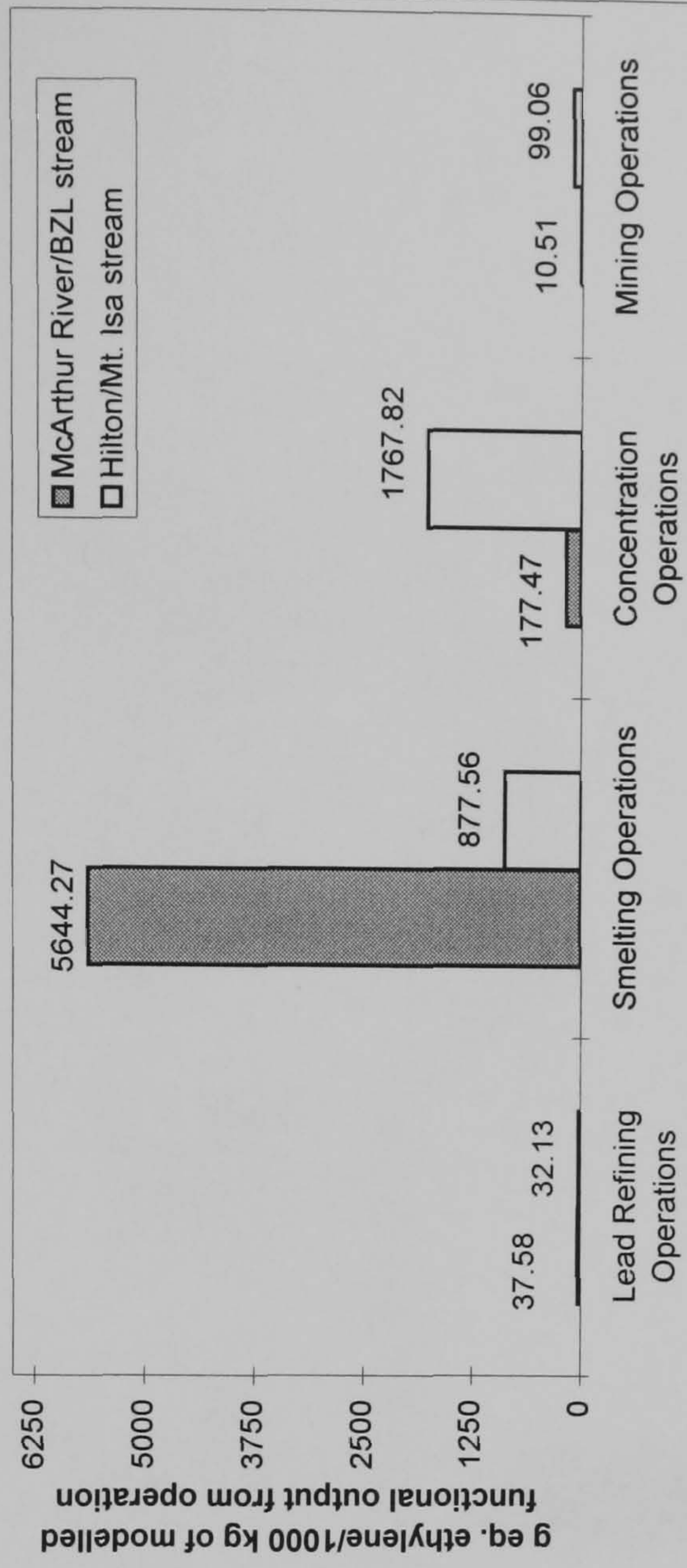
Graph 10.82: WMO -Depletion of the ozone layer (low)



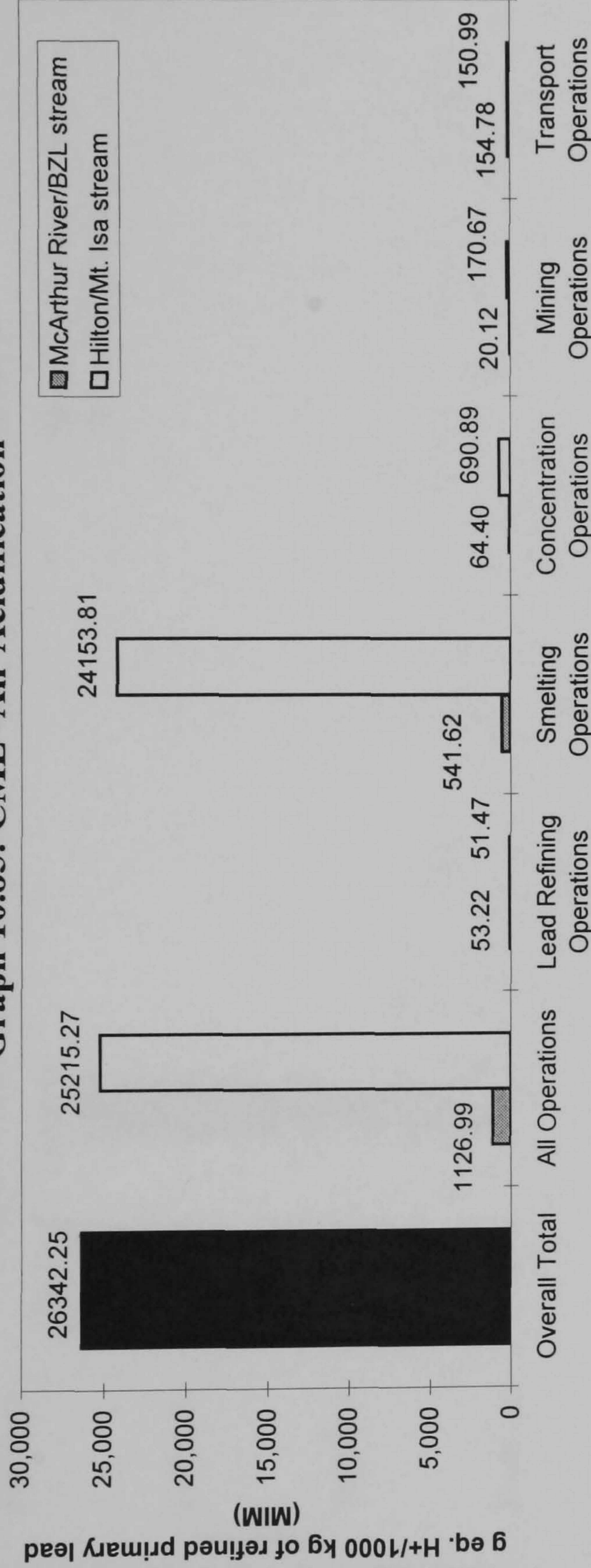
Graph 10.83: WMO - Photochemical oxidant formation (high)



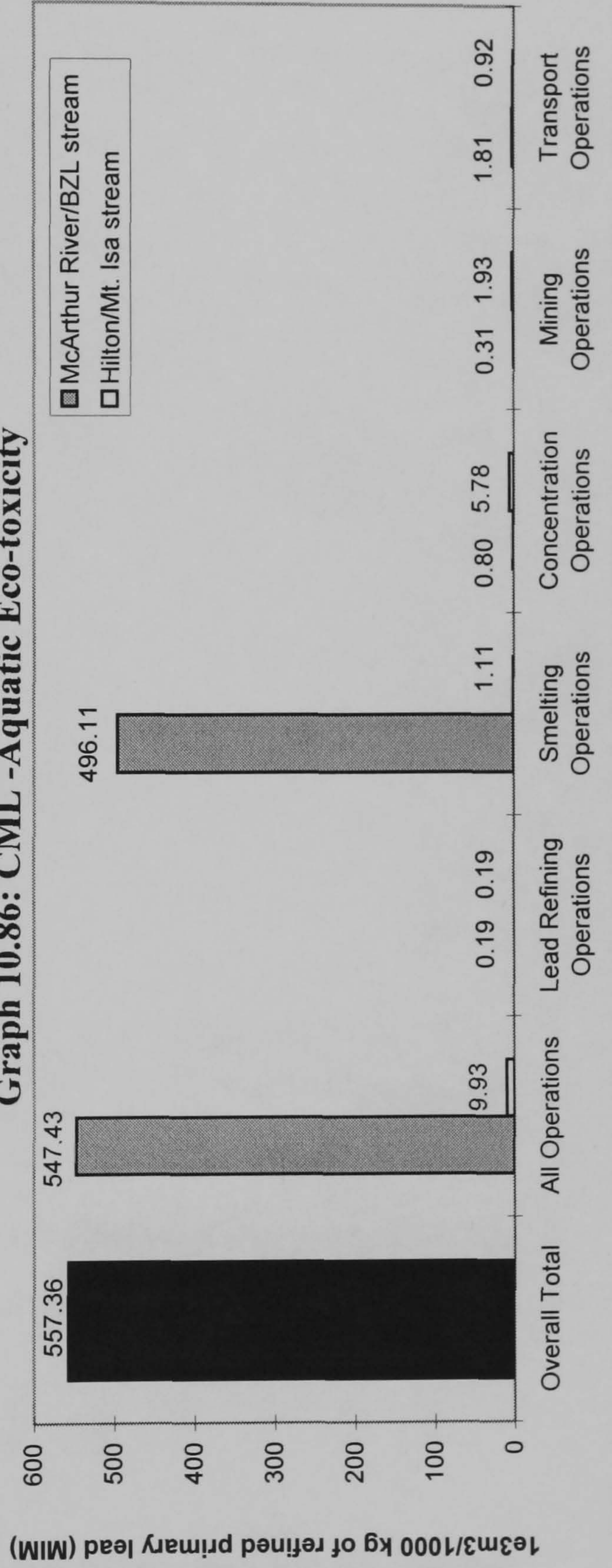
Graph 10.84: WMO - Photochemical oxidant formation (low)



Graph 10.85: CML - Air Acidification

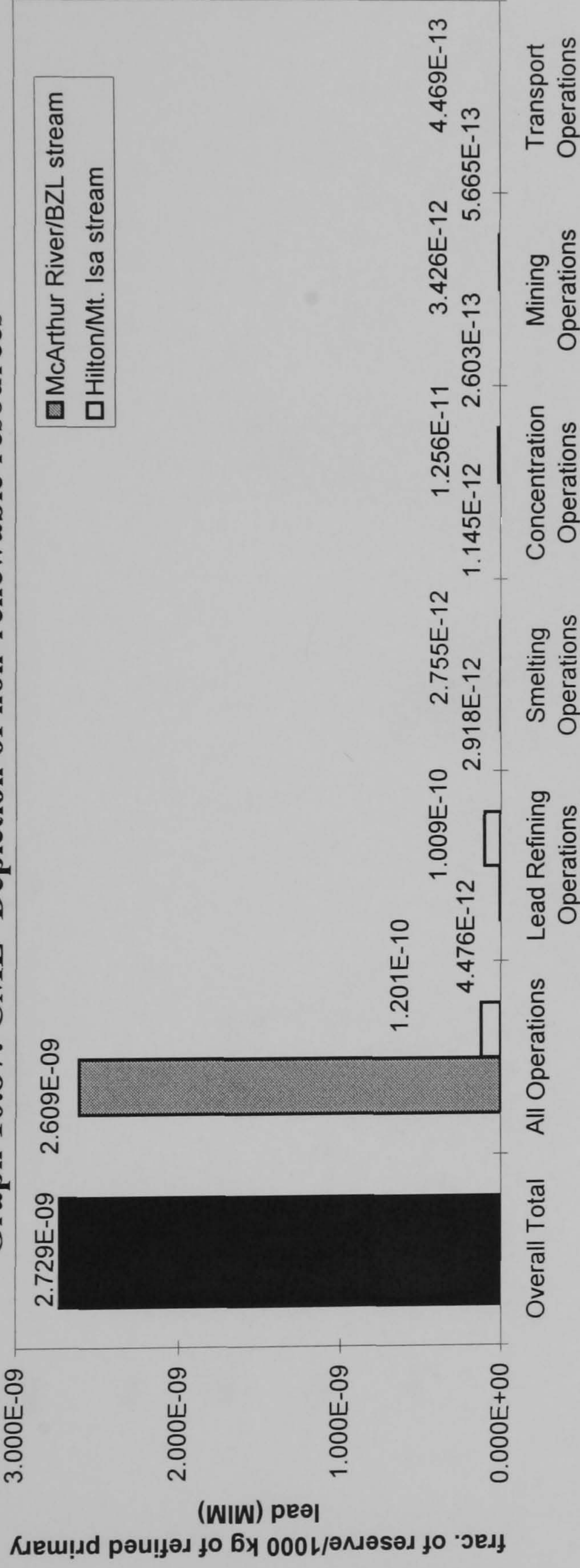


Graph 10.86: CML - Aquatic Eco-toxicity

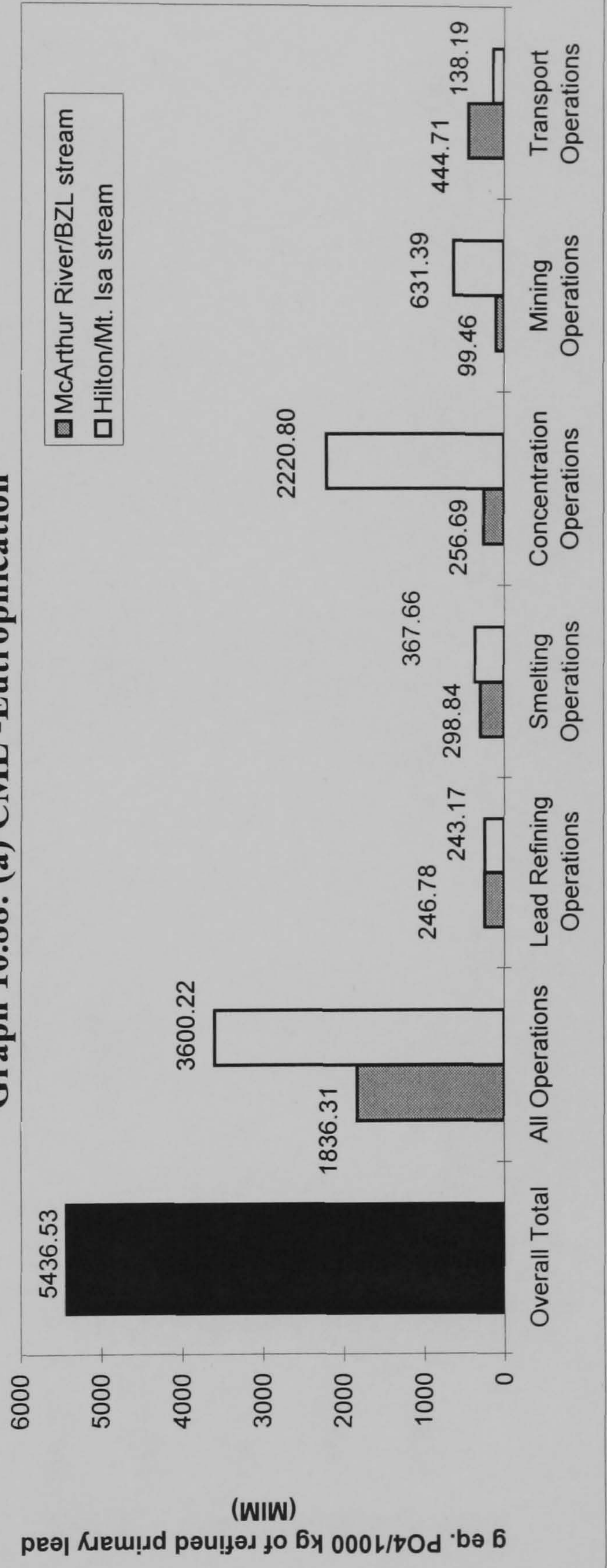


MIM Pb LCA (unallocated)

Graph 10.87: CML - Depletion of non-renewable resources

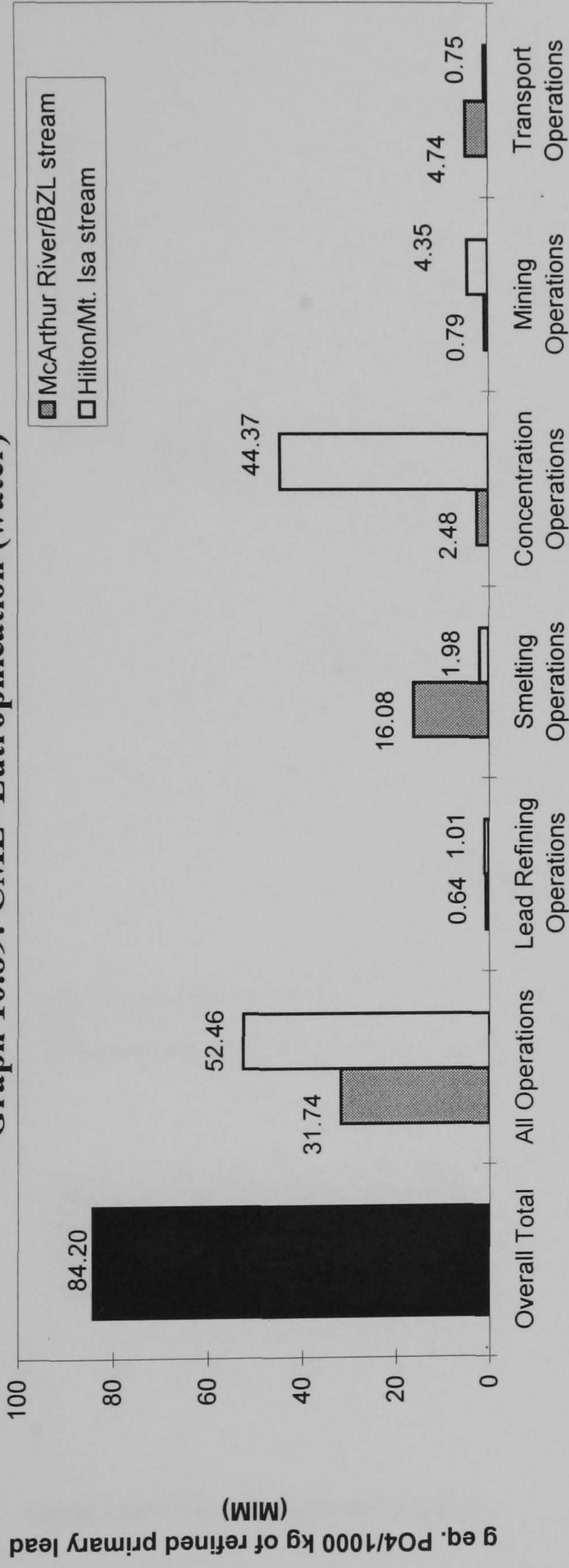


Graph 10.88: (a) CML - Eutrophication

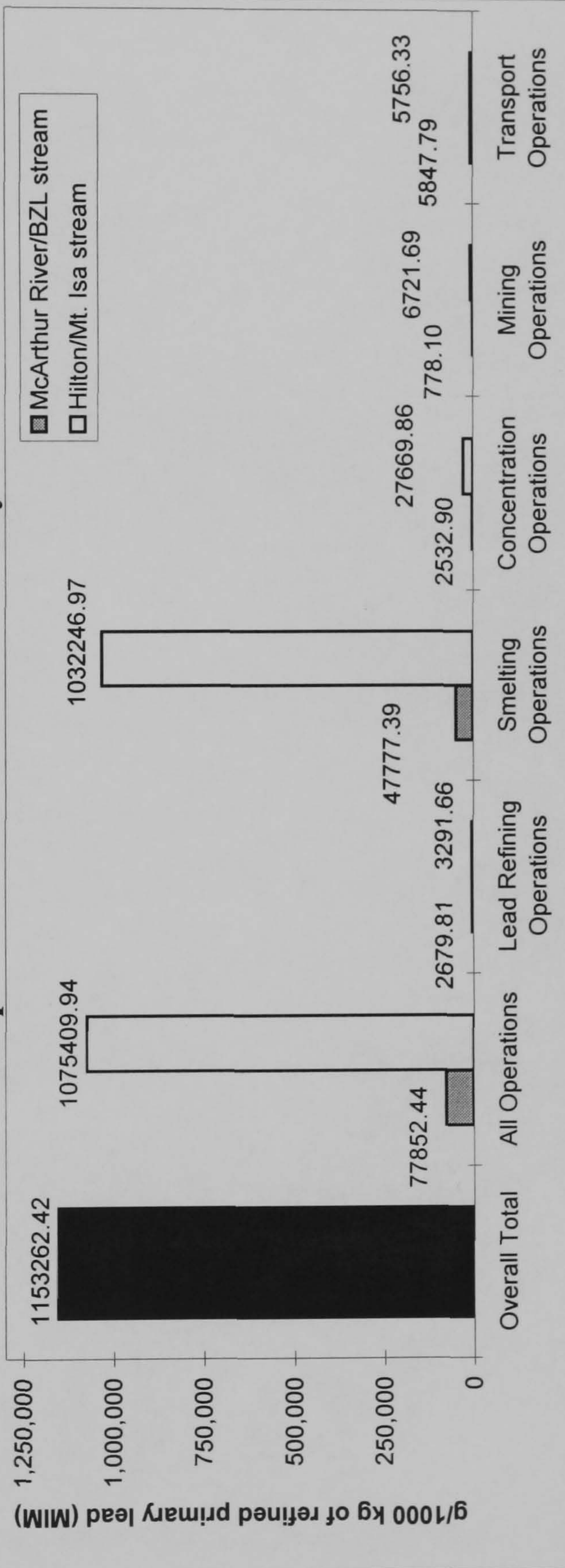


MIM Pb LCA (unallocated)

Graph 10.89: CML -Eutrophication (water)

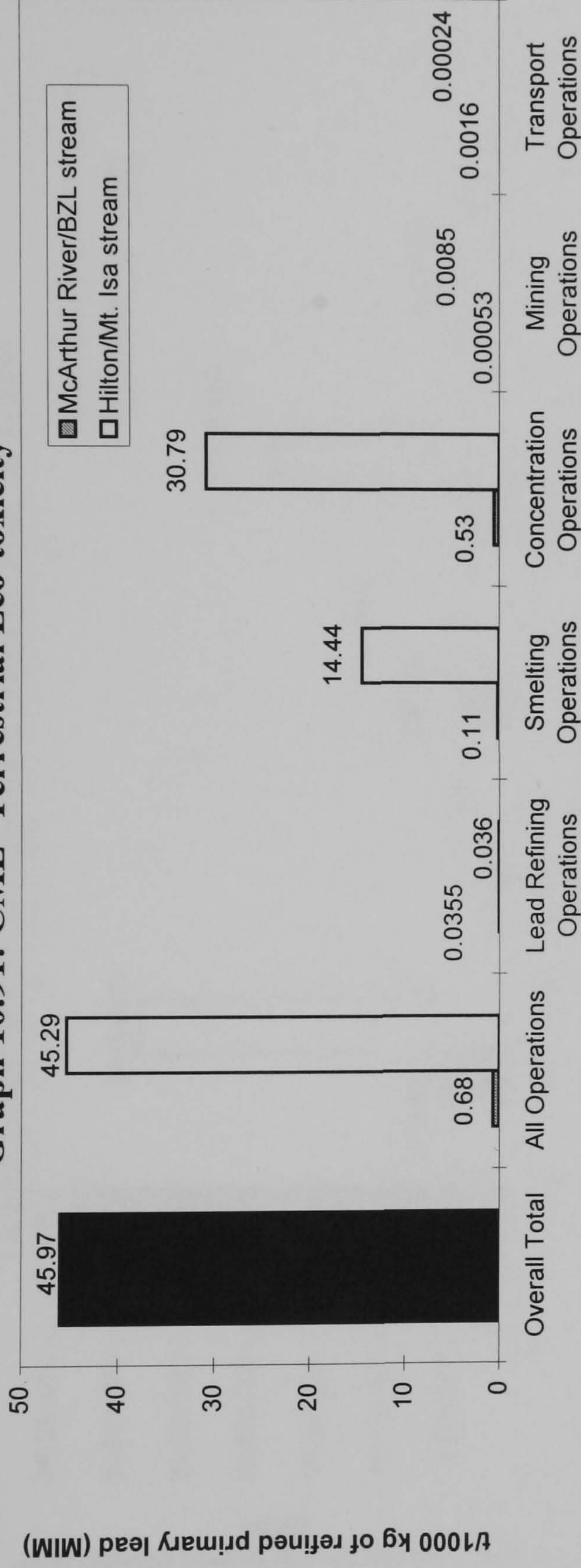


Graph 10.90: CML -Human Toxicity

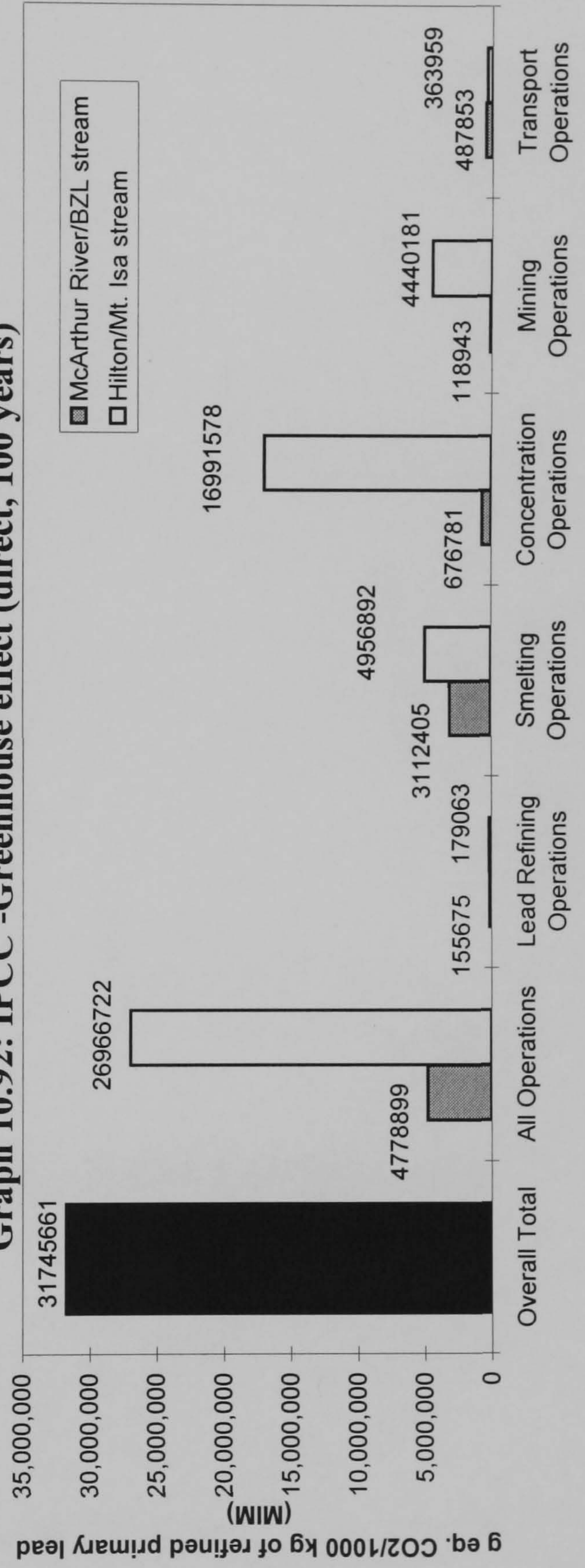


MIM Pb LCA (unallocated)

Graph 10.91: CML -Terrestrial Eco-toxicity

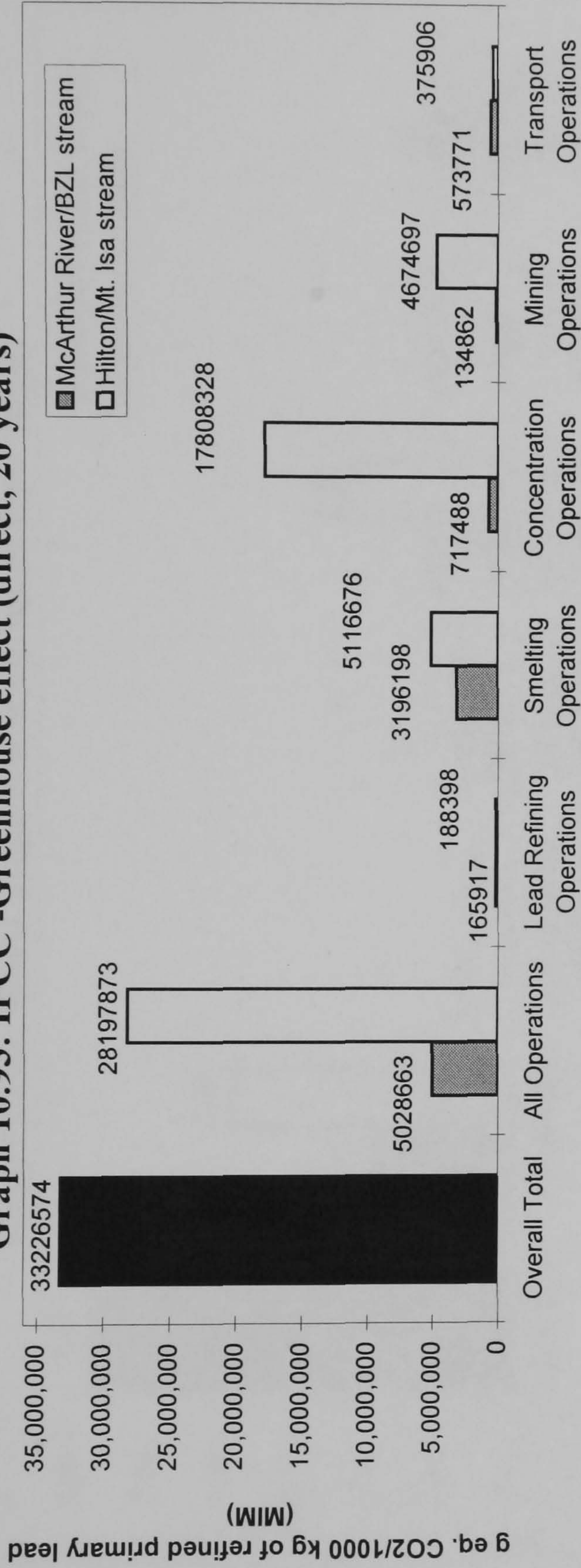


Graph 10.92: IPCC -Greenhouse effect (direct, 100 years)

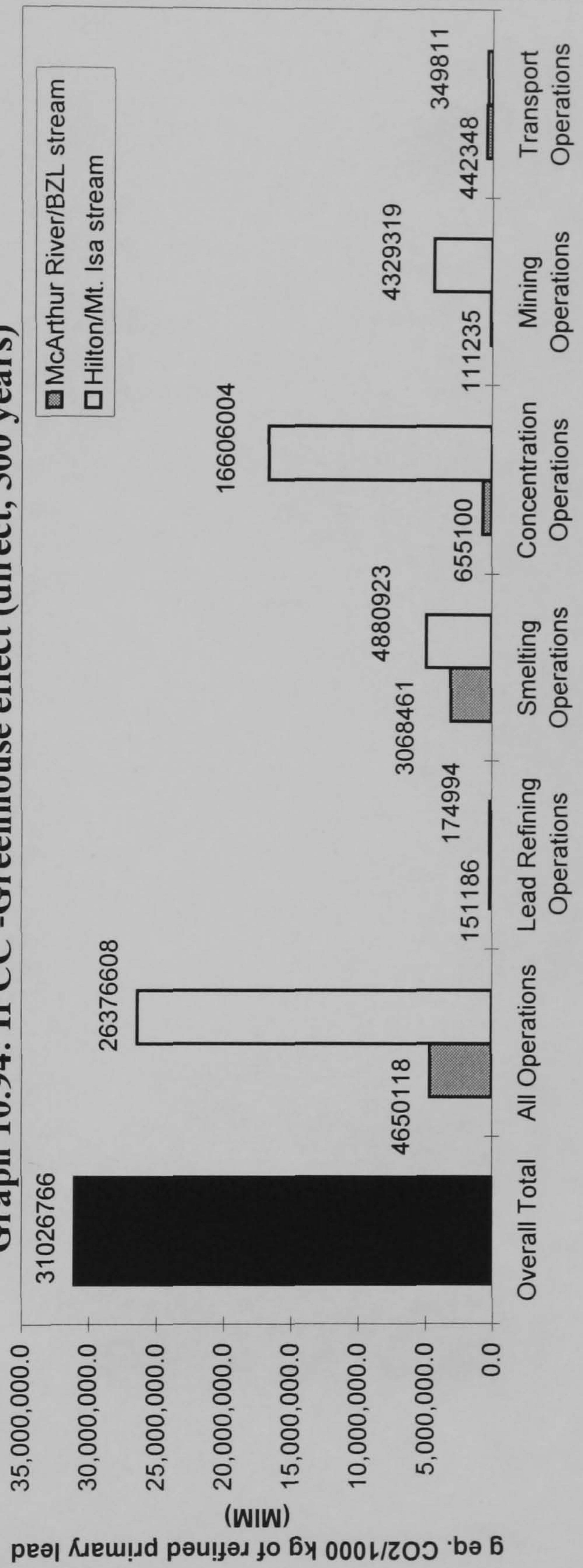


MIM Pb LCA (unallocated)

Graph 10.93: IPCC -Greenhouse effect (direct, 20 years)

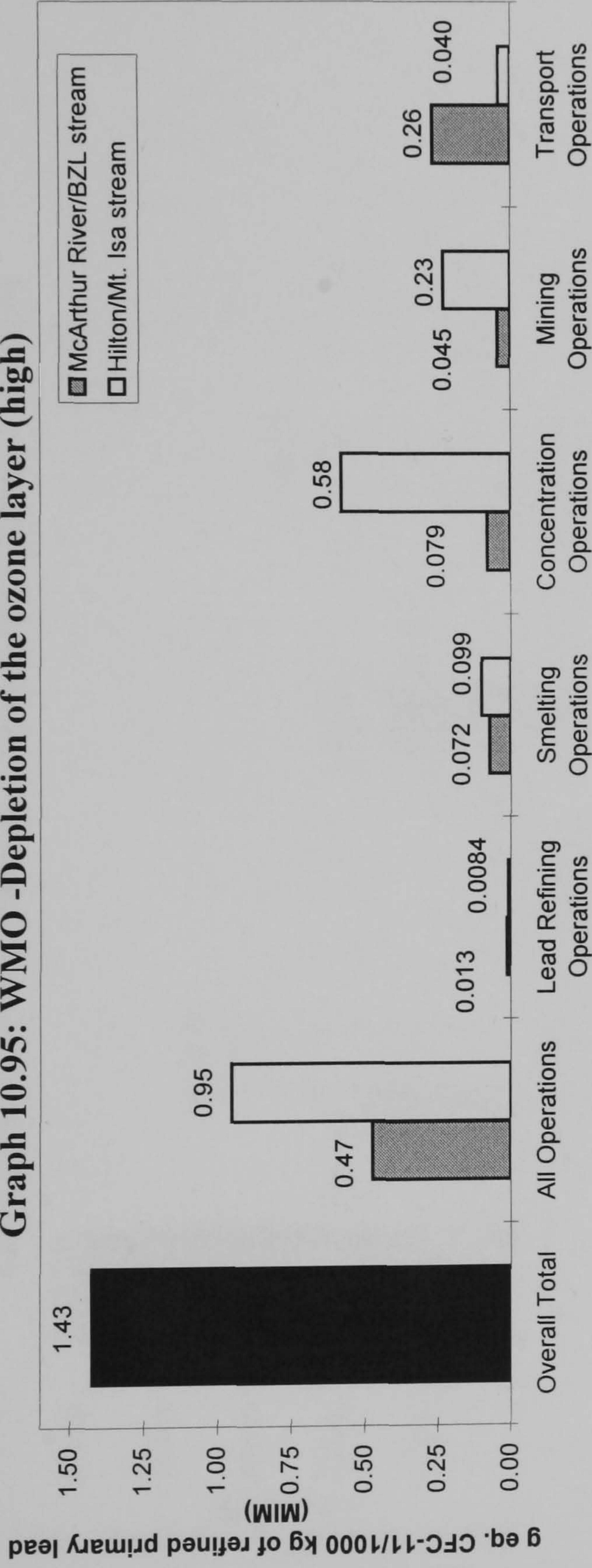


Graph 10.94: IPCC -Greenhouse effect (direct, 500 years)

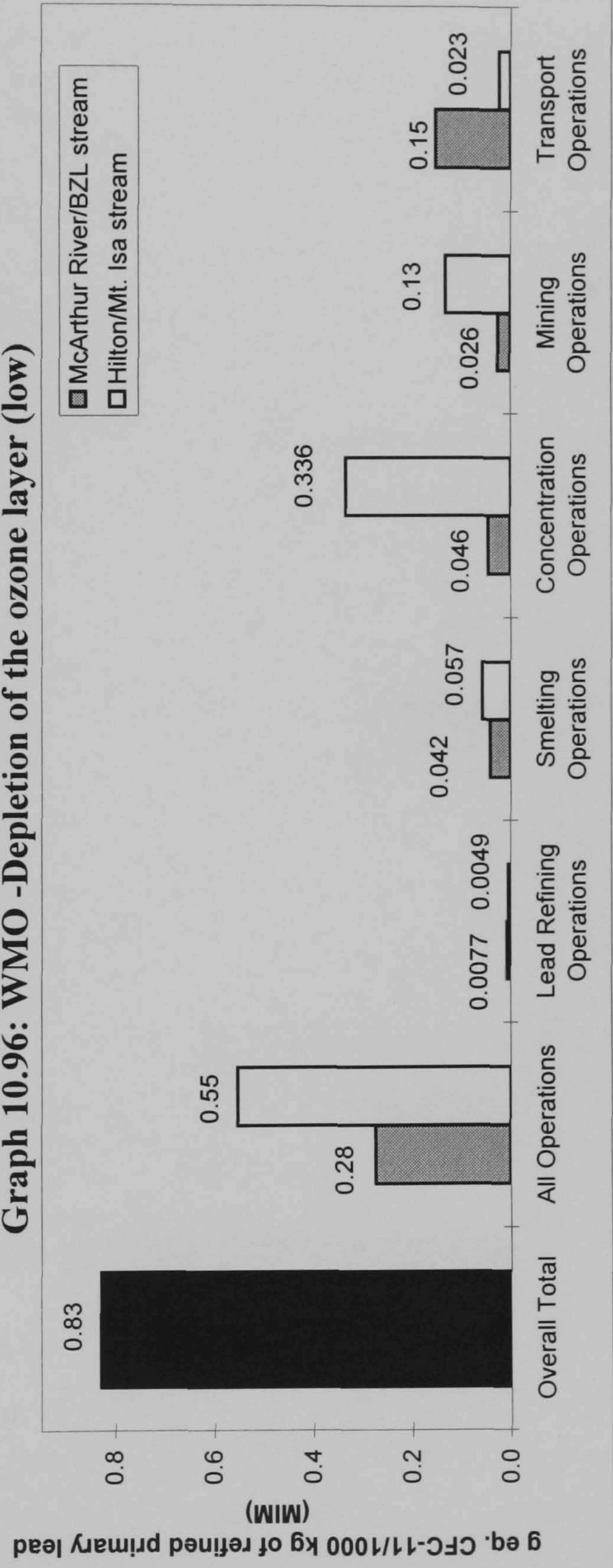


MIM Pb LCA (unallocated)

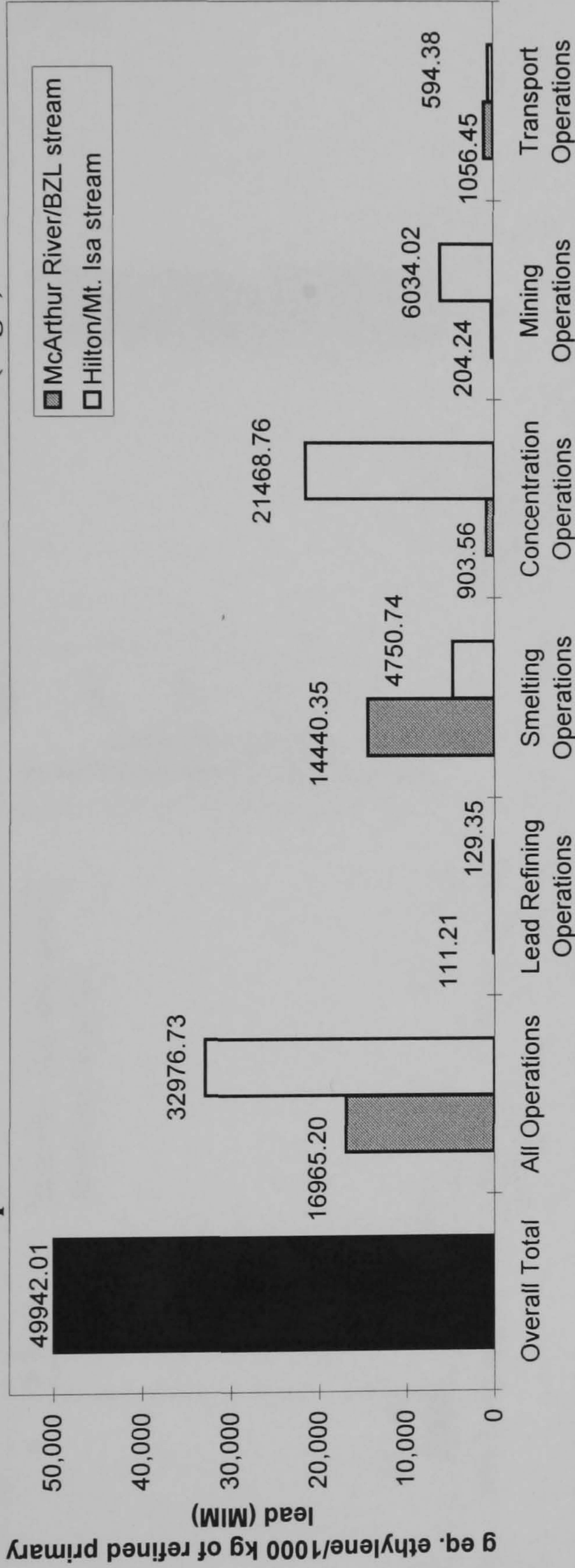
Graph 10.95: WMO -Depletion of the ozone layer (high)



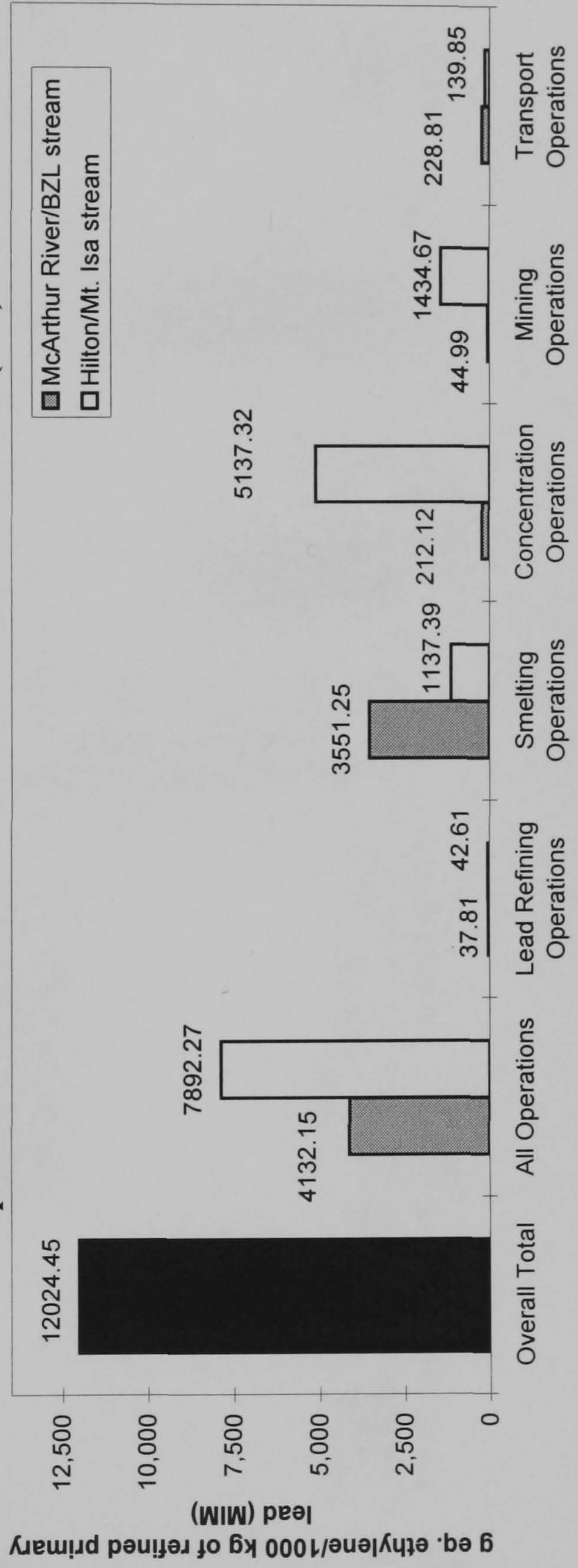
Graph 10.96: WMO -Depletion of the ozone layer (low)



Graph 10.97: WMO -Photochemical oxidant formation (high)

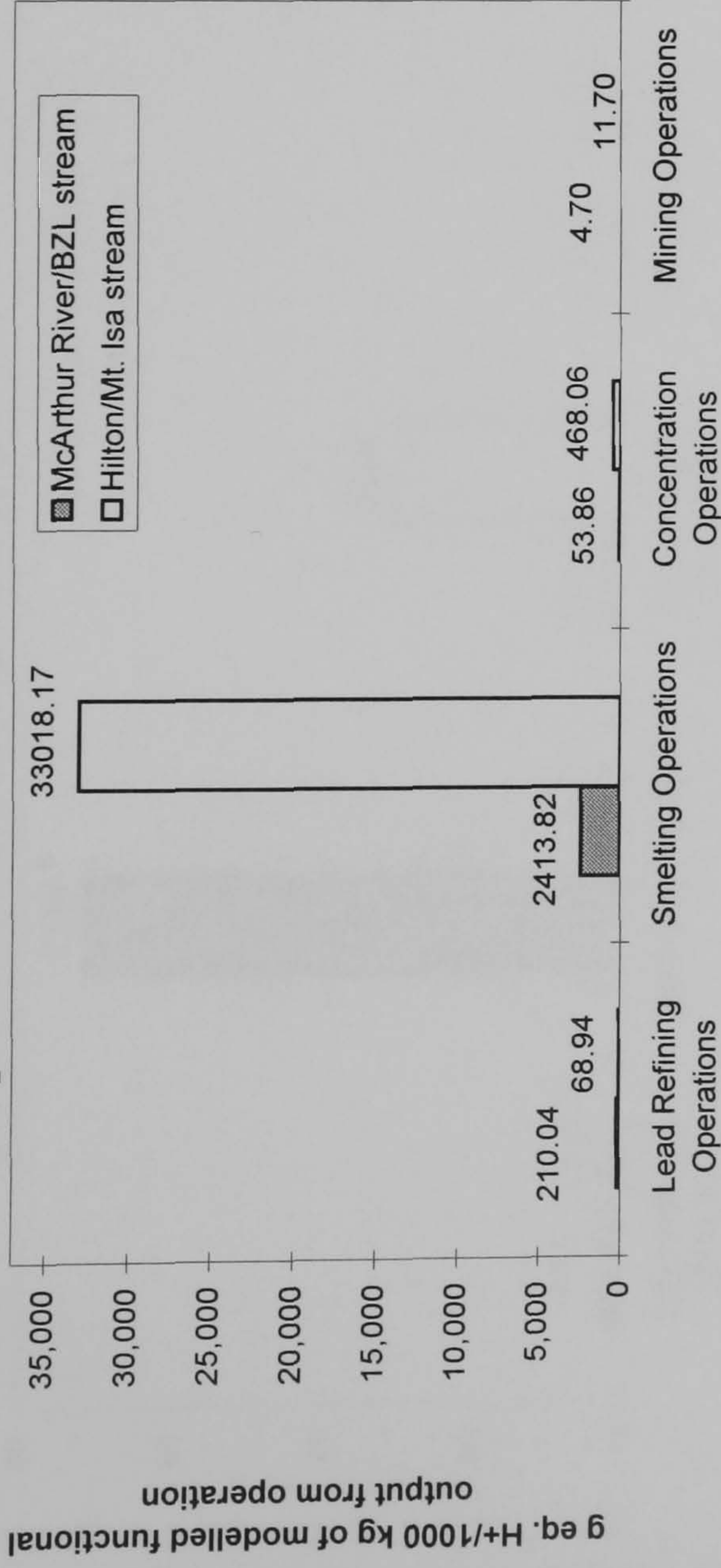


Graph 10.98: WMO -Photochemical oxidant formation (low)

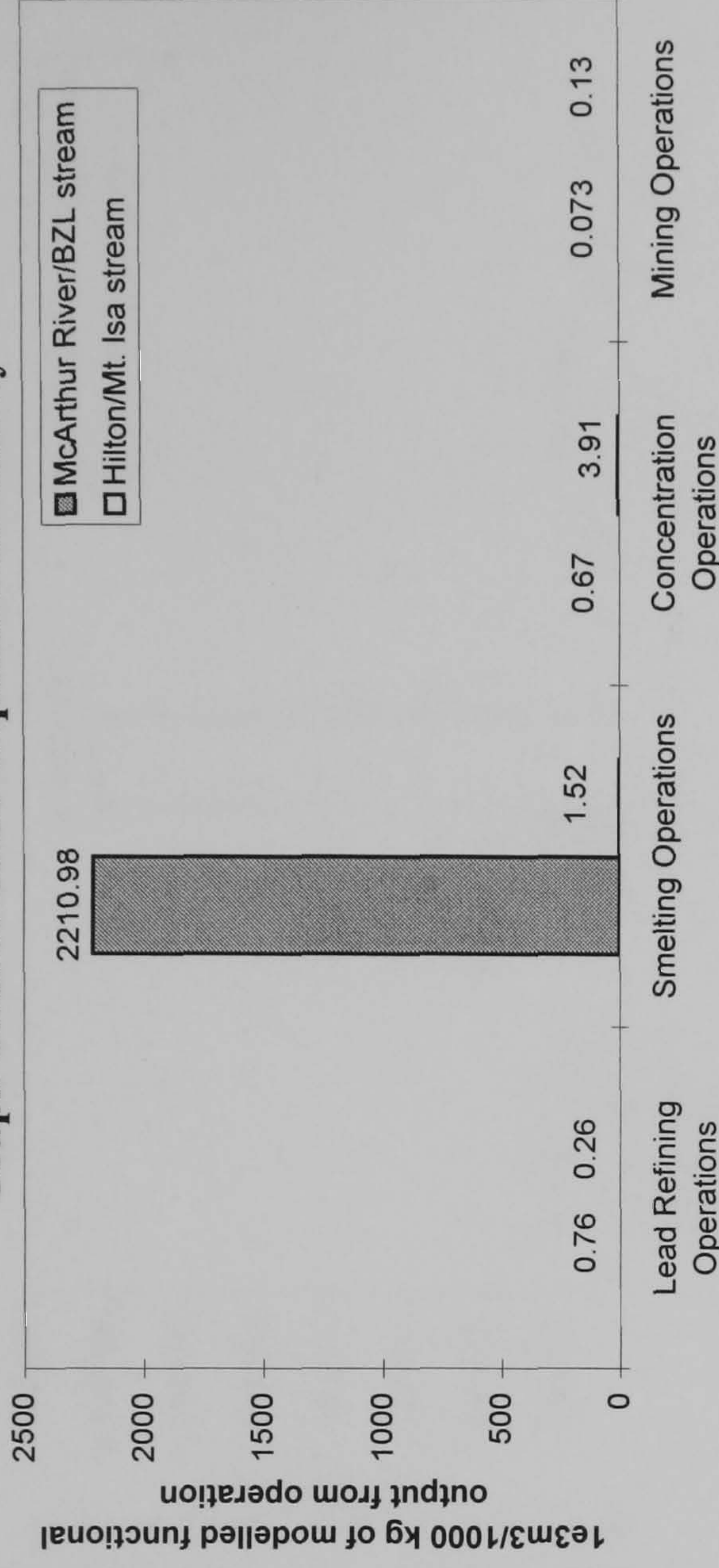


MIM Pb LCA (unallocated)

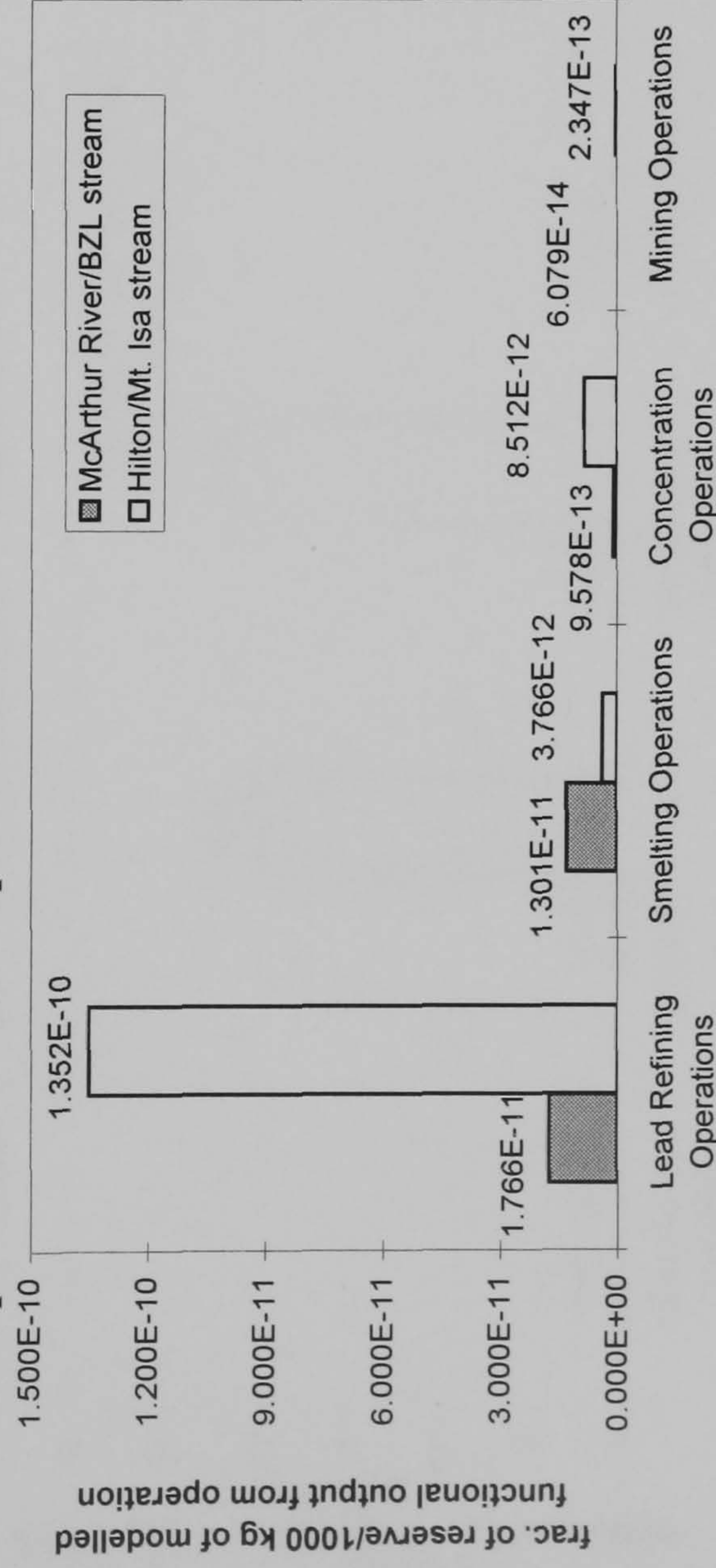
Graph 10.99: CML -Air Acidification



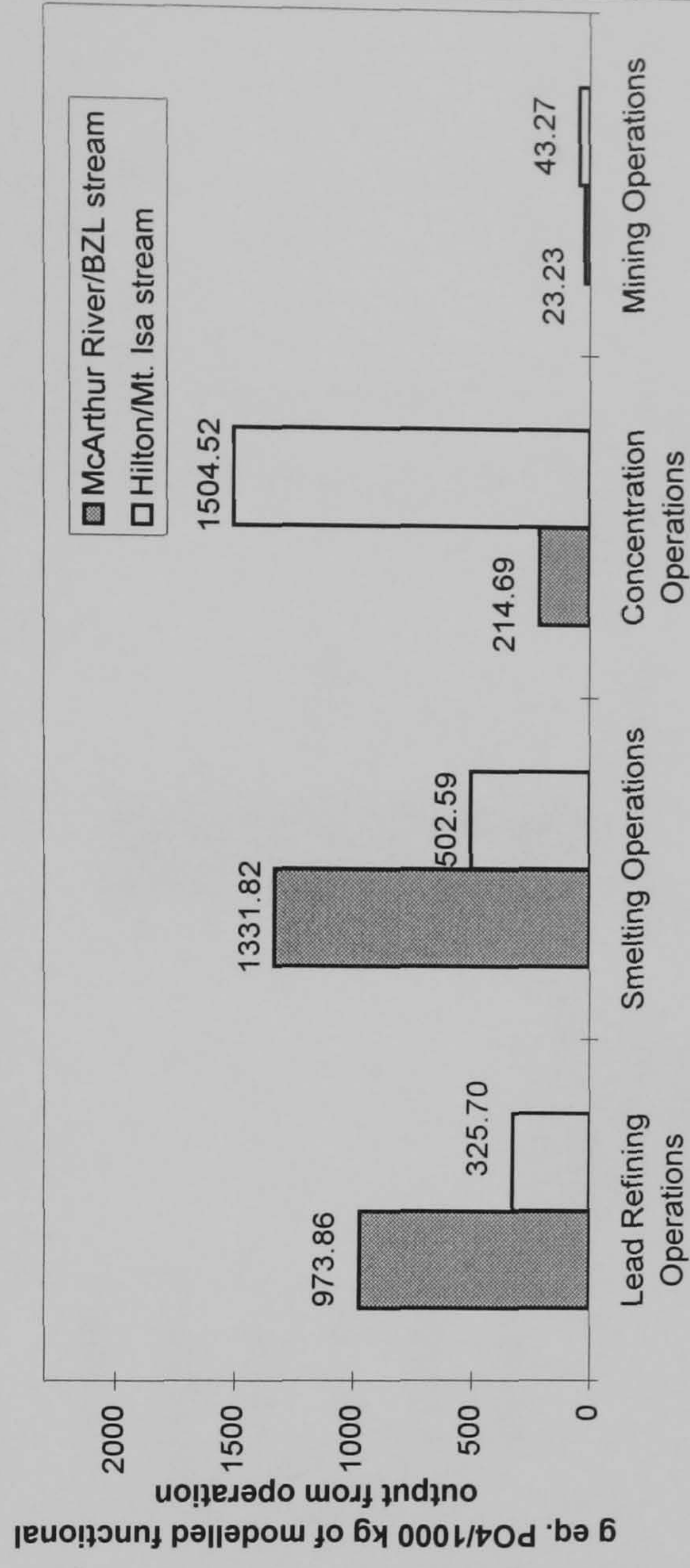
Graph 10.100: CML -Aquatic Eco-toxicity



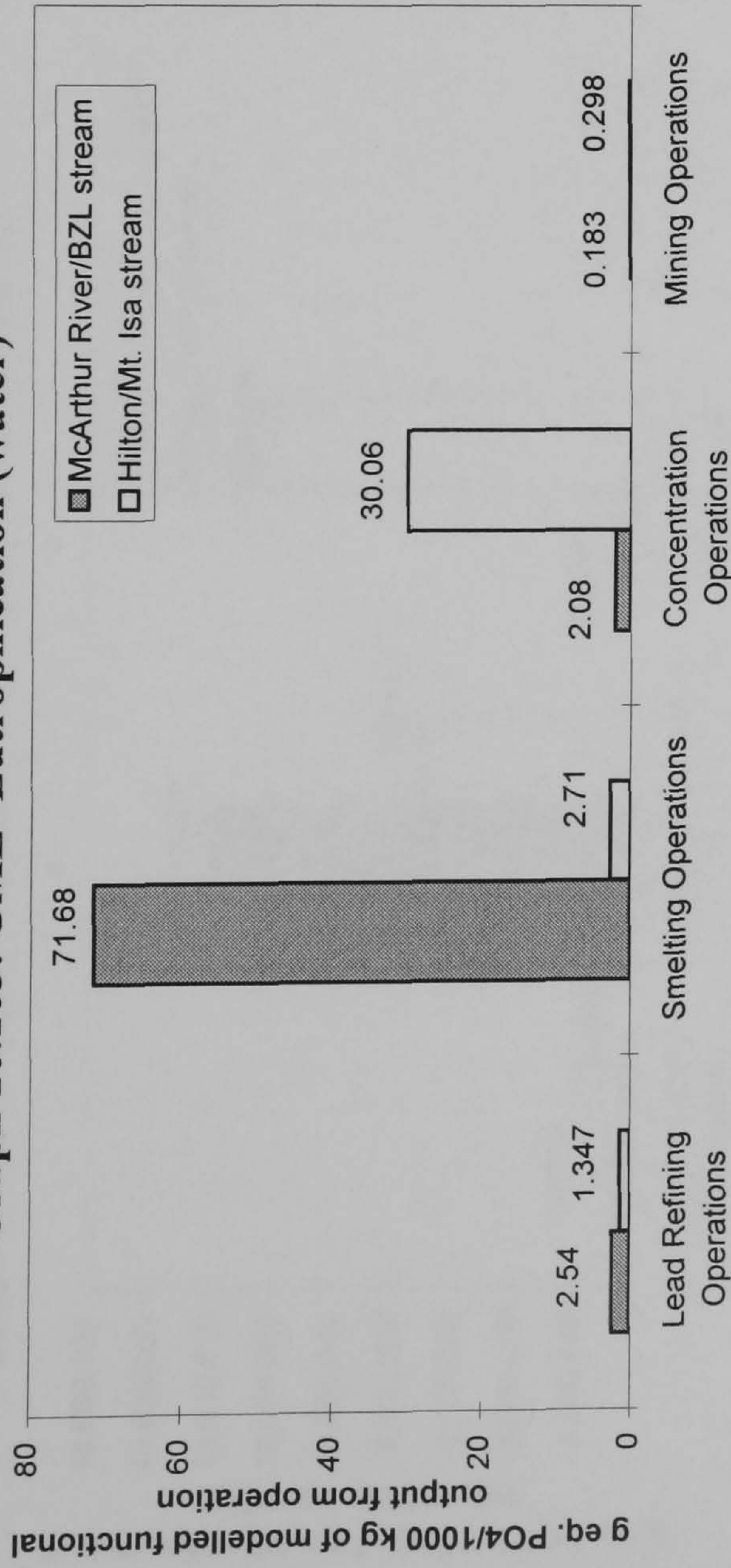
Graph 10.101: CML -Depletion on non-renewable resources



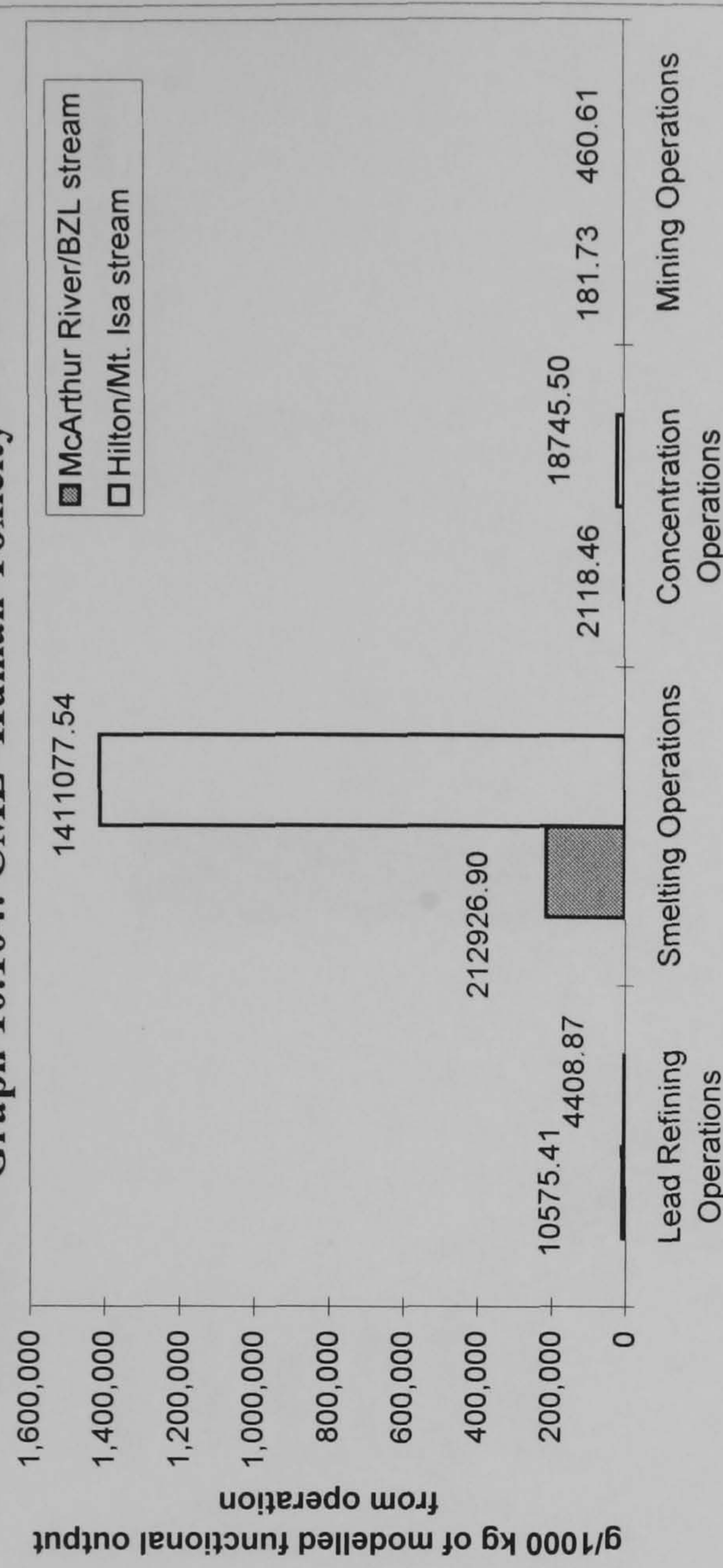
Graph 10.102: CML -Eutrophication



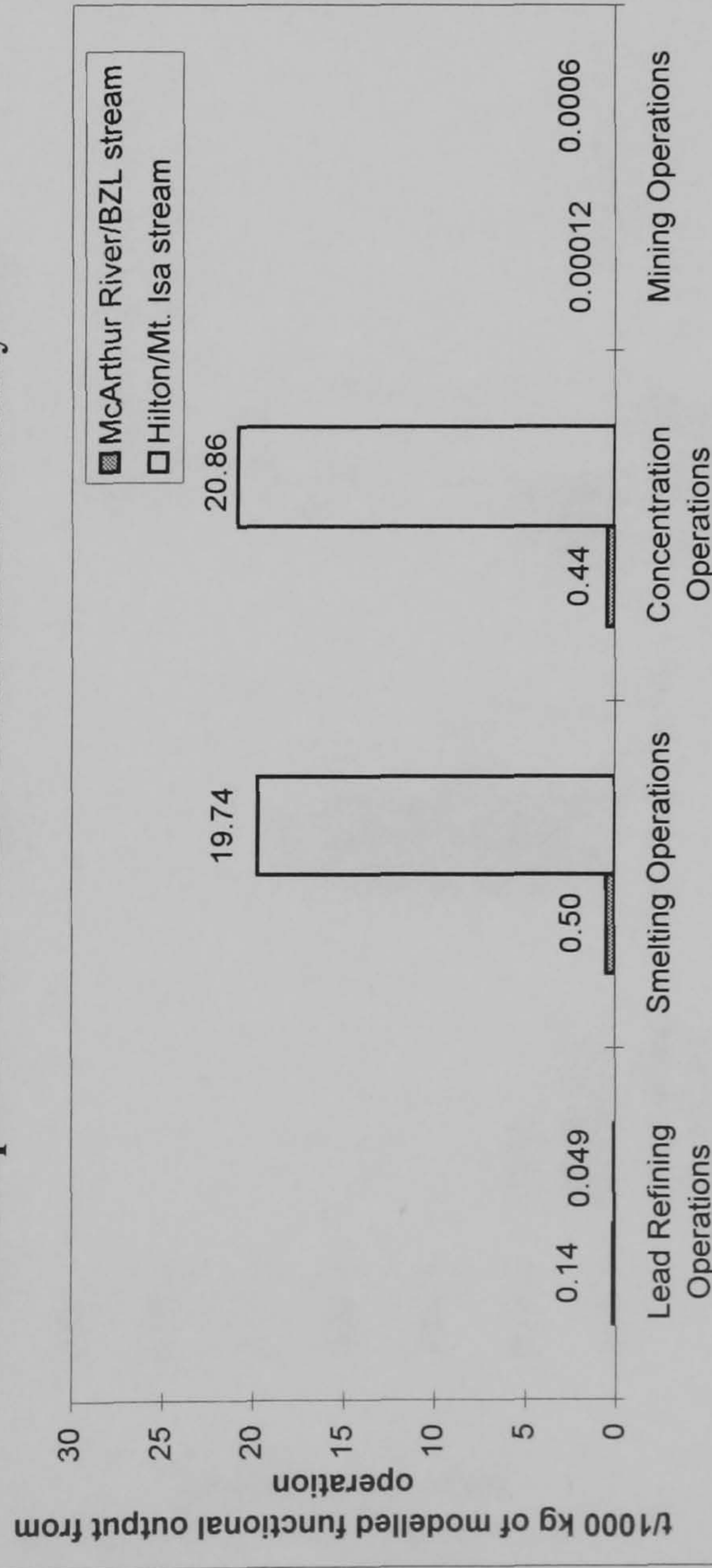
Graph 10.103: CML -Eutrophication (water)



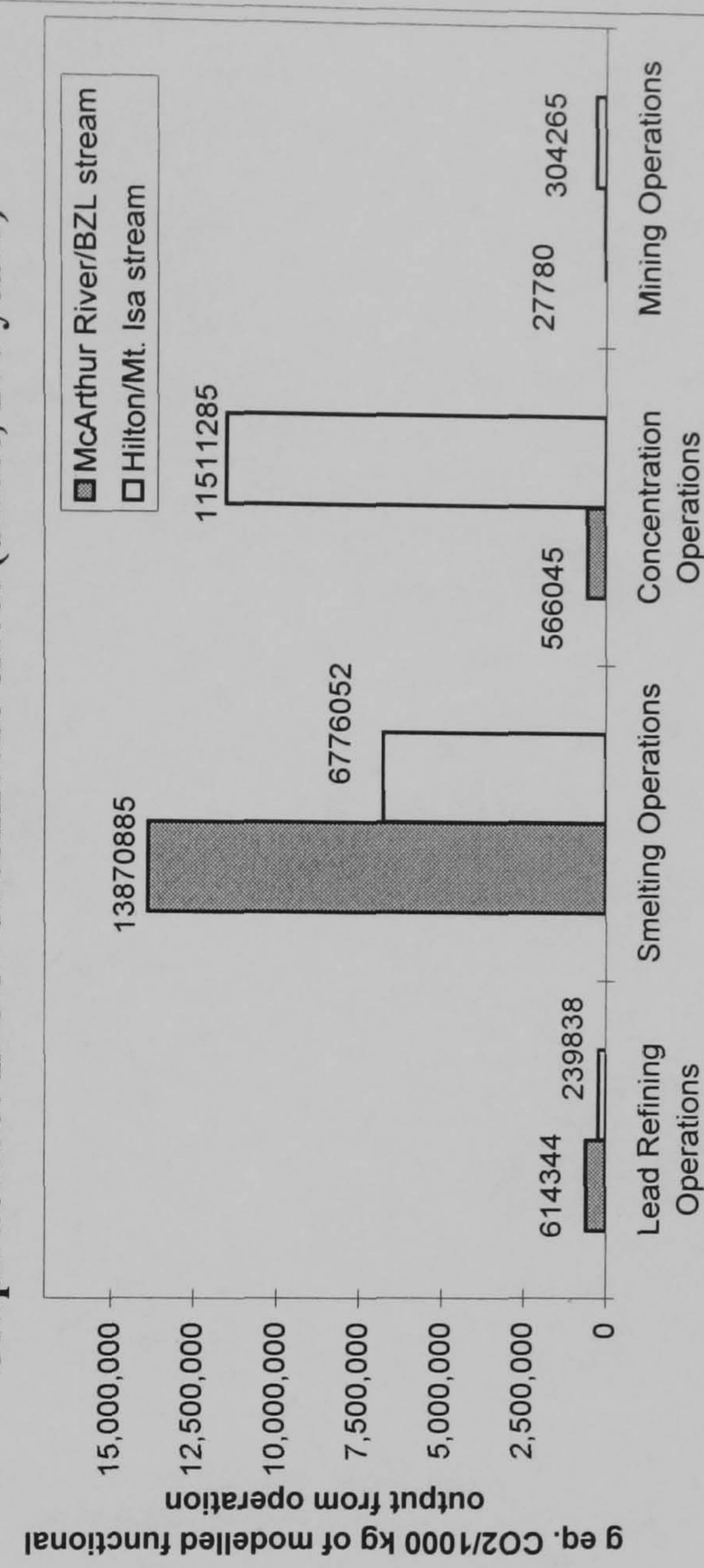
Graph 10.104: CML -Human Toxicity



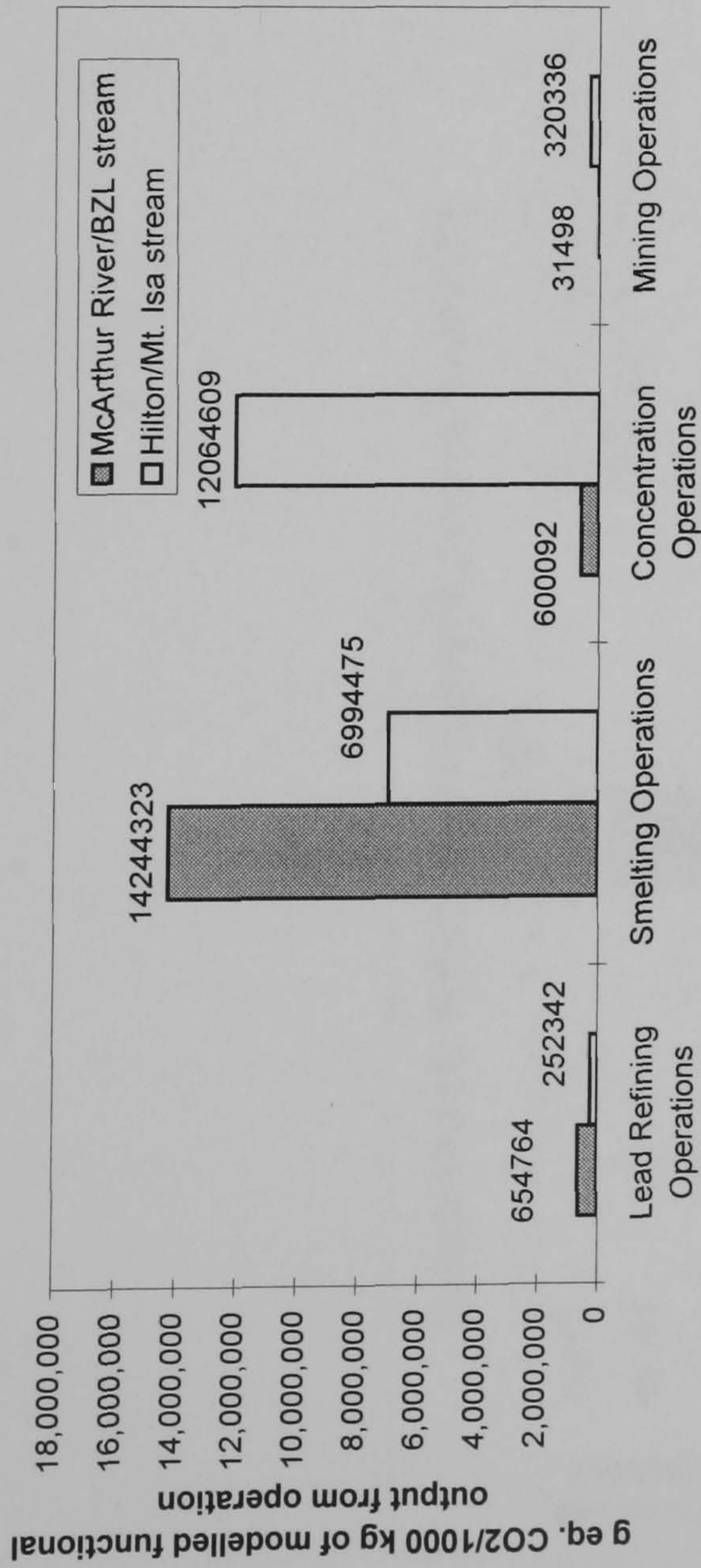
Graph 10.105: CML -Terrestrial Eco-toxicity



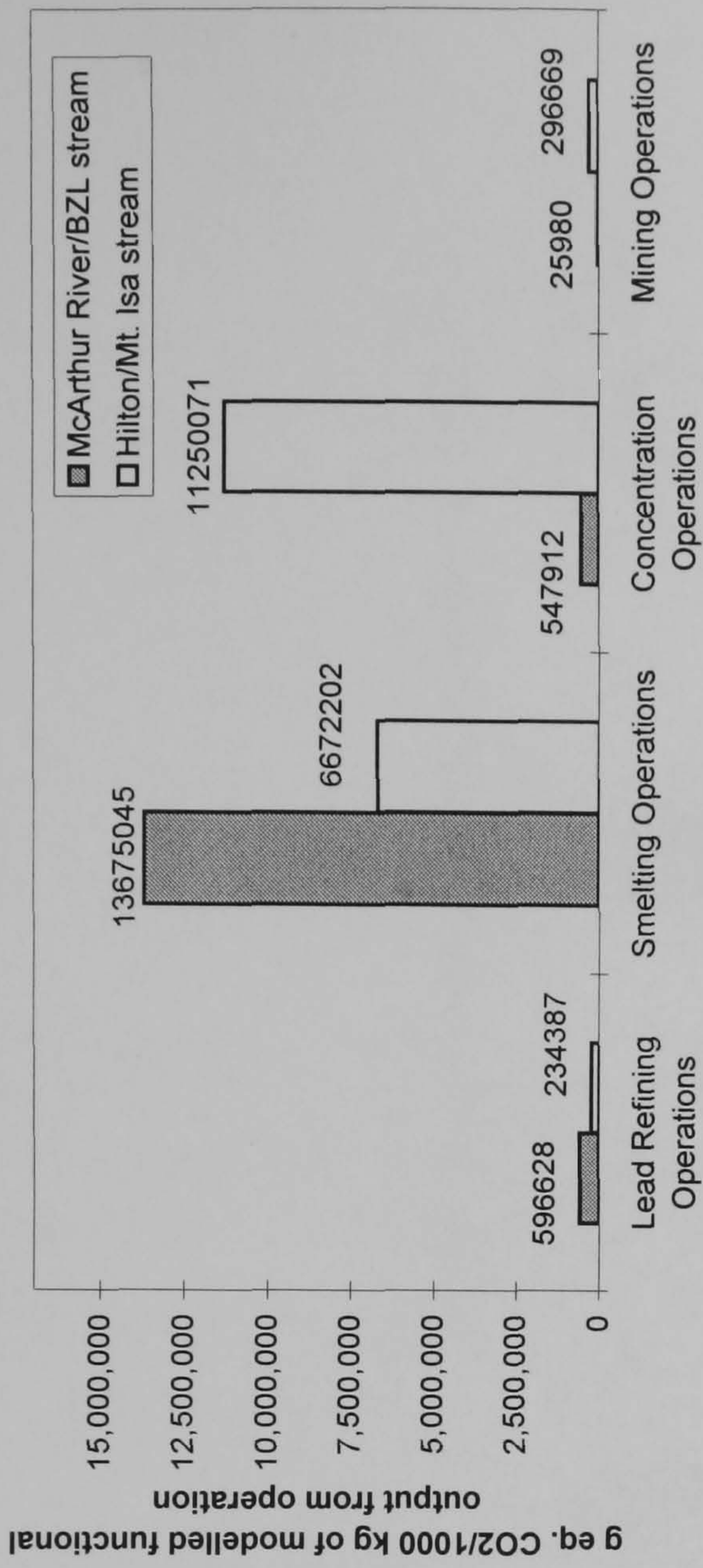
Graph 10.106: IPCC -Greenhouse effect (direct, 100 years)



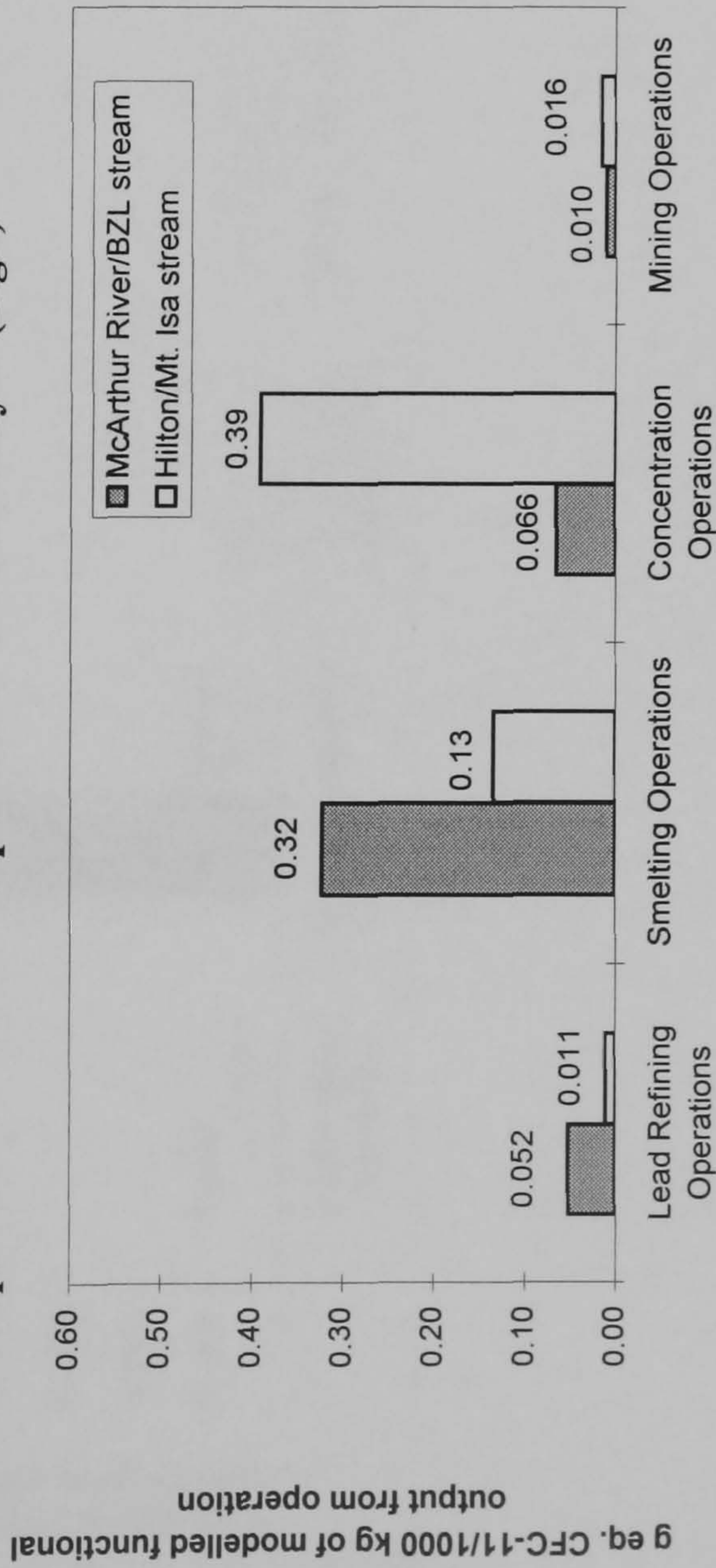
Graph 10.107: IPCC -Greenhouse effect (direct, 20 years)



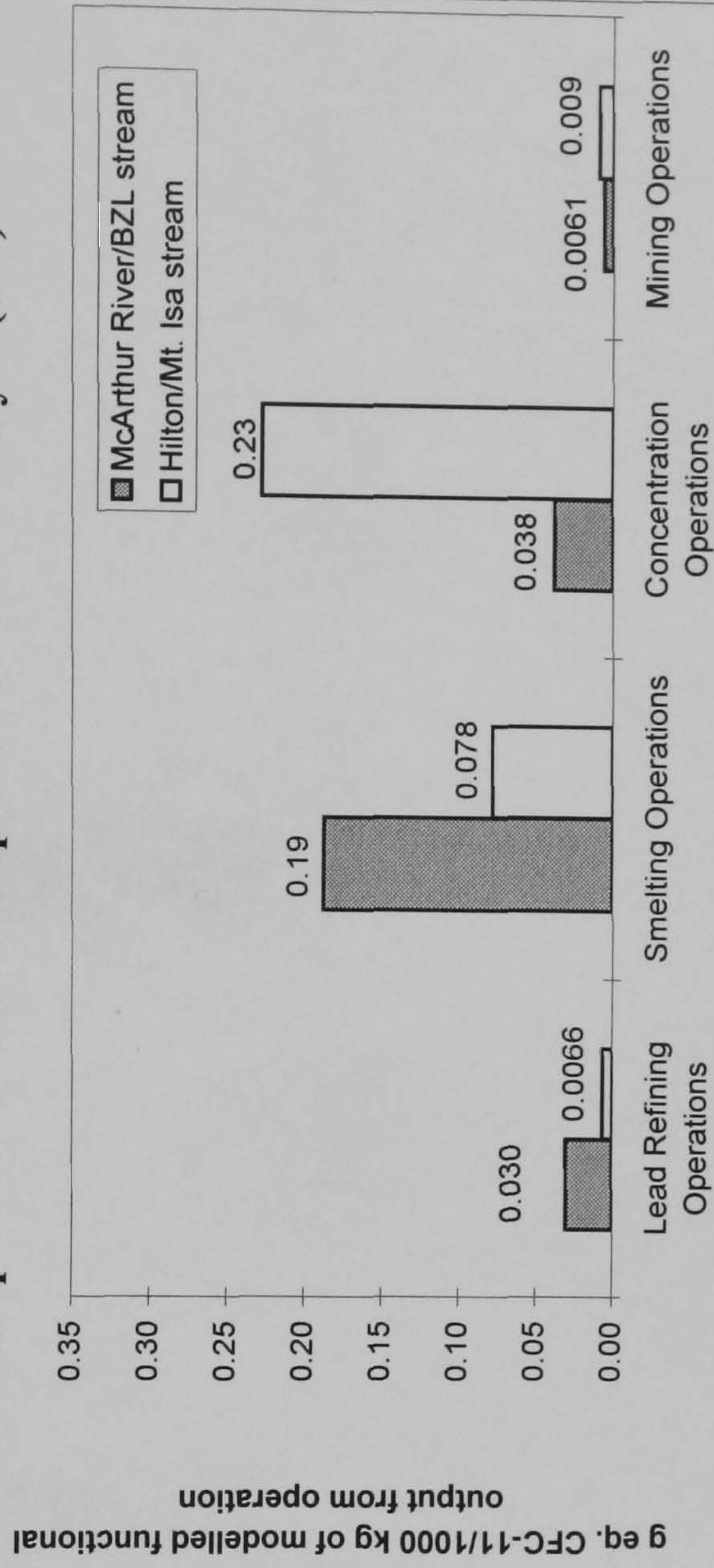
Graph 10.108: IPCC -Greenhouse effect (direct, 500 years)



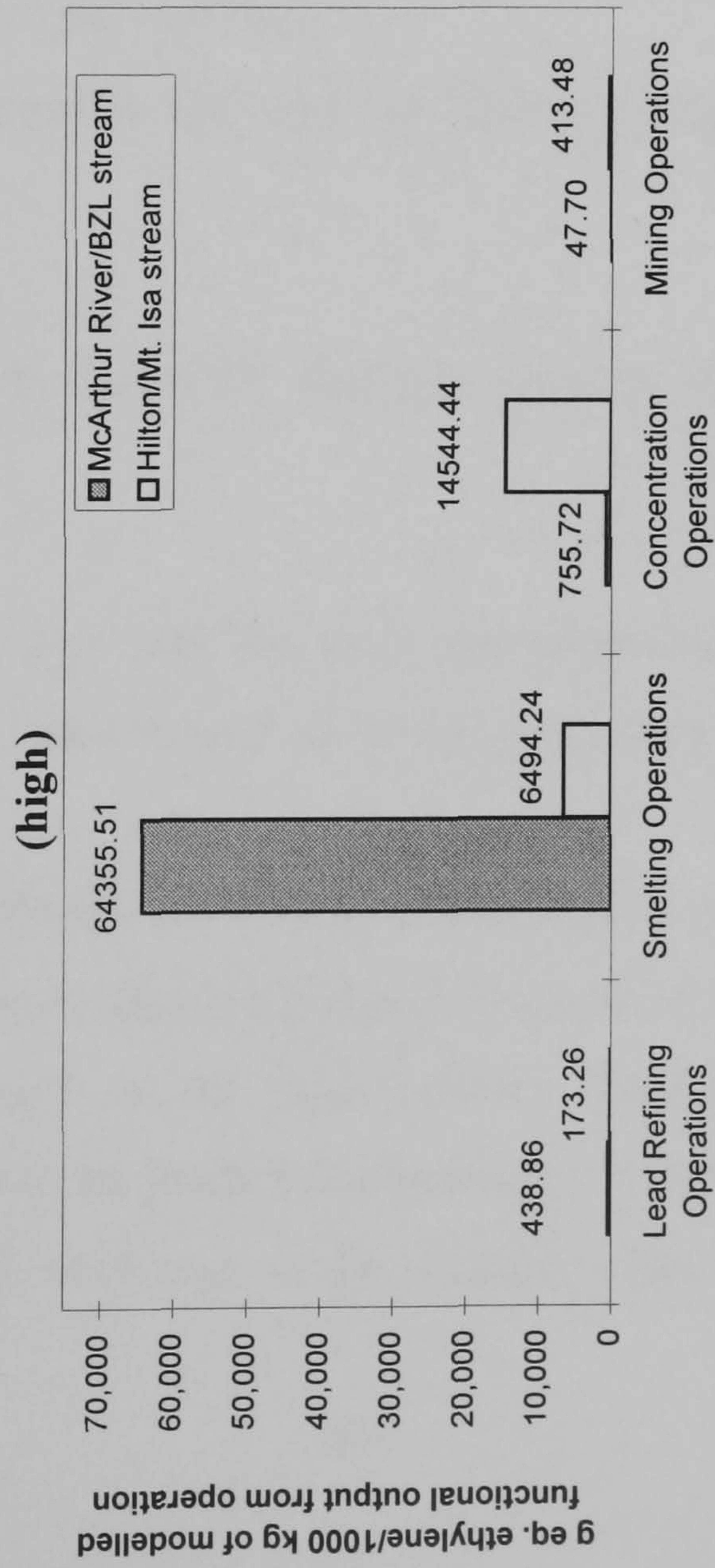
Graph 10.109: WMO -Depletion of the ozone layer (high)



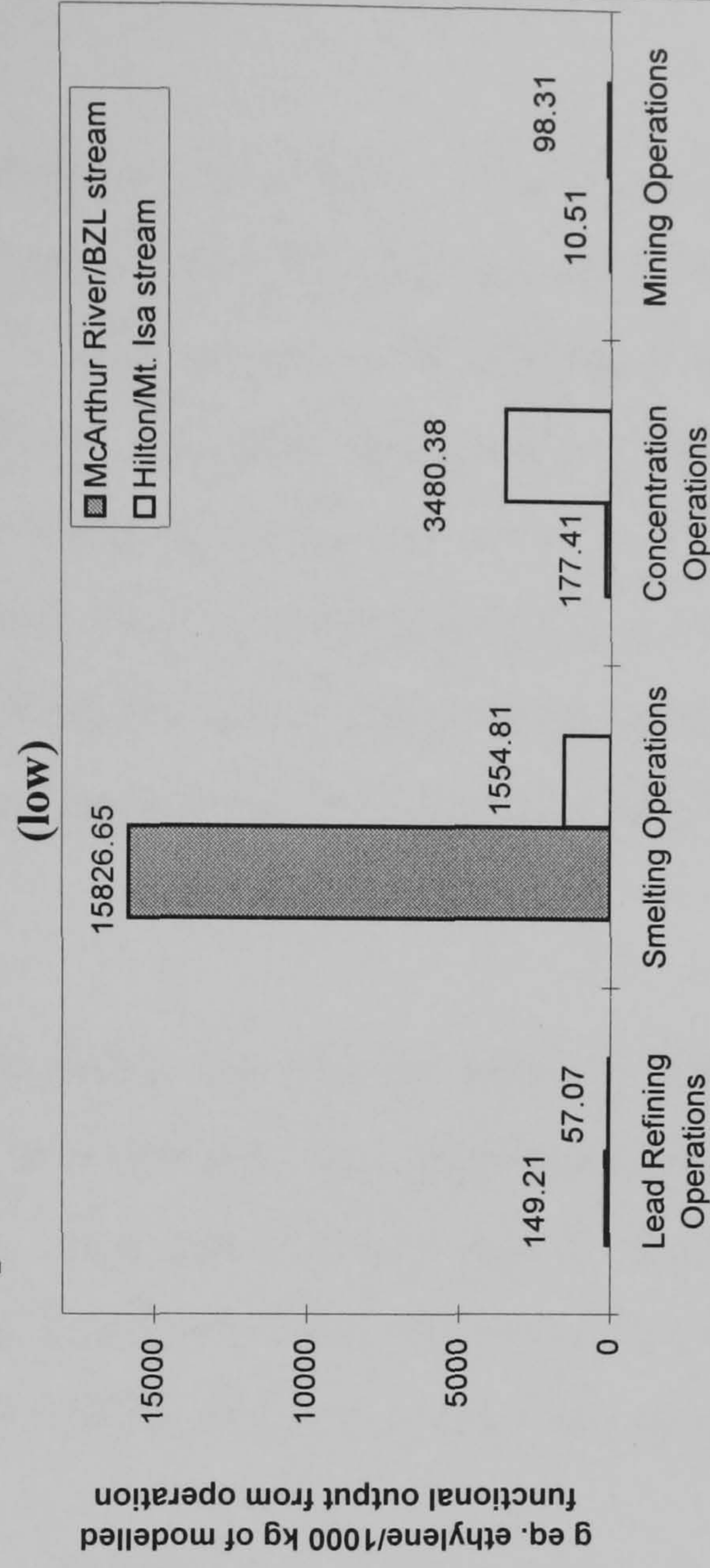
Graph 10.110: WMO -Depletion of the ozone layer (low)



Graph 10.111: WMO -Photochemical oxidant formation



Graph 10.112: WMO -Photochemical oxidant formation



11. Overall Conclusions and Recommendations

This thesis sets out the foundations for changes in the manner in which ‘risk’ is assessed and managed by the lead industry (and by other industries facing similar environmental challenges). In chapters 1 to 3, it is explained that whilst such changes will be needed by all industries, for the lead industry, and these others, the challenges within the foreseeable future, could threaten their entire existence. However, it is also explained that the lead industry has a relatively strong position to defend, and provided appropriate strategies and means to accomplish these strategies are promulgated, it could have a ‘healthy’ future. It is also stressed that the onus for developing these strategies and means rests with the industry itself.

The changes set out in this thesis, are posited within a framework (see section 4.5 of chapter 4) which consists of a strategy, approaches and tools. These changes are both philosophical and technical. They are philosophical, in the sense that they set out the features of a new conceptual paradigm, which has its basis within the concept of the ‘risk society’ (as defined by Beck (1992)), and which when fully developed will be:

- significantly more holistic than currently,
- multi-dimensional (i.e. operates effectively at different geographical and/or managerial scales),
- inherently flexible, and
- reflexive (i.e. developed iteratively through ongoing dialogue with all relevant stakeholders).

They are technical, in the sense that the tools and approaches provide practical means whereby the environmental ‘risks’ may be identified, assessed and managed.

Since the environmental challenge is driven by the changes in the ‘views of society’ of the time, there is a need for a more effective bridge between these views and the attitudes and actions of organisations, such as the lead industry. Whilst it could be argued, the approaches and tools appear to be posited fundamentally within the structuralist paradigm (as explained in section 4.3.2 of chapter 4), the intention is that they will be developed into

the future, through a process of ongoing reflexive dialogue. In this process, they will become part of the new and developing paradigm.

Apparently structuralist approaches and tools have been developed and used in this thesis, because their methodologies and outcomes are in a format familiar to people within the industry, and to those charged with regulating it. This is because they are inculcated currently, almost exclusively, with the structuralist paradigm. The general public in industrialised countries have also been taught to accept such approaches. However, in various contexts, almost all people also have, and exert, more interpretivist views of the world. In the developing 'risk society', societal concerns over the effective management of risks are becoming an increasingly dominant theme, and some, inevitably, are interpretivist in nature. Therefore, if decision makers are to make environmental decisions which continue to be accepted as legitimate, then these interpretivist elements must also be incorporated. As explained in section 4.3.2, for this to happen with optimal effectiveness, the incorporation must be through a process of reflexive dialogue, and this dialogue must take place throughout all stages of the decision making process.

Therefore, the need for a fully effective bridge, developed proactively by the industry, to help it build the foundations for such dialogue is becoming increasingly important. This is one of the purposes of the framework developed in this thesis. In many ways, it is drawing into the decision making process, elements which are already present. This is because, it is itself, a product of this evolution to a new paradigm. Hence, this is by design, not by accident. The crucial benefit for the industry, is that once fully adopted, the framework will enable it to take a much more guiding role, in the development of the new paradigm. It will also place it in an optimal position to argue its environmental case through reflexive dialogue. Hence, the framework (plus the strategy, approaches and tools), which are posited within it, should be viewed not only as providing the foundation step for the evolution of the new paradigm within the industry and its other stakeholders, but also as providing a significant contribution to the evolution of the new paradigm in society at large.

Due to time restrictions in the preparation of the thesis, it has not been possible to develop all of the tools and approaches, needed in a fully integrated decision support approach. Of crucial importance in this respect, is the lack of impact pathway assessment (IPA)

approaches and tools. IPA approaches are needed, because they attempt to estimate the actual human and environmental impacts resulting from fate and effect modelling. However, they are subject to varying degrees of uncertainty, due principally to the difficulties in estimating the fate and effect pathways of emissions into the environment (as explained in section 5.1 of chapter 5). The modelling approaches and tools in the MIM case study, are generalised in the sense that estimations are of potential rather than actual impacts, and are site-independent (i.e. they are assumed to be global). BRM case study also contains modelling approaches and tools, which give rise to estimations of potential impacts in a manner similar to that in the MIM case study. However, unlike the MIM case study, these estimations are site-dependent. Therefore, like the ICI Environmental Burden methodology [ICI (1996)], the BRM case study approaches are hybrids, which help to bridge the gap between IPA and generalised approaches.

The relationship between IPA and generalised approaches, are summarised in Table 5.6 (in chapter 5). It indicates that where site-specific environmental decisions need to be made, such approaches are essential. Whilst the approaches developed in the BRM case study could be used in many circumstances, they would not be appropriate, where the actual numbers of people exposed and/or affected by emissions from specific sources need to be known. Preliminary work on a case study, to develop an IPA approach operating at the single emission source scale, and employing the Advanced Dispersion Modelling System (ADMS) tool has been conducted. This had the aim of estimating the actual numbers of the local population, exposed to emissions of atmospheric lead, particulates and sulphur dioxide, resulting from BRM main stack emissions, along with a methodology which would allow the uncertainties associated with such modelling to be accounted for. It is important, within an integrated strategy, that companies such as BRM, MIM, and others, have effective means of estimating actual effects, of accounting for the uncertainty associated with such estimations, and of incorporating them effectively into decision making. Therefore, this an important area for further research.

With regard to generalised LCA-type modelling approaches, both the allocated and unallocated approaches are important within an integrated strategy. In allocated modelling, the only product output is the one of interest, whilst in unallocated modelling, the product of interest and all of the associated co-products and by-products are outputs. Unallocated approaches have the advantage, that they mimic, more closely, reality. In consequence, site

managers can make direct use of the modelling data to support process engineering, as well as environmental engineering decisions. Allocated modelling approaches, on the other hand, have the advantage that the models (as modules), may either be incorporated directly into other modelling approaches, or be used in direct comparisons with other models. It is recommended, therefore, that both modelling approaches continue to be conducted, in future iterations of the LCAs..

The TEAMTM modelling software, and the modelling approaches adopted for the BRM and MIM case studies, allow all foreground non-transport and transport processes to be considered, either in isolation, or aggregated into various other models, designed as appropriate. This is possible, since all processes have been treated as separate modules (i.e. atoms). The TEAMTM modelling software has an export facility, which enables these manipulations to be conducted easily. All inputs to and outputs from all foreground processes, have also been treated as variables. The ranges of these variables are expressed as coefficient of variation values, which have either been calculated from data or estimated. (Documents 5 and 9, of volume 5 of the Portfolio, indicate the complete set of values used for the BRM whole site model, and for the MIM Pb LCA allocated and unallocated models.) The variable values they may be altered using spreadsheet control panels which are external to the model. The TEAMTM software has an export facility to facilitate the export of these variables.

However, a limitation with the TEAMTM modelling, apparent in both the BRM and MIM case studies, is that when the modelling is complex and the number of variables large, it becomes impracticable to test all of the variables in simulations. For example, the complexity of the MIM Pb LCA allocated model alone, is such that each simulation takes about 52 minutes to calculate on a Pentium 233 MHz computer. Since there are 654 variables, it would take over 23 days to calculate the simulations, and would generate a very large number of Excel files, all of which would need to be examined. Due to time restrictions in the preparation of this thesis, conducting such exhaustive simulations was not possible. However, if such test work were conducted, statistics summarising the actual variation of the model inventories, resulting from the simulations could be produced. Currently, simulations have been conducted only for variables, shown by dominance analysis to contribute 5% or greater, to overall inventories and effects of interest.

However, variation statistics for all of the inventory flows, at the overall system level, have been created for both the BRM whole site and MIM Pb LCA allocated and unallocated models, from Monte Carlo simulations set with a uniform relative standard deviation (i.e. coefficient of variation). These have been enclosed in the final Portfolio (but not with this thesis). Nevertheless, since the actual variation of the different variables is not uniform (as indicated in Documents 5 and 9, of volume 5 of the Portfolio), these simulations can only indicate the relative sensitivity of individual inventory flows to each other. Hence, it is recommended that, in future work, simulations be conducted for all of the foreground variables, and that summary inventory variability statistics be calculated from them.

In addition, the flows in the background data atoms are not variables. This means they cannot be altered in isolation of other flows in the atoms to which they are associated. This hampered the sensitivity analyses in both case studies. It is recommended, therefore, that in future iterations of the modelling, they should also be converted to variables, so they may be modified in isolation. Exhaustive simulations of these flows would also be desirable, but it is appreciated that the number of variables, which would be generated, might prove too large for this to be possible. This warrants further investigation.

In some instances, it has been necessary to use partitioning factors, in the modelling, to facilitate allocation between different products, co-products and/or by-products, where insufficient data are available to determine the actual physical relationships. In accordance with ISO 14041: 1997 (E), the factors which have been applied, reflect the economic (i.e. market) value of the respective products. However, relative market values are subject to some variability. It had been intended to include sensitivity analysis simulation of the effects of such variability on the modelling findings. Due to the time constraints in the preparation of this thesis, however, this has not been possible. Hence, it is recommended as an area for further research.

The inventories and potential environmental effects, from the models in the BRM and MIM case studies (shown in the graphs and discussed in the text), are not intended to be exhaustive. Instead, they serve two purposes. Firstly, they illustrate the capabilities of the modelling, and secondly they examine those inventories and effects deemed, currently, to be of most interest or concern. Sufficient data have, however, been provided in the Portfolio, for any other of the inventory flows, modelled operations, or processes, to be

estimated similarly. In addition, any other potential effects could be calculated with relative ease.

The effects which have been assessed, have been selected from the list of commonly accepted environmental impact categories in Table 5.1. This list is normative, since it will be subject to change, as concerns and knowledge evolves. Therefore, the environmental effects, which will be considered in future iterations of the modelling, must reflect these changes. It should also be borne in mind, that significant uncertainties are associated with the calculation of potential environmental effects from inventories, and these have not been considered in the uncertainty analysis. This approach is considered acceptable, because it is the common practice, currently, in LCA studies to not address this issue in detail. However, it is a significant concern, since the uncertainty with some of the effect categories is less than for others. Two areas of particular concern, are the assumptions in the methodologies for effect assessment, that the dose-response relationships are linear, and that the contributions from different types of substances to a given effect category are additive. The discussion in section 5.2 of chapter 5, indicates that in reality this is often not the case. Concerns are also associated with the assumption, in the methodologies, that the effects are generalised (i.e. global). Whilst this is expected to be the case for effect categories such as the greenhouse effect, and depletion of the ozone layer, effect categories such as the eutrophication of water are likely to be regional and/or local, rather than global. The assumption, in the methodologies, that effects are potential rather actual, overcomes this limitation, at least to some extent. However, it is recommended the LCA research community addresses further these issues. With regard to the BRM and MIM case study models, it is recommended that, in future iterations of the effect assessment, uncertainty assessments for the different effect categories, and their likely influence on the findings, also be provided.

The actual influence of omissions and substitutions, on the findings from the case study models is unknown. In both instances, it has been assumed that, because the number of cases where this has occurred is relatively small, their influence on the findings has also been minor. However, whilst this is likely to be the case, it is not certain. With regard to substitutions, this has appeared to be confirmed by the dominance analysis, which has indicated (with notable exceptions identified in section 9.7.2 of chapter 9, and in section

10.5.2 of chapter 10), that the principle contributors to the graphed inventories and effects of interest, are from non-substituted flows.

From the foregoing discussion, it is apparent that iteration and development of the modelling, inventory interpretations and effect assessments will be needed on an ongoing basis (e.g. annually), to ensure they continue to aid the industry in meeting the environmental challenge with optimal effectiveness. These will enable the ongoing monitoring of environmental performance, and management of environmental ‘hot spots’ (i.e. operations, processes, or emissions sources making a particularly large contributions to an inventory of interest). They will also enable efforts to be made, and monitored, aimed at reducing the uncertainties associated with omissions, substitutions, poor quality data etc.

The environmental challenge facing the lead industry, is also linked with that facing the downstream uses to which its products, co-products, and by-products are put. Therefore, not only are future iterations of the modelling vital, at the scales conducted in the BRM and MIM case studies, but in various other decision making contexts they will need to be expanded, to include modelling of one or more of the following:

- the final manufactured products (e.g. lead-acid batteries, lead sheeting etc.),
- the use of these products, and
- their final disposal or recycling.

The largest scale (which includes all of the above) is full cradle-to-grave modelling. This will be needed, if the challenge made by Lave et al. (1995) (discussed in chapter 4), are to be fully addressed. The project sponsored by the lead industry, between Ecobalance Inc. and the International Lead Zinc Research Organization Inc. (ILZRO), to conduct a global life-cycle inventory of lead-acid batteries (also discussed in chapter 4), can provide a snapshot answer only to their challenge. This is because it will contain various epistemological, methodological and technical uncertainties, some of which cannot be resolved with such a snapshot. In addition, since processes are themselves subject to inherent variability, and are modified on an ongoing basis (for process control reasons), any snapshot can only ever provide an historical record. Therefore, the only way to address, fully, challenges such as those by Lave et al., and others which will be made in the future, is through ongoing (and hence iteratively applied) environmental management approaches.

Since challenges are expected to occur at all scales, ranging from the individual process to the whole cradle-to-grave life-cycle, management approaches must be available which operate at all of these scales. For this to happen, they must be built within, and be under the direct control of the management and other personnel, of the organisations involved, at all of the relevant scales, rather than be conducted by outside agencies. The BRM and MIM case studies, provide the basis for such approaches within BRM and MIM. They also provide a template for the rest of the industry, and for other downstream operations. Active efforts are now required, to develop modelling, and management approaches for these additional scales of focus.

Whilst the initial setting up of the models, and data entry for the BRM and MIM case studies, is an intensive exercise, future iterations of it are expected to be relatively straightforward, for the following reasons:

1. The foreground modelling has been designed in consultation (i.e. dialogue) with the various site process managers (and other site personnel), as well as with members of the senior environmental management team of MIM. This has been conducted, because the aim throughout, has been to design the modelling to match the way in which these personnel manage the various processes.
2. Detailed and regularly updated data, are collected for many of the process inputs and outputs, because they are needed for operational management and/or financial accounting purposes.
3. For emissions to the environment, ongoing and detailed monitoring is required, by the regulators, for all emissions deemed to be potentially significant.

Therefore, for those flows and emissions, where data are collected regularly for process control, financial management, and to meet regulatory requirements, updating the models should simply involve the transference of these data.

The other aim of designing the modelling in consultation with managers and other company personnel, has been to encourage them to feel their views on how the modelling should be conducted, have been incorporated. It is hoped, this will also encourage them to feel the models are relevant to them, and that they will develop feelings of ownership of them, as they continue to evolve in future iterations.

Finally, it needs to be noted, that whilst the current framework, provided in this thesis, does not include decision making approaches, the need for them is indicated in section 4.5 of chapter 4. These approaches must also include valuation approaches, to ensure modelling inventory interpretations and effect assessments are incorporated, with optimal effectiveness, into decision making. It is considered, that reflexive dialogue between the industry and all relevant stakeholders, will be the key to ensuring these decision making (and valuation) approaches are optimally effective. A true reflexive dialogue in a decision making context, would require all participants to reflect critically upon, and to challenge, in a constructive manner, their own pre-conceptions, throughout the process. This would also ensure, that 'best' environmental decision making is achieved, a goal which this entire thesis aims to facilitate. Currently, however, this type of decision making is still an aspiration. Therefore, it is a key area for further research.

The following is a summary of additional aspects from the thesis, recommended for further research. (Chapter and section citation details are also indicated.)

1. Rasmussen (1995) contends, the evidence to support or refute the argument of whether or not trans-boundary atmospheric movement of metals from industrial sources occurs, is still sparse. This is despite the conclusion by the UN-ECE (1995), there is now enough evidence to conclude that it has (chapter 7, section 7.1.2.).
2. Data on typical ambient Australian atmospheric lead (Pb) concentrations in rural and urban and close to mining and processing operations have not been obtained.
3. Data indicating the numbers of people who are exposed to levels of lead (Pb), at or above the current UK national air quality standard (NAQS), of $2.0 \mu\text{g}/\text{m}^3$, resulting from emissions from non-ferrous metal works, is unknown (chapter 7, section 7.12).
4. It is not known whether or not the levels of chronic antimony (Sb) exposure in the general population, actually give rise to any significant gastrointestinal, blood, liver or nervous system, such as have been identified in animal oral exposure studies (chapter 7, section 7.12).

5. In the UK the chronic effects from atmospheric sulphur dioxide (SO₂) emissions are minor. However, data indicating the situation in Australia, have not been obtained (chapter 7, section 7.13).
6. Current evidence suggests that, in terms of acute effects, individuals who are not suffering from respiratory disease will be unaffected by the type of episodic periods of elevated atmospheric nitrogen oxides (NO_x) concentrations such as occur currently in the UK. However, persons suffering from respiratory disorders (including asthma) may experience a worsening of their symptoms during such periods [MAAPE (1992a)]. Information regarding the situation in Australia has not been obtained (chapter 7, section 7.1.5).
7. Data indicating the contribution to air carbon monoxide (CO) levels, either by such BRM and MIM Pb life-cycle processes or by the lead industry in general, have not been obtained. The extent of possible effects on the work force are also unknown (chapter 7, section 7.1.6).
8. Data for the actual chemical and physical nature of poly aromatic hydrocarbon (PAH) compounds, which may be released either from BRM and MIM lead life-cycle processes, or from the lead industry in general, is incomplete. Data on the potential human health effects attributable to emissions of PAHs, are also incomplete.
9. In theory, dose-response coefficients could be used to estimate the direct potential effects from lead emissions to land and water, attributable to the lead industry in general, and to BRM and MIM lead (Pb) life-cycle processes in particular. However, this is not possible, in practice, without modelling to identify that fraction of the lead (Pb) in individual drinking water supplies and foods, which is attributable to direct emissions from these sources, rather than from indirect sources i.e. from secondary, tertiary and higher order sources (chapter 7, section 7.2.3).
10. Further data are needed, to ascertain whether any significant human health effects are actually attributable to antimony exposure from food and drink in the general population. In consequence, it is uncertain whether any significant direct human health effects may be associated with antimony emissions to water and land, either from the lead industry in general, or from BRM and/or MIM Pb life-cycle processes in particular (chapter 7, section 7.2.3).
11. In future iterations of the BRM case study modelling, the following criteria, which have been used for identifying 'significant' flows in the inventories, should be replaced by normatively based criteria:

- a) Flows which are closely associated with flows which have been selected under any of the other criteria.
- b) For the quantity of the flow at the highest system level, in either of the modelled years, when normalised to the functional unit of 1000 kg of final lead (Pb) product, to be $\geq 5.00E+00$ kg for resource consumptions, $\geq 1.00E+03$ mg, kg or litre for ancillary materials (secondary), $\geq 1.00E+03$ g for air, water and ground emissions, and $\geq 5.00E+00$ kg for wastes.

The normatively based criteria should not need to be changed (chapter 9, section 9.6.3.2.2).

- 12. It is impractical within the confines of this thesis, to plot graphs for all of the flows identified in Table 9.3, either at the whole system level or to examine how the nodes listed in Table 9.1 contribute to these total flows (chapter 9, section 9.6.4.2.1).
- 13. For emissions to water of '(w) Cadmium (Cd++)', for the 'BRM Whole Site (a)' model, the difference between the contributions of BRM stream and Isa stream throughput operations is so small, that it has not been possible to ascertain whether or not there is a significant difference between them (chapter 9, section 9.6.4.5.1).
- 14. For emissions to water of '(w) Lead (Pb++, Pb4+)', for the 'BRM Whole Site (a)' model, the difference between the contributions of BRM stream and Isa stream throughput operations is so small, that it has not been possible to ascertain whether or not there is a significant difference between them (chapter 9, section 9.6.4.5.1).
- 15. For emissions to atmosphere of '(a) Sulphur Oxides (SO_x, as SO₂)', for the 'BRM Whole Site (a)' model, the difference between the contributions of BRM stream and Isa stream throughput operations is so small, that it has not been possible to ascertain whether or not there is a significant difference between them (chapter 9, section 9.6.4.5.1).
- 16. For overheads only the differences in the inventory and effect comparison graphs, for the BRM case study, do not represent an actual improvement or deterioration in performance. They should, therefore, be ignored, and it is recommended that a more effective means of apportionment be devised (chapter 9, section 9.6.4.5.3).
- 17. In future iterations of the MIM case study modelling, the following criteria, which have been used for identifying 'significant' flows in the inventories, should be replaced by normatively based criteria:
 - a) Flows which are closely associated with flows which have been selected under any of the other criteria.

b) For the quantity of the flow at the highest system level, in either of the modelled years, when normalised to the functional unit of 1000 kg of final lead (Pb) product, to be $\geq 5.00E+01$ kg for resource consumptions, $\geq 1.00E+04$ mg, kg or litre for ancillary materials (secondary), $\geq 1.00E+04$ g for air, water and ground emissions. and $\geq 1.00E+01$ kg for wastes.

The normatively based criteria should not need to be changed (chapter 10, section 10.4.3.2.2).

18. It is not known whether or not all of the DEAM and other LCI data modules, used to provide background LCI inventories, really do provide industry representative data. This is partly a result of the lack of detailed source information for some modules, and partly due to the time constraints in the preparation of this thesis, which have meant that it has not been possible to cross check them all (chapter 10, section 10.4.4.2.1).
19. The relative domination of the contribution, of the comprising atoms, to the operations shown in the 'Category 2' inventory and effect graphs, for the MIM case study, differs from that for the 'Category 1' graphs. Since, dominance analyses have not been conducted for this form of normalisation, interpretation of the 'Category 2' graphs, currently, is limited (chapter 10, sections 10.4.4.3, 10.4.4.5.1 and 10.4.4.5.2).
20. For emissions to atmosphere of '(a) Carbon Dioxide (CO₂, fossil)', for the unallocated 'MIM Pb LCA' model, the differences between the contributions of Hilton/Mt. Isa stream mining and smelting operations is so small, that it has not been possible to ascertain whether or not there is a significant difference between them (chapter 10, section 10.4.4.5.1).

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12.2. Additional references cited in input/output sheets in Portfolio

The individual references used for each modelled atom in the BRM and MIM case studies, are listed (where appropriate) at the bottom of each of sheet.

The list below collates the references which have been used. However, it excludes:

- *raw data references supplied to the author by site personnel, and*
 - *references which have already been cited in section 12.1.*
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Only the references not cited in either sections 12.1 or 12.2 are listed.

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12.4. Computer software programmes

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13. Appendix A: Case Study Support Documentation

Appendix A1: BRM Whole Site: TEAMTM Model Structure

BRM Whole Site: TEAM™ Model Structure

BRM: Lead Processing Operations at Northfleet, Kent, UK

—	X	BRM: Primary Refined Lead Production Operations	S (Level 1)
—	Y	BRM: Lead and Lead Alloy Product Storage (primary and secondary)	S (Level 2)
—	Z	BRM: Secondary Refined Lead Production Operations	A (Level 2)
			S (Level 2)

X BRM: Primary Refined Lead Production Operations

—	X1	BRM: Primary Lead Production Operations (BRM stream throughput)	S (Level 3)
—	X1,1	BRM: Lead Refining Operations (BRM floor throughput)	S (Level 4)
—	X1,1,1	BRM: Lead Refining (BRM floor throughput)	A (Level 5)
—	X1,1,2	BRM: [Tr.] Ammonium Nitrate	A (Level 5)
—	X1,1,3	BRM: [Tr.] Antimony	A (Level 5)
—	X1,1,4	BRM: [Tr.] Arsenic	A (Level 5)
—	X1,1,5	BRM: [Tr.] Bismuth	A (Level 5)
—	X1,1,6	BRM: [Tr.] Borax (ship)	A (Level 5)
—	X1,1,7	BRM: [Tr.] Borax (truck)	A (Level 5)
—	X1,1,8	BRM: [Tr.] Borax (truck)1	A (Level 5)
—	X1,1,9	BRM: [Tr.] Charcoal	A (Level 5)
—	X1,1,10	BRM: [Tr.] Coil (banding for ingots)	A (Level 5)
—	X1,1,11	BRM: [Tr.] Copper	A (Level 5)
—	X1,1,12	BRM: [Tr.] Diesel Oil (used as fuel)	A (Level 5)
—	X1,1,13	BRM: [Tr.] Magnesium1	A (Level 5)
—	X1,1,14	BRM: [Tr.] Magnesium2	A (Level 5)
—	X1,1,15	BRM: [Tr.] Natural gas (used as fuel)	A (Level 5)
—	X1,1,16	BRM: [Tr.] Nitrogen	A (Level 5)
—	X1,1,17	BRM: [Tr.] Oxygen	A (Level 5)
—	X1,1,18	BRM: [Tr.] Sand	A (Level 5)
—	X1,1,19	BRM: [Tr.] Sodium Hydroxide	A (Level 5)
—	X1,1,20	BRM: [Tr.] Tin	A (Level 5)
—	X1,1,21	BRM: [Tr.] Wood Pulp	A (Level 5)
—	X1,1,22	BRM: [Tr.] Zinc	A (Level 5)
—	X1,1,23	BRM: [Tr.] Slags	A (Level 5)
—	X1,1,24	BRM: [Tr.] Waste (industrial, miscellaneous)	A (Level 5)
—	X1,1,25	Charcoal Production	A (Level 5)
—	X1,1,26	Pipeline Transport: Natural Gas Pumping	A (Level 5)
—	X1,1,27	etc. DEAM data nodes	A (Level 5)
—	X1,2	On-Site Electricity Generation Operations (BRM floor throughput)	S (Level 4)
—	X1,2,1	BRM: On-Site Electricity Generation	A (Level 5)
—	X1,2,2	BRM: [Tr.] Natural Gas (used as fuel)	A (Level 5)
—	X1,2,3	Pipeline Transport: Natural Gas Pumping	A (Level 5)
—	X1,2,4	etc. DEAM data nodes	A (Level 5)

—	X1,3	BRM: Overheads to BZL Input to BRM Floor Throughput Operations	S	(Level 4)
—	—	X1,3,1 BRM: Overheads (BZL bullion processing)	A	(Level 5)
—	—	X1,3,2 BRM: [Tr.] Natural Gas (used as fuel)	A	(Level 5)
—	—	X1,3,3 Pipeline Transport: Natural Gas Pumping	A	(Level 5)
—	—	X1,3,4 etc. <i>DEAM data nodes</i>	A	(Level 5)
—	X1,4	BRM: Overheads to MHD Input to BRM Floor Throughput Operations	S	(Level 4)
—	—	X1,4,1 BRM: Overheads (MHD bullion processing)	A	(Level 5)
—	—	X1,4,2 BRM: [Tr.] Natural Gas (used as fuel)	A	(Level 5)
—	—	X1,4,3 Pipeline Transport: Natural Gas Pumping	A	(Level 5)
—	—	X1,4,4 etc. <i>DEAM data nodes</i>	A	(Level 5)
—	X2	BRM: Refined Lead Production (Isa stream throughput)	S	(Level 3)
—	—	X2,1 BRM: Lead Refining Operations (Isa stream)	S	(Level 4)
—	—	—	A	(Level 5)
—	—	X2,1,1 BRM: Lead refining (Isa stream)	A	(Level 5)
—	—	X2,1,2 BRM: [Tr.] Aluminium	A	(Level 5)
—	—	X2,1,3 BRM: [Tr.] Aluminium1	A	(Level 5)
—	—	X2,1,4 BRM: [Tr.] Ammonium Nitrate	A	(Level 5)
—	—	X2,1,5 BRM: [Tr.] Antimony	A	(Level 5)
—	—	X2,1,6 BRM: [Tr.] Borax (truck)	A	(Level 5)
—	—	X2,1,7 BRM: [Tr.] Borax (ship)	A	(Level 5)
—	—	X2,1,8 BRM: [Tr.] Aluminium	A	(Level 5)
—	—	X2,1,9 BRM: [Tr.] Cadmium	A	(Level 5)
—	—	X2,1,10 BRM: [Tr.] Calgon	A	(Level 5)
—	—	X2,1,11 BRM: [Tr.] Charcoal	A	(Level 5)
—	—	X2,1,12 BRM: [Tr.] Coil (banding for ingots)	A	(Level 5)
—	—	X2,1,13 BRM: [Tr.] Diesel Oil (used as fuel)	A	(Level 5)
—	—	X2,1,14 BRM: [Tr.] Magnesium	A	(Level 5)
—	—	X2,1,15 BRM: [Tr.] Magnesium1	A	(Level 5)
—	—	X2,1,16 BRM: [Tr.] Natural Gas (used as fuel)	A	(Level 5)
—	—	X2,1,17 BRM: [Tr.] Nitrogen	A	(Level 5)
—	—	X2,1,18 BRM: [Tr.] Oxygen	A	(Level 5)
—	—	X2,1,19 BRM: [Tr.] Sand	A	(Level 5)
—	—	X2,1,20 BRM: [Tr.] Sand1	A	(Level 5)
—	—	X2,1,21 BRM: [Tr.] Sodium Hydroxide	A	(Level 5)
—	—	X2,1,22 BRM: [Tr.] Tellurium	A	(Level 5)
—	—	X2,1,23 BRM: [Tr.] Tin	A	(Level 5)
—	—	X2,1,24 BRM: [Tr.] Wood Pulp	A	(Level 5)
—	—	X2,1,25 BRM: [Tr.] Zinc	A	(Level 5)
—	—	X2,1,26 BRM: [Tr.] Slags	A	(Level 5)
—	—	X2,1,27 BRM: [Tr.] Waste (industrial, miscellaneous)	A	(Level 5)
—	—	X2,1,28 Charcoal Production	A	(Level 5)
—	—	X2, 1,29 Pipeline Transport: Natural Gas Pumping	A	(Level 5)
—	—	X2,1,30 etc. <i>DEAM data nodes</i>	A	(Level 5)

<ul style="list-style-type: none"> — X2,2 — X2,2,1 — X2,2,2 — X2,2,3 — X2,2,4 etc. — X2,3 — X2,3,1 — X2,3,2 — X2,3,3 — X2,3,4 etc. — X3 	<p>BRM: On-site Electricity Generation Operations</p> <p>BRM: On-site Electricity Generation</p> <p>BRM: [Tr.] Natural Gas (used as fuel)</p> <p>Pipeline Transport: Natural Gas Pumping</p> <p><i>DEAM data nodes</i></p> <p>BRM: Overheads (Isa stream operations)</p> <p>BRM: Overheads (Isa stream operations)</p> <p>BRM: [Tr.] Natural gas (used as fuel)</p> <p>Pipeline Transport: Natural Gas Pumping</p> <p><i>DEAM data nodes</i></p> <p>BRM: Lead and Lead Alloy Product Storage (primary)</p> <p style="text-align: center;"><i>[No categories requiring tracking.]</i></p>	<p>S (Level 4)</p> <p>A (Level 5)</p> <p>A (Level 5)</p> <p>A (Level 5)</p> <p>A (Level 5)</p> <p>S (Level 4)</p> <p>A (Level 5)</p> <p>A (Level 5)</p> <p>A (Level 5)</p> <p>A (Level 5)</p> <p>A (Level 5)</p> <p>A (Level 3)</p>
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Y BRM: Lead and Lead Alloy Product Storage (primary and secondary)
[No categories requiring tracking.]

Z BRM: Secondary Refined Lead Production Operations

<ul style="list-style-type: none"> — Z1 — Z1,1 — Z1,2 — Z1,3 — Z2 — Z2,1 — Z2,2 — Z2,3 — Z2,4 — Z2,5 — Z2,6 — Z2,7 — Z2,8 — Z2,9 — Z2,10 — Z2,11 — Z2,12 — Z2,13 — Z2,14 — Z2,15 — Z2,16 — Z2,17 — Z2,18 — Z2,19 	<p>BRM (secondary): CX Plant Operations</p> <p>BRM (secondary): CX Plant</p> <p>BRM: [Tr.] Sodium Hydroxide1</p> <p><i>DEAM data nodes</i></p> <p>BRM (secondary): Smelting, Rotary Furnace, Refining and Moulding Operations</p> <p>BRM (secondary): Smelting, Rotary Furnace, Refining and Moulding</p> <p>BRM: [Tr.] Coal (truck)</p> <p>BRM: [Tr.] Coal (truck)1</p> <p>BRM: [Tr.] Coal (ship)</p> <p>BRM: [Tr.] Coal (truck)2</p> <p>BRM: [Tr.] Iron Scrap</p> <p>BRM: [Tr.] Ammonium Nitrate</p> <p>BRM: [Tr.] Oxygen</p> <p>BRM: [Tr.] Coke</p> <p>BRM: [Tr.] Sulphur</p> <p>BRM: [Tr.] Charcoal</p> <p>BRM: [Tr.] Sodium Hydroxide</p> <p>BRM: [Tr.] Tin</p> <p>BRM: [Tr.] Copper</p> <p>BRM: [Tr.] Heavy Fuel Oil (used as fuel)</p> <p>BRM: [Tr.] Heavy Fuel Oil (used as fuel)1</p> <p>BRM: [Tr.] Natural Gas (used as fuel)</p> <p>BRM: [Tr.] Coil (banding for ingots)</p> <p>BRM: [Tr.] Arsenic</p>	<p>S (Level 3)</p> <p>A (Level 4)</p> <p>A (Level 4)</p> <p>A (Level 4)</p> <p>S (Level 3)</p> <p>A (Level 4)</p> <p>A (Level 4)</p> <p>A (Level 4)</p> <p>A (Level 4)</p> <p>A (Level 4)</p> <p>A (Level 4)</p> <p>A (Level 4)</p> <p>A (Level 4)</p> <p>A (Level 4)</p> <p>A (Level 4)</p> <p>A (Level 4)</p> <p>A (Level 4)</p> <p>A (Level 4)</p> <p>A (Level 4)</p> <p>A (Level 4)</p> <p>A (Level 4)</p> <p>A (Level 4)</p> <p>A (Level 4)</p> <p>A (Level 4)</p> <p>A (Level 4)</p> <p>A (Level 4)</p> <p>A (Level 4)</p> <p>A (Level 4)</p> <p>A (Level 4)</p> <p>A (Level 4)</p> <p>A (Level 4)</p> <p>A (Level 4)</p>
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—	Z2,20 BRM: [Tr.] Pyrites	A (Level 4)
—	Z2,21 BRM: [Tr.] Antimony	A (Level 4)
—	Z2,22 BRM: [Tr.] Silica	A (Level 4)
—	Z2,23 BRM: [Tr.] Selenium	A (Level 4)
—	Z2,24 BRM: [Tr.] Slags	A (Level 4)
—	Z2,25 Pipeline Transport: Natural Gas Pumping	A (Level 4)
—	Z2,26 etc. <i>DEAM data nodes</i>	A (Level 4)
—	Z3 BRM: Overheads of Secondary Processing Operations	S (Level 3)
—	Z3,1 BRM (Secondary): Overheads	A (Level 4)
—	Z3,2 BRM: [Tr.] Natural Gas (used as fuel)	A (Level 4)
—	Z3,3 Pipeline Transport: Natural Gas Pumping	A (Level 4)
—	Z3,4 etc. <i>DEAM data nodes</i>	A (Level 4)

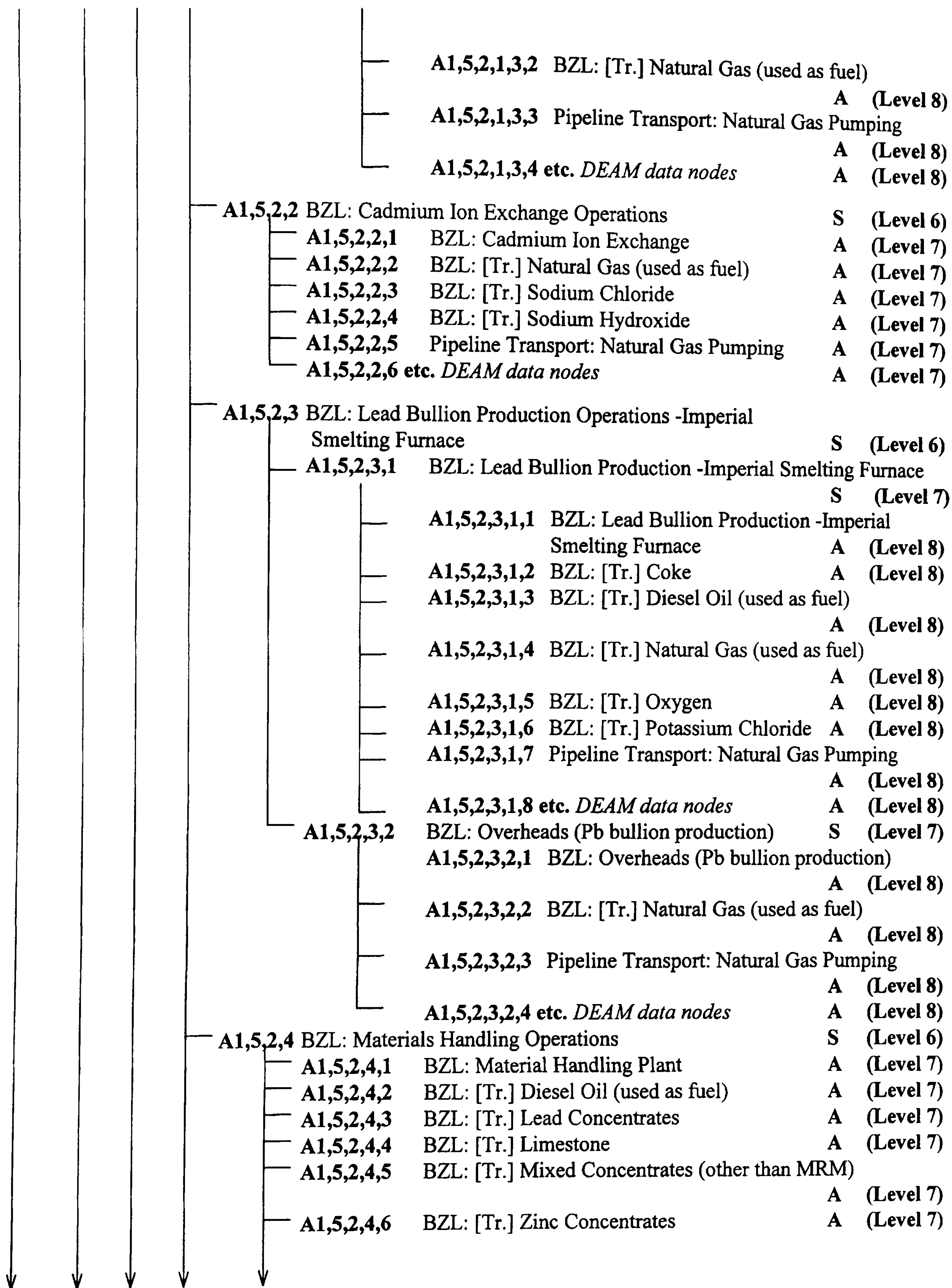
Appendix A2: MIM Pb LCA: TEAM™ Model Structure

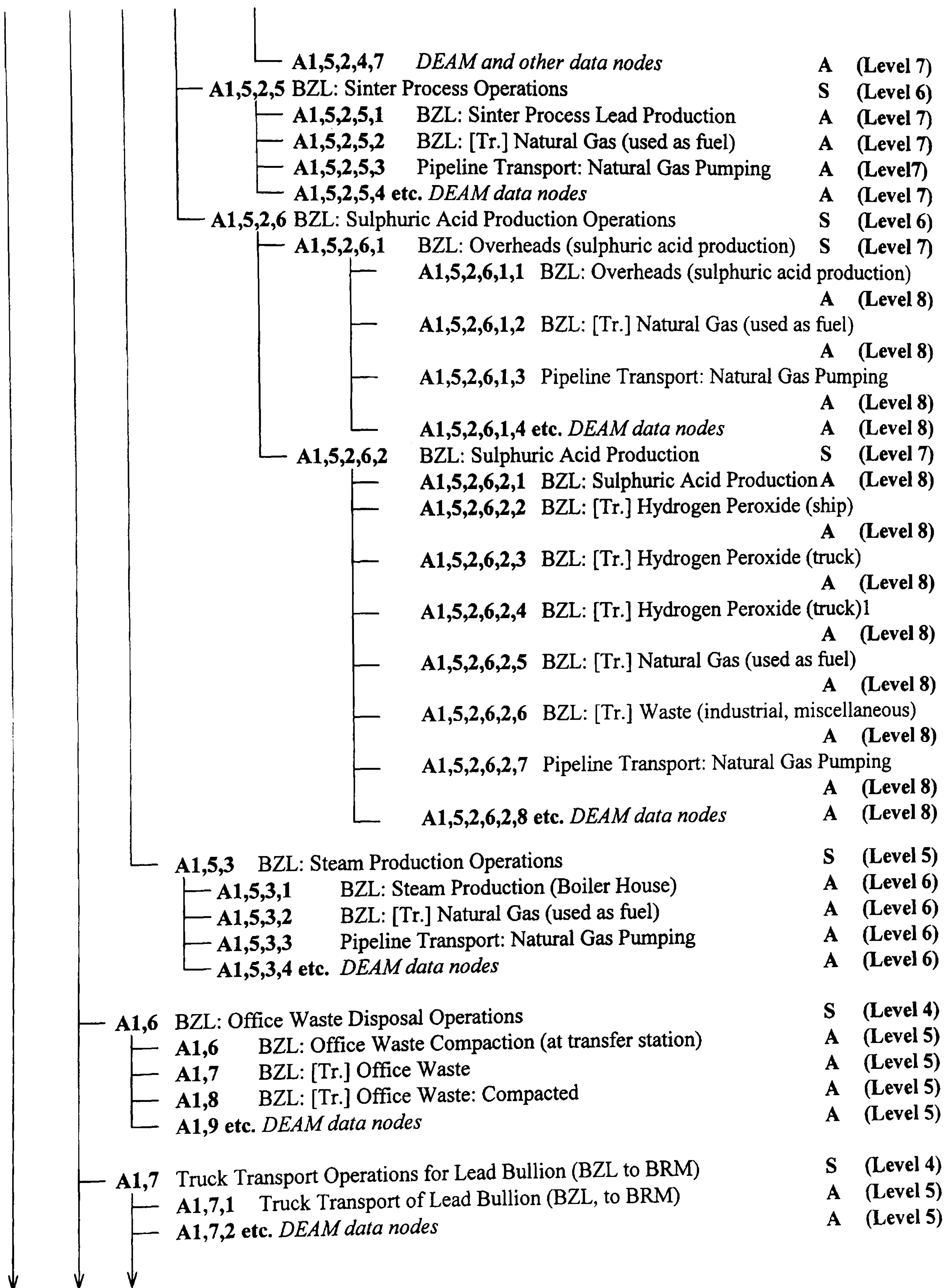
MIM Pb LCA: TEAM™ Model Structure

MIM Pb (all operations)		S (Level 1)
—	A BRM stream (all operations)	S (Level 2)
—	A1 BRM stream (UK operations)	S (Level 3)
—	A2 McArthur River Stream (Australian operations)	S (Level 3)
—	B BRM: Lead and Lead Alloy Product Storage (primary)	A (Level 2)
—	C Isa stream (all operations)	S (Level 2)
—	C1 Isa Stream (Australian operations)	S (Level 3)
—	C2 Isa Stream (UK operations)	S (Level 3)

—	A BRM Stream (all operations)	
—	A1 BRM Stream (UK operations)	S (Level 3)
—	A1,1 BRM: Lead Refining Operations (BRM floor throughput)	S (Level 4)
—	A1,1,1 BRM: Lead Refining (BRM floor throughput)	A (Level 5)
—	A1,1,2 BRM: [Tr.] Ammonium Nitrate	A (Level 5)
—	A1,1,3 BRM: [Tr.] Antimony	A (Level 5)
—	A1,1,4 BRM: [Tr.] Arsenic	A (Level 5)
—	A1,1,5 BRM: [Tr.] Bismuth	A (Level 5)
—	A1,1,6 BRM: [Tr.] Borax (ship)	A (Level 5)
—	A1,1,7 BRM: [Tr.] Borax (truck)	A (Level 5)
—	A1,1,8 BRM: [Tr.] Borax (truck)1	A (Level 5)
—	A1,1,9 BRM: [Tr.] Charcoal	A (Level 5)
—	A1,1,10 BRM: [Tr.] Coil (banding for ingots)	A (Level 5)
—	A1,1,11 BRM: [Tr.] Copper	A (Level 5)
—	A1,1,12 BRM: [Tr.] Diesel Oil (used as fuel)	A (Level 5)
—	A1,1,13 BRM: [Tr.] Magnesium1	A (Level 5)
—	A1,1,14 BRM: [Tr.] Magnesium2	A (Level 5)
—	A1,1,15 BRM: [Tr.] Natural gas (used as fuel)	A (Level 5)
—	A1,1,16 BRM: [Tr.] Nitrogen	A (Level 5)
—	A1,1,17 BRM: [Tr.] Oxygen	A (Level 5)
—	A1,1,18 BRM: [Tr.] Sand	A (Level 5)
—	A1,1,19 BRM: [Tr.] Sodium Hydroxide	A (Level 5)
—	A1,1,20 BRM: [Tr.] Tin	A (Level 5)
—	A1,1,21 BRM: [Tr.] Wood Pulp	A (Level 5)
—	A1,1,22 BRM: [Tr.] Zinc	A (Level 5)
—	A1,1,23 BRM: [Tr.] Slags	A (Level 5)
—	A1,1,24 BRM: [Tr.] Waste (industrial, miscellaneous)	A (Level 5)
—	A1,1,25 Charcoal Production	A (Level 5)
—	A1,1,26 Pipeline Transport: Natural Gas Pumping	A (Level 5)
—	A1,1,27 etc. DEAM data nodes	A (Level 5)
—	A1,2 On-Site Electricity Generation Operations (BRM floor throughput)	S (Level 4)
—	A1,2,1 BRM: On-Site Electricity Generation	A (Level 5)
—	A1,2,2 BRM: [Tr.] Natural Gas (used as fuel)	A (Level 5)
—	A1,2,3 Pipeline Transport: Natural Gas Pumping	A (Level 5)
—	A1,2,4 etc. DEAM data nodes	A (Level 5)

—	A1,3	BRM: Overheads to BZL Input to BRM Floor Throughput Operations	S	(Level 4)
—	—	A1,3,1 BRM: Overheads (BZL bullion processing)	A	(Level 5)
—	—	A1,3,2 BRM: [Tr.] Natural Gas (used as fuel)	A	(Level 5)
—	—	A1,3,3 Pipeline Transport: Natural Gas Pumping	A	(Level 5)
—	—	A1,3,4 etc. <i>DEAM data nodes</i>	A	(Level 5)
—	A1,4	BRM: Overheads to MHD Input to BRM Floor Throughput Operations	S	(Level 4)
—	—	A1,4,1 BRM: Overheads (MHD bullion processing)	A	(Level 5)
—	—	A1,4,2 BRM: [Tr.] Natural Gas (used as fuel)	A	(Level 5)
—	—	A1,4,3 BRM: [Tr.] MHD Lead Bullion (truck)	A	(Level 5)
—	—	A1,4,4 BRM: [Tr.] MHD Lead Bullion (ship)	A	(Level 5)
—	—	A1,4,5 BRM: [Tr.] MHD Lead Bullion (truck)	A	(Level 5)
—	—	A1,4,6 Pipeline Transport: Natural Gas Pumping	A	(Level 5)
—	—	A1,4,7 etc. <i>DEAM and other data nodes</i>	A	(Level 5)
—	A1,5	BZL: Mixed Concentrate Processing Operations at Avonmouth	S	(Level 4)
—	—	A1,5,1 Effluent Treatment Operations	S	(Level 5)
—	—	— A1,5,1,1 Effluent Treatment (in on-site plant)	A	(Level 6)
—	—	— A1,5,1,2 etc. <i>DEAM data nodes</i>	A	(Level 6)
—	—	A1,5,2 BZL: Materials Handling, Sintering, Smelting, Acid Production and Cd and Zn Processing Operations	S	(Level 5)
—	—	— A1,5,2,1 BZL: Cadmium and Zinc Refining Operations	S	(Level 6)
—	—	— — A1,5,2,1,1 BZL: Cadmium and Zinc Refining	S	(Level 7)
—	—	— — — A1,5,2,1,1,1 Cadmium and Zinc Refining Plant	A	(Level 8)
—	—	— — — A1,5,2,1,1,2 BZL: [Tr.] Aluminium	A	(Level 8)
—	—	— — — A1,5,2,1,1,3 BZL: [Tr.] Aluminium ¹	A	(Level 8)
—	—	— — — A1,5,2,1,1,4 BZL: [Tr.] Ammonium Nitrate	A	(Level 8)
—	—	— — — A1,5,2,1,1,5 BZL: [Tr.] Heavy Fuel Oil (used as fuel)	A	(Level 8)
—	—	— — — A1,5,2,1,1,6 BZL: [Tr.] Natural Gas (used as fuel)	A	(Level 8)
—	—	— — — A1,5,2,1,1,7 etc. <i>DEAM data nodes</i>	A	(Level 8)
—	—	— — A1,5,2,1,2 BZL: Overheads (refined Cd production)	S	(Level 7)
—	—	— — — A1,5,2,1,2,1 BZL: Overheads (refined Cd production)	A	(Level 8)
—	—	— — — A1,5,2,1,2,2 BZL: [Tr.] Natural Gas (used as fuel)	A	(Level 8)
—	—	— — — A1,5,2,1,2,3 Pipeline Transport: Natural Gas Pumping	A	(Level 8)
—	—	— — — A1,5,2,1,2,3 etc. <i>DEAM data nodes</i>	A	(Level 8)
—	—	— — A1,5,2,1,3 BZL: Overheads (refined Zn production)	S	(Level 7)
—	—	— — — A1,5,2,1,3,1 BZL: Overheads (refined Zn production)	A	(Level 8)





A2	McArthur River Stream (Australian operations)	S	(Level 3)
A2,1	CMS: Bing Bong Operations	S	(Level 4)
A2,1,1	CMS, Bing Bong Concentrate Handling Operations	S	(Level 5)
A2,1,1,1	CMS: Mixed Concentrate Handling at Bing Bong	A	(Level 6)
A2,1,1,2	CMS: [Tr.] Diesel Oil (used as fuel)	A	(Level 6)
A2,1,1,3 etc.	DEAM data nodes	A	(Level 6)
A2,1,2	CMS: Overheads Associated with Bing Bong Activities	S	(Level 5)
A2,1,2,1	CMS: Bing Bong Overheads	A	(Level 6)
A2,1,2,2	CMS: [Tr.] Water (softened)	A	(Level 6)
A2,1,2,3 etc.	DEAM data nodes	A	(Level 6)
A2,1,3	CMS: Sea Barge Transport Operations	S	(Level 5)
A2,1,3,1	CMS: Mixed Concentrate Transport by Sea Barge (MV Aburri)	A	(Level 5)
A2,1,3,2	CMS: [Tr.] Diesel Oil (used as fuel)	A	(Level 5)
A2,1,3,3 etc.	DEAM data nodes	A	(Level 5)
A2,2	CMS: Electricity Production Operations	S	(Level 4)
A2,2,1	CMS: Electricity Production at Bing Bong	A	(Level 5)
A2,2,2	CMS: [Tr.] Diesel Oil (used as fuel)	A	(Level 5)
A2,2,3 etc.	DEAM data nodes	A	(Level 5)
A2,3	MRM: Electricity Production Operations	S	(Level 4)
A2,3,1	MRM: Electricity Production (at McArthur River)	A	(Level 5)
A2,3,2	MRM: [Tr.] Natural Gas	A	(Level 5)
A2,3,3	Pipeline Transport: Natural Gas Pumping	A	(Level 5)
A2,3,4 etc.	DEAM data nodes	A	(Level 5)
A2,4	MRM: McArthur River Operations	S	(Level 4)
A2,4,1	HTS: Operations Associated with Transport of Mixed Concentrate to Bing Bong	S	(Level 5)
A2,4,1,1	HTS: Road Train Transport of Mixed Concentrate to Bing Bong	A	(Level 6)
A2,4,1,2 etc.	DEAM data nodes	A	(Level 6)
A2,4,2	MRM: Mixed Concentrate Production Operations at McArthur River	S	(Level 5)
A2,4,2,1	MRM: Mixed Concentrate Production	A	(Level 6)
A2,4,2,2	MRM: [Tr.] Cement	A	(Level 6)
A2,4,2,3	MRM: [Tr.] Coil (grinding media, truck)	A	(Level 6)
A2,4,2,4	MRM: [Tr.] Coil (grinding media, rail)	A	(Level 6)
A2,4,2,5	MRM: [Tr.] Diesel Oil (used as fuel)	A	(Level 6)
A2,4,2,6	MRM: [Tr.] Ethanol (rail)	A	(Level 6)
A2,4,2,7	MRM: [Tr.] Ethanol (ship)	A	(Level 6)
A2,4,2,8	MRM: [Tr.] Ethanol (truck)	A	(Level 6)
A2,4,2,9	MRM: [Tr.] Ethanol (truck)	A	(Level 6)
A2,4,2,10	MRM: [Tr.] Lime (quick)	A	(Level 6)

—	A2,4,2,11	MRM: [Tr.] Sodium Chloride	A	(Level 6)
—	A2,4,2,12	MRM: [Tr.] Sodium Sulphate	A	(Level 6)
—	A2,4,2,13	MRM: [Tr.] Sodium Sulphate1	A	(Level 6)
—	A2,4,2,14	MRM: [Tr.] Starch (truck)	A	(Level 6)
—	A2,4,2,15	MRM: [Tr.] Starch (rail)	A	(Level 6)
—	A2,4,2,16 etc. <i>DEAM data nodes</i>		A	(Level 6)
—	A2,4,3	MRM: On-site Transport Operations	S	(Level 5)
—	A2,4,3,1	MRM: On-site Transport at McArthur River	A	(Level 6)
—	A2,4,3,2	MRM: [Tr.] Diesel Oil (used as fuel)	A	(Level 6)
—	A2,4,3,3 etc. <i>DEAM data nodes</i>		A	(Level 6)
—	A2,4,4	MRM: Ore Mining Operations at McArthur River	S	(Level 5)
—	A2,4,4,1	MRM: Ore Mining at McArthur River	A	(Level 6)
—	A2,4,4,2	MRM: [Tr.] Diesel Oil (used as fuel)	A	(Level 6)
—	A2,4,4,3	MRM: [Tr.] Explosives	A	(Level 6)
—	A2,4,4,4 etc. <i>DEAM data nodes</i>		A	(Level 6)
—	A2,4,5	MRM: Overheads Associated with McArthur River Operations	S	(Level 5)
—	A2,4,5,1	MRM: McArthur River Overheads	A	(Level 6)
		[No categories being tracked currently.]		
—	A2,5	Ship Transport Operations for McArthur River Mixed Concentrate	S	(Level 4)
—	A2,5,1	Ship Transport of McArthur River Mixed Concentrate to BZL (UK)	A	(Level 5)
—	A2,5,2	<i>DEAM data nodes</i>	A	(Level 5)

B BRM: Lead and Lead Alloy Product Storage (primary)

[No categories requiring tracking.]

C	Isa Stream (all operations)		S	(Level 2)
—	C1	Isa stream (Australian operations)	S	(Level 3)
—	C1,1	Isa Lead Bullion Shipping Operations	S	(Level 4)
—	C1,1,1	Ship Transport of Lead Bullion (Mt. Isa) to BRM (UK)	A	(Level 5)
—	C1,1,2	<i>DEAM data nodes</i>	A	(Level 5)
—	C1,2	Operations Associated with Mt. Isa Site	S	(Level 4)
—	C1,2,1	Bowen Coke Works (met. Coke production)	S	(Level 5)
—	C1,2,1,1	BCL: Coke Production Operations	S	(Level 6)
—	C1,2,1,1,1	BCL: Coke Production at Bowen	A	(Level 7)
—	C1,2,1,1,2	BCL: [Tr.] Ash	A	(Level 7)
—	C1,2,1,1,3 etc. <i>DEAM data nodes</i>		A	(Level 7)
—	C1,2,1,2	Operations Associated with Transport of Met. Coke to Mt. Isa	S	(Level 6)

	C1,2,1,2,1	Bowen Met. Coke: Rail Transport Operations (BCL to MCPS)	S	(Level 7)
		C1,2,1,2,1,1 BCL Coke for Mt. Isa Pb Smelter: Rail Transport (BCL to MCPS)	A	(Level 8)
		C1,2,1,2,1,2 <i>DEAM data nodes</i>	A	(Level 8)
	C1,2,1,2,2	Bowen Met. Coke: Truck Transport Operations (MCPS to Mt. Isa)	S	(Level 7)
		C1,2,1,2,2,1 BCL Coke for Mt. Isa Pb Smelter: Road Transport (MCPS to Mt. Isa)	A	(Level 8)
		C1,2,1,2,2,2 <i>DEAM data nodes</i>	A	(Level 8)
	C1,2,2	Collinsville Operations (coal for coke production)	S	(Level 5)
	C1,2,2,1	CCL: Coal Mining Operations at Collinsville (coal for coke production)	S	(Level 6)
		C1,2,2,1,1 CCL: Coal Mining at Collinsville	A	(Level 7)
		C1,2,2,1,2 CCL: [Tr.] Diesel Oil (used as fuel)	A	(Level 7)
		C1,2,2,1,3 CCL: [Tr.] Explosive (unspecified)	A	(Level 7)
		C1,2,2,1,4 etc. <i>DEAM data nodes</i>	A	(Level 7)
	C1,2,2,2	Rail Transport of Coal to Mica Creek Power Station	S	(Level 6)
		C1,2,2,2,1 CCL: Coal for Power Generation: Rail Transport to Mica Creek Power Station	A	(Level 7)
		C1,2,2,2,2 etc. <i>DEAM data nodes</i>	A	(Level 7)
	C1,2,3	Collinsville Operations (coal for Mica Creek Power Station)	S	(Level 5)
	C1,2,3,1	CCL: Coal Mining Operations at Collinsville (coal for Mica Creek Power Station)	S	(Level 6)
		C1,2,3,1,1 CCL: Coal Mining at Collinsville	A	(Level 7)
		C1,2,3,1,2 CCL: [Tr.] Diesel Oil (used as fuel)	A	(Level 7)
		C1,2,3,1,3 CCL: [Tr.] Explosive (unspecified)	A	(Level 7)
		C1,2,3,1,4 etc. <i>DEAM data nodes</i>	A	(Level 7)
	C1,2,3,2	Rail Transport of Coal to Mica Creek Power Station	S	(Level 6)
		C1,2,3,2,1 CCL: Coal for Power Generation: Rail Transport to Mica Creek Power Station	A	(Level 7)
		C1,2,3,2,2 etc. <i>DEAM data nodes</i>	A	(Level 7)
	C1,2,4	Hilton Operations	S	(Level 5)
	C1,2,4,1	Hilton Mine Ore Transport Operations	S	(Level 6)
		C1,2,4,1,1 Hilton Mine ore: Truck Transport by KMC & MIM to Mt. Isa	A	(Level 7)
		C1,2,4,1,2 MIM: [Tr.] Hilton Ore at Mt. Isa	A	(Level 7)
		C1,2,4,1,3 etc. <i>DEAM data nodes</i>	A	(Level 7)
	C1,2,4,2	Hilton Mining Operations	S	(Level 6)
		C1,2,4,2,1 MIM: Zinc-Lead-Silver Ore Mining at Hilton	A	(Level 7)
		C1,2,4,2,2 MIM: [Tr.] Diesel Oil (used as fuel)	A	(Level 7)
		C1,2,4,2,3 MIM: [Tr.] Explosive (Hilton, unspecified)	A	(Level 7)
		C1,2,4,2,4 etc. <i>DEAM data nodes</i>	A	(Level 7)

C1,2,5 MCPS: Electricity Production Operations (Mica Creek Power Station)		S	(Level 5)
└─	C1,2,5,1 MCPS: Electricity Production (Mica Creek Power Station)	A	(Level 6)
└─	C1,2,5,2 MCPS: [Tr.] Diesel Oil	A	(Level 6)
└─	C1,2,5,3 MCPS: [Tr.] Natural Gas	A	(Level 6)
C1,2,6 Mount Isa Lead Stream Processing Operations		S	(Level 5)
└─	C1,2,6,1 MIM: Lead Smelting On-Site Transport Process	S	(Level 6)
└─└─	C1,2,6,1,1 MIM: Mt. Isa Mine Ore (on-site, truck)	A	(Level 7)
└─└─	C1,2,6,1,2 etc. <i>DEAM data nodes</i>	A	(Level 7)
└─	C1,2,6,2 MIM: Lead Smelting Processes at Mt. Isa	S	(Level 6)
└─└─	C1,2,6,2,1 MIM: Lead Smelting at Mount Isa	S	(Level 7)
└─└─	C1,2,6,2,2 MIM: [Tr.] Limestone	A	(Level 7)
└─└─	C1,2,6,2,3 etc. <i>DEAM data nodes</i>	A	(Level 7)
└─	C1,2,6,3 MIM: Zinc-Lead-Silver Ore Concentration Processes at Mount Isa	S	(Level 6)
└─└─	C1,2,6,3,1 MIM: Zinc-Lead-Silver Ore Concentration at Mount Isa	A	(Level 7)
└─└─	C1,2,6,3,2 MIM: [Tr.] Cement (truck)	A	(Level 7)
└─└─	C1,2,6,3,3 MIM: [Tr.] Coil (grinding media, train)	A	(Level 7)
└─└─	C1,2,6,3,4 MIM: [Tr.] Coil1 (grinding media, train)	A	(Level 7)
└─└─	C1,2,6,3,5 MIM: [Tr.] Ethanol (train)	A	(Level 7)
└─└─	C1,2,6,3,6 MIM: [Tr.] Ethanol (truck)	A	(Level 7)
└─└─	C1,2,6,3,7 MIM: [Tr.] Ethanol (ship)	A	(Level 7)
└─└─	C1,2,6,3,8 MIM: [Tr.] Ethanol1 (truck)	A	(Level 7)
└─└─	C1,2,6,3,9 MIM: [Tr.] Ferrosilicon	A	(Level 7)
└─└─	C1,2,6,3,10 MIM: [Tr.] Lime (slaked)	A	(Level 7)
└─└─	C1,2,6,3,11 MIM: [Tr.] Soda Ash	A	(Level 7)
└─└─	C1,2,6,3,12 MIM: [Tr.] Sodium Cyanide (train)	A	(Level 7)
└─└─	C1,2,6,3,13 MIM: [Tr.] Sodium Cyanide (truck)	A	(Level 7)
└─└─	C1,2,6,3,14 MIM: [Tr.] Sodium Sulphate1 (train)	A	(Level 7)
└─└─	C1,2,6,3,15 MIM: [Tr.] Sodium Sulphate1 (ship)	A	(Level 7)
└─└─	C1,2,6,3,16 MIM: [Tr.] Starch (train)	A	(Level 7)
└─└─	C1,2,6,3,17 <i>DEAM data nodes</i>	A	(Level 7)
└─	C1,2,6,4 MIM: Zinc-Lead-Silver Ore Mining Processes at Mount Isa	S	(Level 6)
└─└─	C1,2,6,4,1 MIM: Zinc-Lead-Silver Ore Mining at Mount Isa	A	(Level 7)
└─└─	C1,2,6,4,2 MIM: [tr.] Cement1 (train)	A	(Level 7)
└─└─	C1,2,6,4,3 MIM: [Tr.] Explosive (Mt. Isa, unspecified)	A	(Level 7)
└─└─	C1,2,6,4,4 <i>DEAM data nodes</i>	A	(Level 7)
└─	C1,2,6,5 MIM: Processes Associated with Lead Product Stream Overheads at Mt. Isa	S	(Level 6)
└─└─	C1,2,6,5,1 MIM: Mt. Isa Overheads (Isa lead stream) [No categories being tracked currently.]	A	(Level 7)

		— C1,2,6,6	MIM: Processes Associated with transport of Isa Lead Bullion to Townsville	S (Level 6)
		— C1,2,6,6,1	MIM: Mt. Isa Pb Crude Rail and Road Transport to Townsville	A (Level 7)
		— C1,2,6,6,2 etc.	DEAM data nodes	A (Level 7)
		C1,2,7	MPS: Bulk Oxygen Production Operations	S (Level 5)
		— C1,2,7,1	MPS: Liquid Oxygen Production	A (Level 6)
		— C1,2,7,2	MPS: [Tr.] Natural Gas (used as fuel)	A (Level 6)
		— C1,2,7,3	MPS: [Tr.] Sulphuric Acid (rail)	A (Level 6)
		— C1,2,7,4	MPS: [Tr.] Sulphuric Acid (truck)	A (Level 6)
		— C1,2,7,5	Pipeline Transport: Natural Gas Pumping	A (Level 6)
		— C1,2,7,6 etc.	DEAM data nodes	A (Level 6)
		C1,3	Townsville Isa Lead Bullion Handling Operations	S (Level 4)
		— C1,3,1	Isa Lead bullion; Storage and Loading Operations at Townsville	S (Level 5)
		— C1,3,1,1	Isa Lead Bullion; Storage and Loading at Townsville [No categories being tracked currently.]	A (Level 6)
		— C1,3,2	Overheads Associated with Townsville Isa Lead bullion Handling Operations	S (Level 5)
		— C1,3,2,1	Townsville: Overheads Associated with Isa lead Bullion Handling [No categories being tracked currently.]	A (Level 6)
		C2	Isa Stream (UK operations)	S (Level 3)
		— C2,1	BRM: Lead Refining Operations (Isa stream)	S (Level 4)
		— C2,1,1	BRM: Lead refining (Isa stream)	A (Level 5)
		— C2,1,2	BRM: [Tr.] Aluminium	A (Level 5)
		— C2,1,3	BRM: [Tr.] Aluminium1	A (Level 5)
		— C2,1,4	BRM: [Tr.] Ammonium Nitrate	A (Level 5)
		— C2,1,5	BRM: [Tr.] Antimony	A (Level 5)
		— C2,1,6	BRM: [Tr.] Borax (truck)	A (Level 5)
		— C2,1,7	BRM: [Tr.] Borax (ship)	A (Level 5)
		— C2,1,8	BRM: [Tr.] Aluminium	A (Level 5)
		— C2,1,9	BRM: [Tr.] Cadmium	A (Level 5)
		— C2,1,10	BRM: [Tr.] Calgon	A (Level 5)
		— C2,1,11	BRM: [Tr.] Charcoal	A (Level 5)
		— C2,1,12	BRM: [Tr.] Coil (banding for ingots)	A (Level 5)
		— C2,1,13	BRM: [Tr.] Diesel Oil (used as fuel)	A (Level 5)
		— C2,1,14	BRM: [Tr.] Magnesium	A (Level 5)
		— C2,1,15	BRM: [Tr.] Magnesium1	A (Level 5)
		— C2,1,16	BRM: [Tr.] Natural Gas (used as fuel)	A (Level 5)
		— C2,1,17	BRM: [Tr.] Nitrogen	A (Level 5)
		— C2,1,18	BRM: [Tr.] Oxygen	A (Level 5)
		— C2,1,19	BRM: [Tr.] Sand	A (Level 5)

—	C2,1,20	BRM: [Tr.] Sand1	A	(Level 5)
—	C2,1,21	BRM: [Tr.] Sodium Hydroxide	A	(Level 5)
—	C2,1,22	BRM: [Tr.] Tellurium	A	(Level 5)
—	C2,1,23	BRM: [Tr.] Tin	A	(Level 5)
—	C2,1,24	BRM: [Tr.] Wood Pulp	A	(Level 5)
—	C2,1,25	BRM: [Tr.] Zinc	A	(Level 5)
—	C2,1,26	BRM: [Tr.] Slags	A	(Level 5)
—	C2,1,27	BRM: [Tr.] Waste (industrial, miscellaneous)	A	(Level 5)
—	C2,1,28	Charcoal Production	A	(Level 5)
—	C2,1,29	Pipeline Transport: Natural Gas Pumping	A	(Level 5)
—	C2,1,30 etc.	<i>DEAM data nodes</i>	A	(Level 5)
—	C2,2	BRM: On-site Electricity Generation Operations	S	(Level 4)
—	C2,2,1	BRM: On-site Electricity Generation	A	(Level 5)
—	C2,2,2	BRM: [Tr.] Natural Gas (used as fuel)	A	(Level 5)
—	C2,2,3	Pipeline Transport: Natural Gas Pumping	A	(Level 5)
—	C2,2,4 etc.	<i>DEAM data nodes</i>	A	(Level 5)
—	C2,3	BRM: Overheads (Isa stream operations)	S	(Level 4)
—	C2,3,1	BRM: Overheads (Isa stream operations)	A	(Level 5)
—	C2,3,2	BRM: [Tr.] Natural gas (used as fuel)	A	(Level 5)
—	C2,3,3	Pipeline Transport: Natural Gas Pumping	A	(Level 5)
—	C2,3,4 etc.	<i>DEAM data nodes</i>	A	(Level 5)