E.Ls 31/90 Redpa (Carbonate Hills)
32/90 Montagu
33/90 Brittons Swamp (Togari)

Annual Report to the Division of Mines

Mineral Holdings Australia Pty Ltd

by
Vic Threader

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Vic Threader and Associates Pty Ltd
Kingston Beach

CONTENTS

Introduction

The three exploration licences are held by Mineral Holdings Australia Pty Ltd for their potential resources of Smithton Dolomite. In the case of EL 31/90 there is also a resource of Tertiary limestone which has already been investigated (A.R. 1992).

These tenements are situated in northwest Tasmania as shown on the locality map:

No.	Area	Location	Rd Distance Smithton	Pt Latta
EL31/90	6 km^2	S. of Bass Highway near Redpa	43 (Sthn part of EL)	67
32/90	32 "	S. of Bass Highway near Tagari	25 (via Montagu Rd to Mid E.L.)	55
33/90	62 "	Between Bass Hwy and Montagu Road	27 Sthn part of EL	55

Previous Exploration (1991-1992)

EL31/90. Diamond, hammer drilling and surface sampling of the Tertiary limestone and Smithton Dolomite were carried out in 1991 and reported in April 1992. This report contains drill logs and chemical analyses and physical tests by David Mitchell Ltd, Herbert Lange, Vertriebs gesellschaft mbH, APPM and Comalco.

The Tertiary limestone was evaluated by Melocco Pty Ltd and found to take a high polish with an attractive (pink) colour and texture but was not thick enough in the areas drilled to produce blocks of the required size (1 x 2 x 2).

Two samples of white limestone were calcined satisfactorily at 1150°C and 1250°C and a pink limestone sample was overburnt at 1350°C. All pieces remained hard with no tendency to crumble or collapse to powder.

The limestone is inferred to retain its physical integrity in a shaft kiln but with a tendency to overburn.

Colour and brightness tests on the white dolomite indicated that the white dolomite was unsuitable as a paper filler or coating medium.

It was suggested that fine milling and ozone leaching may improve the dolomite but in its unbeneficiated state was unsuitable for paper filling or coating.

The dolomite has been tested satisfactorily as a flux in ferrosilicon and silicomanganese production by Temco.

EL32/90. Surface sampling but no subsurface investigations carried out to date.

Most outcropping dolomite occurred either within the Montagu River Reserve or in a "Caves Reserve" declared by the landowner, A.P.P.M. This latter reserve has no official status but was made to protect a deposit of megafaunal remains which are thought to be of zoological significance. (Murray P and Geode [1976] 47th ANZAAS Congr. Hbt Aust) - see Appendix A.R.1992.

EL33/90. Surface sampling but no subsurface investigations have been carried out to date.

The samples were taken from exposures along Montagu River and tributary drains.

The results of chemical analyses give an average composition combining both 32 and 33/90.

		Theoretical dolomite
SiO_2	0.25	-
TiO_2	<0.01	-
Al_2O_3	0.08	-
Fe_2O_3	0.43	-

MnO	0.01	-
MgO	20.64	21.7
CaO	31.44	30.4
Na_2O	0.13	-
K_2O	0.18	
P_2O_5	0.006	-
SO_3	0.05	-
LOI	46.67	47.9
$\frac{CaO}{MgO}$	1.66	1.4

Current Exploration (1992-1993)

There has been no field work in these licence areas during the current year.

Dolomite samples from the licences have been tested as furnace feed in furnace trials in U.S.A. for the production of magnesium metal. The process employed is a modification of the magnatherm process called the Silicothermic process by its developer, Dr. A. Cameron of Manchester University.

The Australian rights to this process are held by Mineral Holdings Australia Pty Ltd. Expenditure in acquiring these rights, the costs associated with providing sample material for testing, contributions to the furnace trials and preparation of the pre-Feasibility study by consulting metallurgist Dr J. Nixon (appendix) represent the holding company's exploration activity for the current year.

Proposed Exploration (1993-1994)

A moratorium on active field work has been granted until the renewal dates of ELs 31/90 (3.4.94), 32/90 (3.5.94) and 33/90 (7.6.90).

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APPENDIX

MINERAL HOLDINGS AUSTRALIA PTY. LIMITED

A.C.N. 004 759 853

P R O P O S A L

FOR A

FEASIBILITY STUDY

INTO

THE PRODUCTION OF MAGNESIUM METAL

FROM ORES IN NORTHERN TASMANIA

27 April, 1993.

N. M. THOMAS
Chairman

J.C. NIXON
Consulting Metallurgist

135 Collins Street
Melbourne, Vic 2000
Australia.

PROPOSAL FOR A FEASIBILITY STUDY INTO THE PRODUCTION OF MAGNESIUM METAL FROM ORES IN NORTHERN TASMANIA

A. MAGNESIUM METAL

1. INTRODUCTION

The western world production of magnesium is about 250,000 tonnes per annum and there is maybe another 70,000 tonnes production in the former Communist countries. Australia does not produce any magnesium in spite of the presence of several world class ore deposits. It has a consumption of about 5000 tonnes per annum.

For decades, there have been predictions that magnesium "is about to take off". The 20 kg of magnesium used by the Volkswagon "Beetle" for die cast crankcase and transmission housings was often quoted as "proof" that the metal had penetrated the automotive industry but in fact it had not. There was, however, an increase of 35% in the use of magnesium in the U.S. auto industry over the past three years (1).

What has held back the growth of magnesium consumption ? It has not been

- the scarcity of magnesium ores
- excessive energy consumption
- difficult casting and fabrication technologies
- flammability problems
- environmental restrictions

The answer to the question is firstly price relative to aluminium and secondly (to some extent) the structure of the industry.

The principal object of this Proposal is to suggest that improved technology to which Mineral Holdings Australia (MHA) has access, together with the availability of excellent ores of magnesium and silicon in coastal deposits of Northern Tasmania, may offer a cost competitive entry into magnesium production.

2. THE PRICE REDUCTION REQUIRED

The principal competitor of magnesium is aluminium and the early growth of magnesium will depend largely on its ability to displace some of the aluminium and also zinc die castings currently used in the automotive industry. Magnesium has this potential because it is only 67% of the weight of aluminium for the same volume and 24% of the weight of zinc. Replacement of ferrous materials is even more favourable but the cost differential is of course greater.

A prediction by M. Holland of Ford Motor Co. in 1980 (2) was that magnesium could begin to displace aluminium in minor automotive applications when the Mg/Al price ratio was 1.7, a figure related to the difference in density. The aluminium price is depressed at present (US$1.15 - 1.20/kg) but with a more realistic figure of say $1.50, a price of $2.55/kg ($1.15/lb.) would be required for magnesium to satisfy the ratio of 1.7.

The current price of magnesium is about $3.15/kg ($1.43/lb.) which is 60 cents/kg or 23.5% above $2.55. Dr. A.M. Cameron, the inventor of the new technology to be described, is confident that his improvements to the conventional Magnetherm process of Societe Francaise d'Electrometallurgie (SOFREM), a subsidiary of Pechiney, will yield savings of much more than 20% in the cost of magnesium production (see later).

3. ENVIRONMENTAL PRESSURE FOR INCREASED MAGNESIUM PRODUCTION

After many years of speculation about the future of magnesium, there are now positive indications that governments are moving faster to reduce the weight of automobiles for environmental reasons. The Japan Government now requires the average weight per car to be reduced to 1,200 kg by 1995 and 850 kg by 2000. The Japanese Automotive Association consequently expects the weight reduction to require the amount of magnesium used per average car to increase by 3900% between 1989 and 2000.

While it has become fashionable to predict the western world consumption of magnesium to be "1 million tonnes by the year 2000", these forecasts now raise the prediction to "1.6 million t.p.a. over the next 10 years" (3). Be that as it may, there is little doubt that the consumption of magnesium will grow and that Australia is well placed to play a significant part in this growth.

4. TECHNOLOGY FOR MAGNESIUM REDUCTION

The western world magnesium industry has a relatively small output of primary metal which is currently valued at about US$0.8 billion p.a. It consists of some large producers using the chloride electrolysis route technology and a larger number of smaller producers using the thermal route. Most of the magnesium producers are also producers of aluminium and over half of the magnesium produced is later alloyed with aluminium. In most cases, the amount of magnesium in the alloy is small, being only one or two percent.

The chloride route technology is tightly held by those companies using it. This technology involves two distinct parts - the preparation of magnesium chloride from sea water, brine, dolomite or magnesite followed by its electrolysis and the recycling of chlorine. The producers will licence out part of their technology but not all of it. For example, Queensland Metals Corporation is reported to have an option to use an existing electrolysis cell but is developing its own anhydrous magnesium-chloride preparation technology which it is doing with the assistance of C.S.I.R.O , the government research organisation in Australia.

The thermal route technology can readily be purchased and is operated in 10 countries. The largest installation 36,000 - 40,000 t.p.a. is at Northwest Alloys Inc., Washington, U.S.A., a subsidiary of ALCOA and consists of nine 4 MW Magnetherm units.

The improved technology that is the subject of this Proposal is a thermal process owned by the University of Manchester Institute of Science and Technology (UMIST). (There is a royalty arrangement with Royal Dutch Shell.)

An option agreement is held by MHA for Australia/New Zealand and all other countries with the exception of U.S.A. where the rights are held by Northwest Alloys Inc.

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5. SELECTION OF REDUCTION TECHNOLOGY

The following is an extract from a report commissioned by the U.S. Dept. of Energy (DOE) dated February, 1981 entitled "An Assessment of Magnesium Primary Production Technology" by M.C. Flemings et al. of MIT (4).

"In the opinion of the writers, the current and potential costs of producing magnesium by the electrolysis versus the metallothermic route are sufficiently close that the optimum magnesium primary production process depends, not on the intrinsic technological advantage, but rather site selection with respect to the availability of raw materials, energy, labor and markets for both magnesium and process by-products. Given the variation in resources in industrial regions in the United States, electrolytic and metallothermic magnesium production technologies can both be expected to remain competitive for at least the medium term (20 years)."

The small number of producers and the low total production of magnesium have had the effect of limiting the amount of available information about the industry. The DOE report is probably still the best collective source even though it is over 12 years old, possibly because the industry has not changed much and the output has remained fairly constant.

Some figures quoted in the report are given in Table 1.

TABLE 1: MAGNESIUM INDUSTRY STATISTICS IN 1980

	Metallothermic	Electrolytic
1980 world capacity (tons)	83,000 (27.5%)	218,500 (72.5%)
Max. plant size (tons)	26,000	125,000
Average plant size (tons)	10,375	54,625
Total energy requirements (equiv. kwh thermal/lb Mg)	41.1	42.8
Estimated capital cost (US$/annual ton for a 20,000 tpa plant in 1980)	3,500	4,500

The proportions of capacity coming from the two routes have not changed much over the decade indicating that the metallothermic or thermal route is still viable in spite of its smaller unit capacity (Table 2.).

TABLE 2: MAGNESIUM PRODUCTION: INSTALLED CAPACITY IN 1991 (5)

Metallothermic Country	m.t.p.a.	Electrolytic Country	m.t.p.a.
Brazil : Brasmag	6,000	Canada : Norsk Hydro	40,000
Canada : Timminco	12,000	Norway : Norsk Hydro	55,000
China (est.)	9,000	U.S.A. : Dow Chem.	90,000
France : Pechiney	18,000	U.S.A. : Mag. Company	36,000
India : Southern M & C	600	U.S.S.R.(est.)2 plants	90,000
Italy : SIM	12,000		
Japan : Japan Met. & Chem.	5,000		
Japan : Ube Industries	9,000		
USA : N.W. Alloys	36,000		
Yugoslavia: Magnorhom	5,000		
Total	112,600		311,000
Average plant size	11,260.		51,830

There are many factors to be considered in the choice of the route to magnesium if a 60,000 tonne per annum plant were to be contemplated but for a plant with a final capacity of 5,000 to 10,000 t.p.a. the choice would certainly be thermal. That such plants outnumber electrolytic plants at low tonnages is "attributable to the simplicity of thermic reduction equipment design and ease of operation. Thermic facilities also have the advantages of less restrictive site selection criteria, low capacity economies of scale and consequently lower initial investment requirements" (6).

It is preferable, when commencing a new venture with a view to early entry into established world markets, to begin on a small scale and increase gradually. An acceptable procedure would be to start with a production of 5,000 t.p.a. from a single thermal furnace and increase it in similar increments when larger local and overseas markets become available. This would be particularly important in relation to a commodity like magnesium which has for decades defied predictions of rapid world growth.

The electrolytic process is not as amenable to low tonnage operation as the thermal route, providing other essential requirements can be satisfied.

6. THE MAGNETHERM PROCESS

Magnetherm is the most modern process for thermal production of magnesium. It is based on the reduction of magnesium oxide by silicon contained in ferrosilicon:

$$2MgO.CaO + (xFe)\ Si + nAl_2O_3 \rightarrow$$
$$2Mg + 2CaO.SiO_2.nAl_2O_3 + xFe$$

The slag composition is held close to 55% CaO by weight, 25% SiO_2, 14% Al_2O_3 and 6% MgO which at the operating temperature of 1550°C is not fully molten. The temperature cannot be allowed to go much higher because the graphite furnace lining will react to form CO which will oxidise the magnesium vapour produced. Nor can the silicon level in the residual ferrosilicon be allowed to go below about 20%.

The Magnetherm process is conducted in an AC arc furnace comprising an upper water-cooled electrode with current flow through the bath to the carbon hearth. The slag has to be electrically conducting so that the passage of current heats the bath. The reaction by which the magnesium is formed and released as a gas occurs at the surface and is strongly endothermic, requiring heat to be transferred there from the body of the melt.

Many improvements have been made to the Magnetherm process over the years but it still has the disability of operating under vacuum in order for the production of magnesium to proceed at an acceptable rate, a reasonable temperature, and with satisfactory silicon consumption. The sub-atmospheric operating pressure allows some leakage of air into the condenser and causes a loss of metal production. Also, it requires the vacuum to be broken twice per day to tap slag and to change the condenser.

According to Fleming et al: "conversion (of Magnetherm) to continuous operation at a positive pressure would significantly reduce energy consumption and labor requirements, substantially increase the production capacity of the reduction unit and reduce both capital and operating cost requirements" (7).

7. THE CAMERON PROCESS

7.1 Introduction

Several improvements of the Magnetherm process have been developed by Dr Andrew M. Cameron of UMIST. They are covered by International Patent WO89/00613 with a priority date of 10th July, 1987 and the following with the same content and priority date:

Granted: USA 5090 996
South African 88/4985
Australian Acceptance No. 618272;

Pending : South Korean Application No. 775/89.

In discussing the history of the development, Cameron said that he graduated from the Universities of Strathclyde and London (Royal School of Mines, Imperial College) in the mid-seventies and then joined the Thornton Research Centre, Chester of Shell Research Ltd. After several years he was transferred to Shell's Billiton laboratories in the Netherlands as officer-in-charge of pilot plant operations. He worked on the carbothermic reduction of magnesium using a D.C. plasma arc furnace but he had little confidence in this route. He took a position with UMIST where he had the opportunity to develop his improvement to the Magnetherm technology on the basis of detailed chemical thermodynamic studies.

The technology was subsequently piloted continuously at Billiton in a D.C. plasma arc furnace which had an input of 0.6 MW. Enough information was obtained to prove the thermodynamics and kinetics of the technology although further work is required to confirm the engineering, equipment and operational aspects (8).

The DC plasma transferred arc generator is constructed of graphite and is not water-cooled. Such equipment has so far only been used for melting and other 'unsophisticated' applications such as vaporising zinc from steel plant dusts. Intensities of 40 MW are possible with this type of equipment(9). The Cameron process would be the first to make full use of its unique characteristics for a metallurgical reduction process

Incidentally, the Council for Mineral Technology (Mintek), South Africa has patented the use of a DC plasma arc using the Magnetherm slag conditions but Cameron believes this is not practicable and that low silicon use and poor condensation efficiencies would result.

7.2 Basis of the Cameron Technology

Ideal conditions for the silicothermal reduction of magnesium according to the reaction:

$$2\ MgO + Si \longrightarrow SiO_2 + 2Mg(g)$$

include the following:

- a slag saturated with MgO
- a slag with a low activity of SiO_2
- molten reactants in the reaction zone
- the reaction zone located at the surface of the slag for ready Mg gas evolution
- a high temperature in the reaction zone.

Careful examination of the phase diagrams of the MgO, CaO, $A\ell_2O_3$, SiO_2 system indicates that the required conditions can be found in the periclase (MgO) region.

The conditions provide a strong thermodynamic driving force at temperatures of the order of 1600-1650°C which permits the reaction to proceed at a satisfactory rate at atmospheric pressure. Furthermore, it enables the silicon reductant to be used efficiently allowing the silicon in the residual ferrosilicon to be reduced to a very low level (provided a graphite furnace lining is not used as in Magnetherm).

The DC transferred arc operation does not require the bath composition to be governed by its ohmic resistance in order to generate heat as in Magnetherm. Most of the heat transfer from arc to bath is by convection and radiation. A magnesite refractory brick bonded with dicalcium silicate could be used as the furnace lining instead of carbon and it could be similar in composition to the bath and have a frozen wall. Only the area under the arc needs to be fully molten.

Reference to the phase diagram in the Cameron patent indicates that the level of MgO in the slag at operating temperature could be held at 13% or above compared with 6 to 8% in Magnetherm. The volume of slag produced per unit weight of magnesium produced will be 15% lower than the Magnetherm. It would be the ultimate objective that the process would operate with an invariant slag composition which would minimise refractory wear with continuous feeding and maybe continuous tapping of slag and continuous condensation. No maximum furnace size is indicated at the present time.

7.3 Improved Efficiencies and Cost of Production

UMIST claims that the successful 0.6 MW pilot plant trial in the Netherlands confirmed several predicted improvements to the Magnetherm process. Although magnesium was not actually condensed during the trial, analysis of the off-gas indicated that the efficiency of condensation of magnesium vapour to metal would improve because of the substantial reduction in the production of magnesium oxide and nitride. Ingress of air to the condenser was much reduced as the operation was under slightly positive rather than substantially negative pressure. The saving was believed to be equivalent to a 25% increase in magnesium production at no extra cost compared with Magnetherm.

The second source of saving resulting from atmospheric pressure operation was due to not having to break the vacuum to tap slag from the furnace and to replace the condenser. This will reduce daily downtime from 15% to 10%. Of course there would also be capital and operating cost savings by avoiding the need for vacuum pumps and related equipment.

Cameron estimates that the operating cost for the production of magnesium metal would be reduced from US$2.60 to less than US$2.00 per kg. Continuous operation would reduce this further.

7.4 Return on Investment

MHA is not able to make an estimate of the return on investment of the Cameron Process at this time because a detailed estimate of capital and operating costs cannot be made until after the proposed semi-commercial trial.

Published information on the cost of magnesium production is rare but a 1992 paper by Foley of Commodities Research Unit (CRU) and Gilbert of British Sulphur Consultants on the structural use of magnesium contains some interesting estimates of both capital and operating costs (10). These refer to a hypothetical 60,000 tpa chloride-route magnesium plant but MHA would expect that a plant such as the 40,000 tpa Magnetherm plant (such as that of Northwest Alloys Inc., Addy) when converted to the Cameron Process could well have comparable costs. (Note that future interest costs will be less than the 20% predicted in this article.)

MHA is particularly encouraged by the interest and enthusiasm for the Cameron Process by Northwest Alloys which operates the largest and most modern Magnetherm plant in the world and must be well aware of its position on the world cost curves.

8. RAW MATERIALS FOR CAMERON PROCESS MAGNESIUM PRODUCTION

The raw materials required for a 4 MW single furnace operation of the Cameron process producing 5,000 t.p.a. magnesium metal would depend on whether aluminium scrap was available at a suitable price to replace portion of the silicon reductant and to provide alumina to achieve the appropriate slag characteristics. Otherwise some calcined bauxite would be required. Two possible situations would be as follows:

For 5,000 t.p.a. Magnesium production

Option A: Aluminium Scrap		Option B: Bauxite
Calcined dolomite	20,400 tonnes	29,400 tonnes
Calcined magnesite	3,000	620
Aluminium metal	1,140	-
Alumina in bauxite	-	3,120
75% Si ferrosilicon	3,020	4,360
	27,560	37,500

The nature of the raw materials can be changed depending on local economics provided the specified MgO, CaO, $A\ell_2O$ and SiO_2 contents of the slag were maintained. For example, dolomite could be replaced by a mixture of magnesia, lime or magnesia-enriched lime.

B. MAGNESIUM AND CALCIUM ORE RESOURCES

1. INTRODUCTION

MHA's mineral exploration in N.W.Tasmania has been conducted for over 18 years. Exploration, testing, consulting and drilling costs have been substantial on a number of minerals. It is believed that these Tertiary and Precambrian prospects have indications on the surface of very large mineral bodies which will be economically mined as open-cut mines with little overburden.

Consideration of the establishment of a magnesium metal industry in northwest Tasmania provided an added incentive to evaluate deposits of high grade carbonate and silicate minerals which are likely to be of international significance for a number of markets. The potential of the magnesite, dolomite, limestone and silica has been recognized by MHA and others for some time but the available markets to date have not provided the necessary opportunity for their closer examination or development.

Recent further drilling programmes have delineated high grade metamorphosed carbonates and quartzites at depth.

The non-fragility of these ores ensures minimum dust and recent calcination tests have indicated that the ore would have excellent furnace performance with minimum decrepitation.

MHA has mineral leases in the following areas:

EL.25/89	:	Dolomite south of Smithton adjoining an existing small quarry (see map in Appendix).
EL.31/90, EL.32/90, EL.33/90	:	Limestone, magnesium-rich limestone, dolomite in three locations being west of Smithton near Redpa, Togari and Montagu.
EL.25/88	:	High grade quartzite rock at the Thomas Mountain Mine in the Dip Range.

N.B. The quartzite, with very low Al_2O_3 has been successfully run in B.H.P. furnaces at Bell Bay, with low decrepitation and very low energy costs for the production of ferrosilicon.

In addition, CRA Limited (75%) and MHA (25%) hold very extensive magnesite leases near Arthur River and Lyons River west of Hellyer Gorge (RL.8717 and RL.8718).

It has not yet been possible to make detailed estimates of the tonnages available but the surface expressions and drilling already conducted leave no doubt that the exploration licences cover a huge carbonate resource which could support major export operations both in respect to quality and quantity. Some details are given in the Appendix.

2. LOCATION/INFRASTRUCTURE

The location of the deposits is excellent being on flat undulating cleared land with much of the deposit being mainly on private land with some Crown land. The near-seaboard carbonate deposit locations shown in the Appendix are serviced by the ports of Stanley (30,000 tonne vessels), Port Latta (110,000 tonne vessels) and Burnie (45,000 tonne vessels) with established bulk loading facilities. All ports have much free time. MHA has an option for rights to a non-metallic bulk storage area at Burnie Port. A full infrastructure exists nearby, including water, airport, labour, roads, railways, hydro-power and ready accommodation, as many employees would be resident at Smithton. These existing infrastructures should greatly enhance the viability of a mine with minimum capital costs.

3. ENERGY

The existing energy sources are generated by the State's low cost hydro-electricity plants.

A possible alternative for energy could be Amoco's recent Yolla discovery of natural gas, about 100 km offshore in shallow water in the Bass Basin, or B.H.P. gas from the Gippsland Basin field. MHA is hopeful that natural gas will become available on site at Port Latta - being the nearest on-shore site to Yolla - for calcining. These energy factors will enhance the viability of a substantial industrial development in this area. MHA has an assurance of an allocation of hydro-power from the Tasmanian Government and also of a site and some assurance of assistance with other development costs.

4. TRANSPORT - TASMANIA AND MAINLAND AUSTRALIA

The existing local rail and road infrastructure will be utilised for Tasmanian industries. The Federal Government Freight Interstate Equalisation Scheme is proving of benefit to Tasmanian industry by subsidising exports to all States on the mainland. This scheme covers any containerised materials and some bulk shipments with substantial subsidies ensuring that a Tasmanian industry is not at a disadvantage to a mainland industry, ie. basically it allows Tasmanian industry to transport its product at much the same road freight cost that exists between States, ie. Victoria to New South Wales, Queensland or Western Australia.

Hopefully reform on the waterfront will greatly reduce bulk transport costs to the mainland and overseas.

C. THE PROPOSALS

1. INTRODUCTION

MHA wishes to find a joint venture partner to collaborate in the further evaluation in a step-wise manner of the economic potential of the Cameron Process and of the dolomite, limestone and silica deposits in its exploration leases.

MHA plans to pass over the management and 50% of the joint venture to the partner following a positive conclusion of a Feasibility Study.

The Feasibility Study will include a trial of the Cameron Process in a full-size, commercial furnace. As mentioned earlier, the rights for the Process in USA are held by Northwest Alloys Inc. (NWA), a subsidiary of ALCOA, which operates nine 4 MW Magnetherm furnaces in its plant at Addy, Washington.

Because of the downturn in the world commodity markets several of the NWA furnaces are currently shut down. During visits to Addy by N.M. Thomas and J.C. Nixon in May and August, 1992, NWA advised that they were keen to convert an idle furnace to the Cameron technology and operate it in 1993 for a period of 6 months. They invited MHA to participate and to share the cost of the trial.

2. PROPOSAL FOR FEASIBILITY STUDY FOR MAGNESIUM PRODUCTION

The following steps are proposed:

2.1 Stage 1: Preliminary Study - June, 1993 to March, 1994.

MHA will organize and manage a Feasibility Study with the assistance of geological, mining, engineering and metallurgical consultants in association with the joint venture partner, UMIST and the other licence holder of the UMIST technology.

The Study will consist of further explorational drilling and will recommend the preferred mining and smelting sites, taking account of the available existing infrastructures. Some experimental work on calcination and other aspects is envisaged.

The costs will include further detailed mapping, drilling, assaying and testing of the mineral deposits; consulting fees; part of UMIST licence fees; part reimbursement of former MHA exploration costs; MHA administration; preliminary environmental studies, etc.

Cost: US$1 million.

2.2 Stage 2: Construction and Operation of Cameron Process - June, 1993 - March, 1994.

Concurrently with Stage 1, one 4 MW Magnetherm furnace at the Addy smelter will be converted to the Cameron process and operated to produce over 2000 tonnes of refined magnesium for sale. MHA's own materials will be used for prolonged tests.

Costs will include extensive alterations to an existing furnace including provision of new electric cabling and a transformer-rectifier, training of the metallurgical and engineering staff of MHA and partner and preparation of drawings sufficient for orders to be placed for smelting equipment.

Net Cost :	US$7.0 million
Contingency:	US$1.0 million

2.3 Stage 3: Final Feasibility Study, Cost Estimates and Infrastructure Preparation - April, 1994 to December 1994

Sufficient information should be available after 3 months operation of the Cameron furnace to enable a decision to be made whether to proceed with a smelter project. (The actual timing of Stages 3 and 4 will depend on when the transformer-rectifier can be ordered and delivered to the Northwest Alloys plant.)

Stage 3 will include the planning and selection of the smelter site; design of roads, storage and loading facilities for smelter feed; environmental studies; MHA co-ordination and administration.

The joint venture partner would have earned 50% equity in the project in this stage and would have the option of taking over the management.

Cost: US$ 1.5 million

2.4 Stage 4: Construction of Cameron Smelter - January, 1995 to December, 1995.

Stage 4 will include the construction and completion of all facilities for calcination, smelting, refining, storage, shipping and administration.

Cost: not available until Stage 3.

3. RIGHTS EARNED BY JOINT VENTURE PARTNER

As mentioned above, MHA's joint venture partner (JVP) will have earned, during Stage 3 of the Feasibility Study a 50% share in the information generated. This is expected to yield:

(a) sufficient information to construct a Cameron magnesium smelter;

(b) a 50% ownership of the Cameron technology in GCC countries;

(c) an assurance that MHA would be able to supply Tasmanian feed materials for the Cameron Process delivered to international ports at competitive prices;

(d) sufficient information for JVP to decide whether to purchase a 50% share in the ownership of MHA Pty Ltd.

Note that all of the above have been agreed in principle with the particular owners but the details are subject to final confirmation.

4. PRODUCTION ROYALTIES

In consideration of past performance and expenditure, and the availability of substantial tax losses available to MHA, MHA will claim royalties as follows:

(a) if JVP decides not to purchase a 50% share in MHA, royalty charges on MHA's ores will be included in the sale price of ores to JVP but JVP will not be obliged to purchase same;

(b) if JVP decides to take 50% ownership of MHA Pty Ltd., MHA will be entitled to a royalty of 3.5% of the indexed sale price of any ore and 1% of the price of any processed product (except magnesium metal) arising from the current exploration leases;

(c) we believe that UMIST will charge a royalty of not more than 3.0% of the value of Cameron Process metal and MHA will charge an additional 1%.

N.M. Thomas
Chairman
Mineral Holdings Australia Pty Ltd

J.C. Nixon
Consulting Metallurgist

26 April, 1993.

REFERENCES

1. "Magnesium", November/December, 1991, p.4.

2. M.C. Flemings, G.B. Kenney, D.R. Sadoway, J.P. Clark, J. Szekely, "An Assessment of Magnesium Primary Production Technology", U.S. Dept. of Energy (DOE), Washington, February, 1981 - page 13.

3. Queensland Metals Corporation Annual Report 1991, p. 47.

4. Ref. 2, p.15.

5. International Magnesium Association (private communication December, 1991).

6. Ref. 2, p.82.

7. Ref. 2, p.118.

8. A.M. Cameron, D.L. Canham and V.G. Aurich,"Magnesium Production by Plasma-Powered Processding", Journal of Metals, April 1990, p.46-48. (copy attached)

9. N.A. Barcza, "The Development of Large-Scale Thermal-Plasma Systems", Mintek Review, No. 6, 1987.

10. P.T. Foley and K. Gilbert,"Magnesium as a Structural Metal : Can the Dream Come True?", Proceedings 49th Annual World Conference, International Magnesium Association, May, 1992, p.7. (")

APPENDIX

NOTES ON MINERAL HOLDINGS AUSTRALIA'S TASMANIAN LEASES BASED ON A REPORT BY MR V. THREADER, CONSULTING GEOLOGIST, HOBART.

DOLOMITE

1. Smithton Basin

Carey & Scott (1952) correlated all carbonate sequences in the Smithton Basin with the Smithton Dolomite, in the belief that there was only one carbonate succession in the Basin. More recent mapping and geophysical data has provided evidence that this original correlation is not valid. This work indicates that there are two carbonate sequences: an upper one - Smithton Dolomite of the Duck River and Montagu River drainage systems and a lower one - Black River Dolomite (a dominantly silicified carbonate sequence). These two carbonates are separated by the Crimson Creek Formation or its correlates (a sequence of volcaniclastics). For more detailed information see Brown A.V. in Burrett C.F. and Martin E.L. (eds) (1989) Geology and Mineral Resources in Tasmania Spec. Publ. Geol. Soc. Aust. 15.

The dolomite resource within the tenements EL.25/89 (Smithton), EL.31/90 (Redpa), EL.32/90 (Montagu Plains) and EL.33/90 (Brittons Swamp) are stratigraphically within the Smithton Dolomite.

2. EL.25/89

Twenty hammer holes were drilled in this tenement and 8 surface samples taken. The results indicated continuity of the high grade dolomite which was located by B.H.P. in ten diamond drill holes to the north of the area now occupied by the Circular Head Dolomite Company.

The area drilled was 100,000m² and the depth of drilling was 10m, i.e. 1,000,000m³ or 2.4 million tonnes (mt).

The licence area covers about 2km² south of Bass Highway which is small holdings farm land and has not been examined and would not be unless a mining venture could gain approval. A similar area, i.e. 2km², of high prospectivity lies to the west of 102m/71 (237 ha) held by the Circular Head Dolomite Company.

3. EL.31/90

The (Precambrian) Smithton Dolomite is over 1000m thick and covers 1km² (outcropping sporadically through the area). There is therefore a potential 2 million tonnes per metre depth in the licence and the depth would appear to be limited only by the practicalities of mining.

The quality of dolomite, from hammer drill and diamond drill samples is high, and in places is pure dolomite.

Analysis of surface samples gives around 20% MgO and in borehole samples the range is MgO 18.98-21.89% CaO 28.45-32.48% and LOI 41.97-46.91%.

The degree of solution cavity is unknown and could only be established by more drilling. Pattern drilling at say 100m centres for a start is required with a mix of open holing for sampling and core drilling for prevalence of voids (recovery).

In addition to pure or nearly pure dolomite there is a rock type which has been described as dolomitic limestone or magnesium limestone (which could be the result of de-dolomitisation). This occurs in the eastern portion of the licence and its precise stratigraphic position is not clear but it appears to be lower in the sequence (perhaps on the contact with the underlying Caroline Creek Formation). The composition of this rock is: ?

CaO	35.80-47.0%
MgO	4.77-16.4%
LOI	43.67-46.43%
Fe_2O_3	0.03- 0.1%
SiO_2 + Al_2O_3	0.19- 1.89%

This was examined in outcrop and borehole but more data is required to identify a resource.

4. EL's. 32/90 & 33/90 CARBONATE HILLS

These licence areas lie to the east of EL.30/90. The Smithton Dolomite is flatter dipping here than it is in EL.30/90 (which lies on the steeply dipping western limb of a syncline).

There has been no drilling in these areas as yet but the rock quality of surface samples indicates that it is consistently of high quality e.g. Montagu (32/90) - average of 4 samples.

MgO 20.64%; CaO 31.44%; SiO_2 0.25%; Al_2O_3 0.08%; $Fe_2O_3$0.43%.

A scout drilling is proposed for these areas when the most suitable areas have been identified (on the lines of landowner agreements, and environmental considerations).

These two areas combined cover some tens of square kilometres and have a very large potential resource.

5. DOLOMITE GENERAL

The former consultant of M.H.A., a one time Chief Government Geologist in Tasmania (and later Director of the Bureau of Mineral Resources for Australia until his retirement), Mr. P.B. Nye, long held the belief that the Smithton Dolomite was a huge resource of high quality and from the recent mapping by the Geological Survey of Tasmania and the exploration by M.H.A., this would appear to be the case.

The maximum suggested by R. Glenie for these licences:

31/90 - 200mt, 32/90 - 300mt, 33/90 - 1600mt, 25/89 - 200mt.

is about the right order of magnitude. There is no point at present of assuming a greater depth of resource than 20m although the greater potential is indicated by stating it as 20+.

MAGNESITE: RL.8717 & RL.8718

The magnesite resource (+40% MgO) at Lyons (30mt) and Keith Rivers (30mt) has been estimated to a nominal depth of 100m. Diamond drilling has established continuity of the deposit to much greater depth and so the reserves of magnesite would be correspondingly greater. There are also considerable tonnages of low grade magnesite - dolomite which could be beneficiated.

LIMESTONE RESOURCE: EL.31/90 CARBONATE HILLS, REDPA

An indicated resource of 3/4 million tonnes is estimated less solution cavities which may be a significant proportion judging by paucity of outcrop and lack of limestone intersections (open holes) drilled between outcrops.

A thickness of 5m only was applied in this estimate to allow for soft rock below the depth as in DD5 and 6.

A suggestion by R. Glenie that the limestone is thicker than indicated may be the case if the limestone was deposited on an uneven floor but the Geological Survey geologist who mapped the area does not support the view that the limestone extends below plains level.

The quality of the main limestone resource is high:

CaO 53-55%; Fe_2O_3 0.03-0.7%; MgO 0.5-1.75%; SiO^2 + Al^2O^3 0.5-2.9%.

The status of the resource must remain at an inferred level due to the lack of information between outcrops.

This estimate refers only to Michaels and Coffeys Hills. Outlying and prospective areas have the potential to double this reserve but more drilling is required to establish this and close pattern and deeper drilling is required to improve the status of the estimate.

Before any further drilling is done, a larger scale topographic map is required for more accurate plotting of data.

SILICA

Ferrosilicon is required as a reductant for magnesium oxide in the Cameron process. It was formerly manufactured by the BHP subsidiary TEMCO at Bell Bay on the north-east coast of Tasmania which is connected to the Smithton area by road and rail.

Substantial deposits of high grade quartzite rock are held by MHA at Thomas Mountain in the Dip Ranges, south of Rocky Cap about 8 km east of Smithton. This material would be suitable for the manufacture of ferrosilicon and silicon metal.

CASSITERITE

In the north-east of Tasmania, MHA holds two Retention Leases 8715 ($6km^2$) and 8723 ($7km^2$) which have been explored for alluvial tin in the Fosters Marsh area and a reserve of $45000m^3$ of grade 450 grams per m^3 have been estimated. There is an area of higher grade cassiterite *(tin)* at "Bowlers Lagoon" in this licence with 850 grams per m^3 that would be "ideal" to commence dredging. A contiguous off-shore area which represents a northerly extension of this deposit into Ringarooma Bay has also been examined and reserves of 3300-4500t of tin metal (grade 80g per m^2) were estimated at depth of 20-40 metres. Associated rutile, zircon, gold and minor monazite were found which added approximately 20% to the resource value.

This prospect would be included in the 50% equity sale should the partner so desire.

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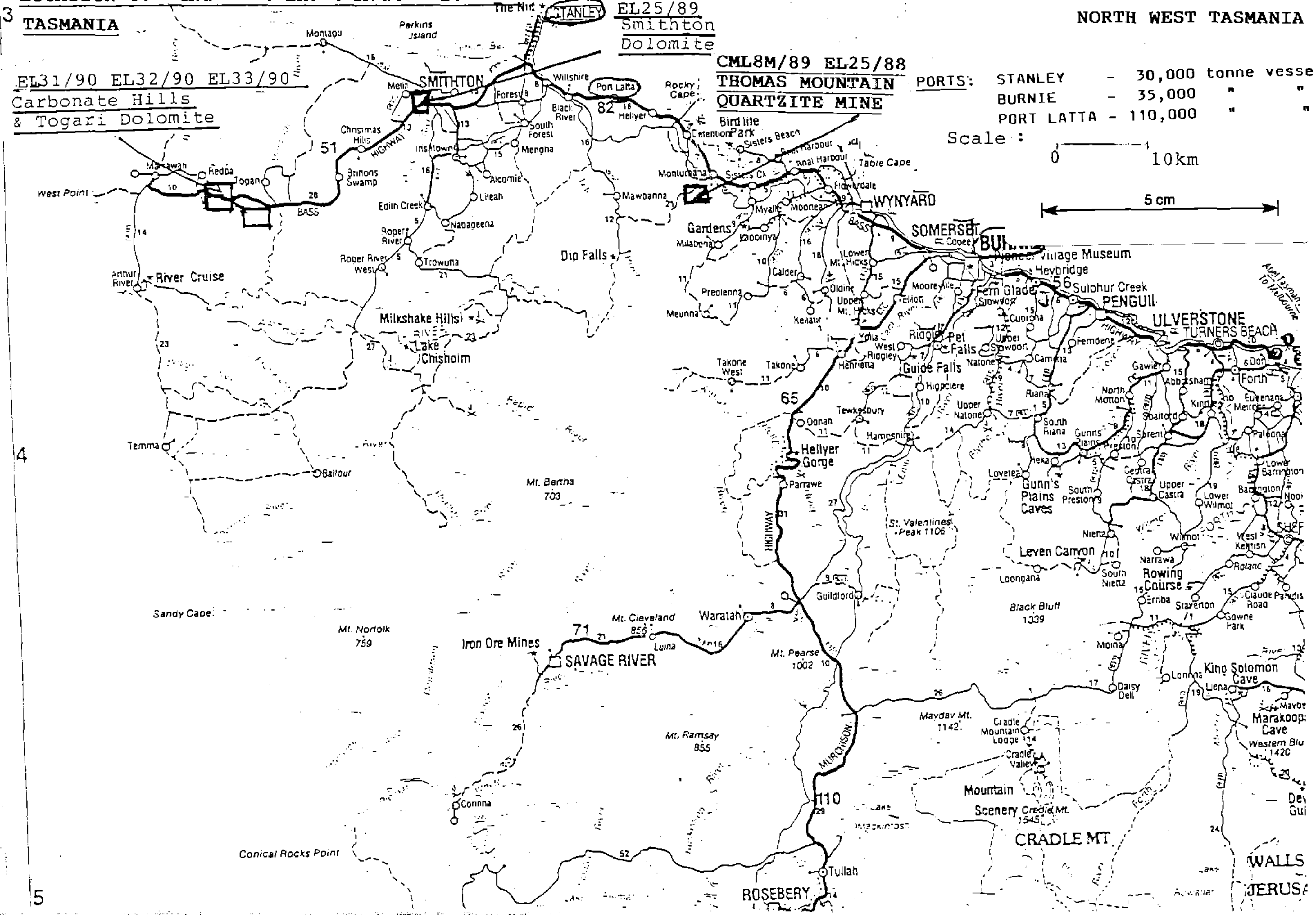
MINERAL HOLDINGS AUST. PTY. LIMITED

LOCATION OF MINERAL & EXPLORATION LICENCES

TASMANIA



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Magnesium Production by Plasma-Powered Processing

A.M. Cameron, D.L. Canham and V.G. Aurich

JOM

The Journal of The Minerals, Metals & Materials Society

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Magnesium Production by Plasma-Powered Processing

A.M. Cameron, D.L. Canham and V.G. Aurich

A new process has been developed to extract magnesium from aluminosilicate slags which have high basicity ratios. The process is dependent on the effective utilization of the characteristics of transferred-arc gas plasmas and has important advantages over alternative pyrometallurgical methods of magnesium production. The need for careful control of an invariant slag composition is eliminated, as is the requirement of a vacuum condenser or complex gas quench technology. Significantly improved magnesium yields, when combined with highly efficient usage of the reductant, will greatly enhance the economics of the pyrometallurgical route to magnesium.

INTRODUCTION

Magnesium markets are currently dominated by a small number of high tonnage producers. This reflects the existing preference for electrolytic extraction from $MgCl_2$ over the alternative pyrometallurgical processes such as the Magnetherm or carbothermic technologies.[1] *Nevertheless, pyrometallurgy offers* many potential advantages, including higher space-time yields (as measured in tonnes · m^{-3} $hr.^{-1}$) and lower capital investments than those associated with electrolytic plants. Furthermore, the ability to make use of relatively inexpensive and abundant ores such as magnesite or dolomite avoids the technological difficulties inherent in the recovery and subsequent dehydration of magnesium chloride from vast quantities of seawater or waste brines. For these reasons the Magnetherm process accounts for some 20% of magnesium production capacity. If the efficiency of such a process could be substantially improved, it would have important repercussions for the economic viability of pyrometallurgical magnesium production.

It has been suggested that the high energy densities attainable in plasma systems (gas enthalpies of 3–8 kWh per normal m^3) could usefully be harnessed for the production of metals from their oxides when the reduction reactions involved are highly endothermic.[2] A new process has been developed which succeeds in combining the use of dolomitic feedstock with effective utilization of a transferred arc plasma furnace.[3] The new process has significant advantages when compared with existing methods of magnesium production. For comparison, more conventional alternative technologies are described in the sidebar.

THE PLASMA PROCESS

The objective of a plasma process must be to obviate the shortcomings of the traditional pyrometallurgical technologies. Hence, the basic requirements are operation at atmospheric pressure, efficient use of the reductant, and the ability to employ a simple condenser rather than a gas quench. The desire to avoid a gas quench has led to the retention of ferrosilicon as the reductant for the new process and hence the overall reaction may again be approximated to that given by Equation C in the sidebar. The conditions necessary to enable atmospheric operation can therefore be considered on the basis of Equation 1:

$$\Delta G = \Delta G^\circ + RT \ln\left(\frac{(P_{Mg})^2 \cdot a_{SiO_2}}{(a_{MgO})^2 \cdot a_{Si}}\right) \quad (1)$$

From this equation, it is clear that for a constant slag composition and temperature, increased magnesium pressures are only possible at the expense of the efficiency of silicon consumption. This has been the main obstacle to high-pressure operation of the Magnetherm process. It is also obvious, since ΔG° decreases with temperature in accordance with the entropy increase associated with the reaction, that atmospheric operation should eventually be possible at elevated temperatures, even with low values of silicon activity in the reductant. The two main problems to be addressed in developing an atmospheric process were, therefore, the attainment and containment of the high temperatures required and delineation of appropriate slag composition(s). These can be *solved via an appreciation of the charac*teristics of transferred-arc plasma reactors and the thermodynamics of slags in the quatemary CaO-MgO-Al_2O_3-SiO_2 system.

PLASMA HEATING

Plasma heating is now a well-established technology, and the principles of industrial plasma systems have been the subject of many excellent reviews.[11,12] The main features of interest to the process metallurgist are, arguably, the ability to generate extremes of temperature (temperatures of ~12,000K have been ascribed to the core of the ionized gas column) and the fact that power generation within the column is independent of the electrical conductivity of the material processed. This allows slag compositions to be chosen which do not compromise the process thermodynamics at the expense of the required physical properties. In spite of this, plasma heating has, to date, only found application in areas such as tundish heating, melting or blast augmentation, since few smelting operations have been dependent on, or benefited sufficiently from, the unique characteristics of plasma power.

It is recognized that the magnesium-producing reactions of both the Magnetherm and more recent carbothermic processes take place at the surface of the slag systems employed.[7,9] This was the motivation for pilot-scale trials of the slag bath carbothermic process in a plasma reactor. The configuration of the plasma reactor used is shown in Figure 1. This configuration enables power to be delivered directly to the surface slag layer where the endothermic reduction reaction takes place, and avoids heat-transfer limitations which may otherwise arise from the use of submerged-arc resistance heating. Temperature profiles were measured for both modes of heating during the development of the carbothermic process (Figure 2).

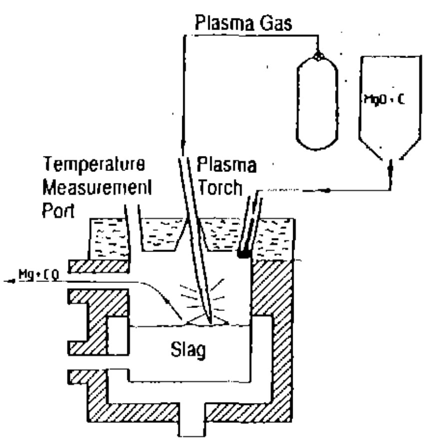

Figure 1. The plasma reactor configuration used during pilot trials of the slag bath carbothermic process.

The profiles indicate that plasma heating is potentially capable of generating high surface temperatures which could sustain an atmospheric/silicothermic reaction, while retaining bulk slag temperatures to allow the use of conventional refractory materials.

SLAG COMPOSITIONS

A suitable slag system must result in the efficient use of the ferrosilicon reductant and allow the generation of a high purity magnesium vapor. These requirements are met by selecting an initial slag composition which: will maintain low silica activities, in spite of an increasing silica content resulting from the reduction reaction; remains at, or close to, magnesia saturation throughout the process; and is effective in passivating other oxides which may be introduced as feedstock impurities and could react to contaminate the vapor phase.

This precludes a plasma process based on the use of the Magnetherm process slag. Because the Magnetherm slag is only saturated with respect to MgO at temperatures below about 1,823K, it cannot retain unit activity magnesia to the higher temperatures needed for effective atmospheric operation. A consequence of simply replacing the traditional Magnetherm power source by a plasma system as proposed by Barcza[13] must, therefore, be a reduction in the already poor silicon consumption, as witnessed by Equation I.

In contrast, the necessary conditions can be satisfied by employing slag compositions which lie entirely within the periclase primary recrystallization field of the $MgO\text{-}CaO\text{-}Al_2O_3\text{-}SiO_2$ phase diagram. Initial estimates of the activities of the component oxides of such slags can be obtained by reference to the measured data for the ternary $CaO\text{-}Al_2O_3\text{-}SiO_2$ system[14] by the simple device of treating MgO and CaO as a single component. This is justified by observations that, on a weight percent basis, and up to concentrations of at least 10%, the effect of MgO on silica activity is approximately equivalent to that of CaO in the quaternary system.[14,15] These estimates support the view that silica activities are suitably low over a wide range of compositions in the periclase region. It is then a simple task to select magnesia contents which ensure slag saturation at the desired reaction temperature of 2,173–2,273K.

A statistical thermodynamic model of slag systems which has been shown to accurately predict relevant sections of the phase diagram[16] has also been employed in order to validate the predicted activities. The results are in broad agreement with the initial estimates.

The derived activity data have been used to show that the desired process conditions are met by employing an initial slag comprising 25 wt.% MgO, 33 wt.% CaO and 42 wt.% Al_2O_3. This slag

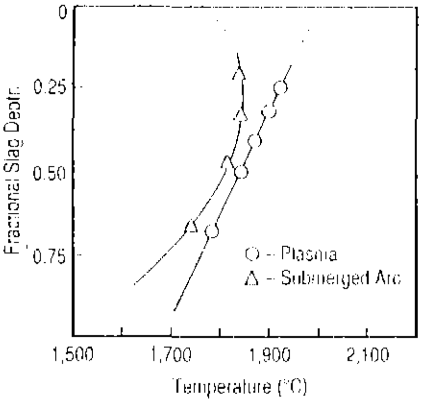

Figure 2. A comparison of slag temperature profiles resulting from conventional arc resistance heating and transferred arc plasma heating.

TRADITIONAL PYROMETALLURGICAL TECHNOLOGIES

Carbothermic Processes

Of the limited number of species capable of reducing MgO, carbon is both the least expensive and most readily available. An early process utilizing carbon as reductant was developed by Hansgirg and operated at Permanente. A flowsheet of the Permanente Process is given in Figure A.

The overall reaction was:

$$MgO(s) + C(s) = Mg(g) + CO(g) \quad (A)$$

The reaction took place by charging the magnesia-containing feedstock onto a bed of hot metallurgical coke maintained at 2,000°C in an electric arc furnace. The magnesium was recovered from the gas phase by shock cooling in a stream of natural gas. The process had several disadvantages: pyrophoric magnesium dust was formed during the inefficient quench step; a relatively pure source of MgO was required (i.e., seawater magnesia); and the poor selectivity of the reduction reaction necessitated purification of the product by sublimation.

It has recently been suggested that improvements to this process would arise from the use of a molten slag bath which would act as a heat transfer medium to the reactants as well as being a sink for impurities contained in the feedstocks.[7] Hence magnesia was reduced from a $MgO\text{-}CaO\text{-}Al_2O_3\text{-}(SiO_2)$ slag, the composition of which (20 wt.% MgO, 35 wt.% CaO and 45 wt.% Al_2O_3) at the start of the process was chosen to maintain saturation with respect to magnesia, while minimizing the activities of the other components.

While it could be demonstrated that magnesium vapor of high purity was obtained, the difficulty of recovering the metal from a reactive, high-temperature gas mixture remained. Liquid metal spraying was suggested as a means of achieving the high heat and mass transfer rates required of an effective gas quench. This would also enable the magnesium to be recovered in liquid form. In spite of this, difficulties remain in relation to the interface between the furnace and quench unit. Such engineering difficulties, when seen in combination with the rapid kinetics of gas phase reactions at temperatures close to 2,000K, will inevitably result in substantial product loss due to reaction between magnesium and carbon monoxide as the gas mixture cools.

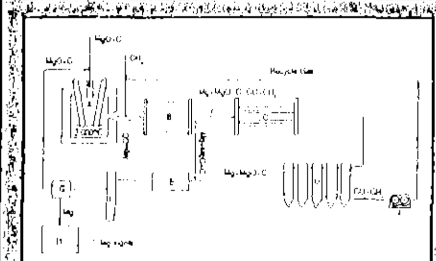

Figure A. The flow sheet for carbothermic production of magnesium by the Permanente process: (A) Arc furnace; (B) quench unit; (C) gas cooler; (D) bag filters; (E) solids collection/pelletizer; (F) retorts; (G) magnesium cooling; (H) foundry; (I) gas Blower.

The Magnetherm Process

Ferrosilicon is used to reduce magnesia from a dolomitic feedstock according to an overall reaction which has been represented by:

$$2CaO \cdot MgO(s) + x(Fe)Si(s) + nAl_2O_3(s) = 2CaO \cdot SiO_2 \cdot nAl_2O_3(l) + 2Mg(g) + xFe(s) \quad (B)$$

A simplified flowsheet for the process is given in Figure B.

The reaction is favored by a low silica activity in the aluminosilicate slag and by operation of the process at a reduced pressure of 0.05 atm. Alumina additions are made to maintain a fixed slag composition of 55 wt.% CaO, 6 wt.% MgO, 14 wt.% Al_2O_3 and 25 wt.% SiO_2, which at the operating temperature of 1,823K is doubly saturated with respect to magnesia and dicalcium silicate. This facilitates thermodynamic analysis of the process, which has been adequately represented by considering the magnesium production reaction to be:

$$2(MgO) + Si = (SiO_2) + 2Mg(g) \quad (C)$$

The process has several disadvantages. For example, the consumption of the ferrosilicon is incomplete and the residue contains 20% Si. There are also high product losses in the vacuum condenser due to the ingress of air. One report estimates that some 20% of the magnesium product is lost as a consequence.[10] Finally, extended downtime results from the vacuum requirement, which is by necessity operated in a batch mode.

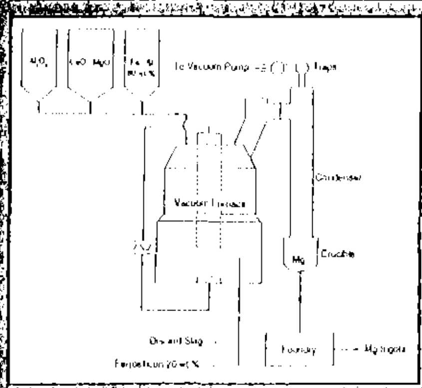

Figure B. The Magnetherm process for silicothermic reduction of calcined dolomite.

Table I. Typical Composition Changes Resulting from Plasma-Powered Production of Magnesium from a Liquid Slag

Mg Produced (kg)	Slag Composition (wt.%) MgO	CaO	Al_2O_3	SiO_2	Excess Base (from Eq. 2)
0	25	33	42	0	0.93
40	24.7	38.6	23.1	13.6	0.92
80	24.6	40.7	15.9	18.8	0.92
120	24.5	41.8	12.1	21.5	0.92
160	24.5	42.1	10.8	22.4	0.91

has a liquidus temperature of approximately 2,153K and, *since it lies in the* periclase region of the phase diagram, has unit activity of MgO at this temperature. Variations in the activities of the component oxides are to be expected as the slag composition changes as a result of magnesium production. The changes in activity of magnesia and silica are extremely small, provided that dolomite, magnesia and ferrosilicon are charged so as to maintain a near constant value of "excess base" defined as:

$$\text{Excess Base} = n\text{CaO} + n\text{MgO} - (2/3)n\text{Al}_2\text{O}_3 - n\text{SiO}_2 \qquad (2)$$

where n is the number of moles of the oxides in 100 g equivalent of slag.

For example, the addition of MgO, CaO and Si (as ferrosilicon) to 200 kg of slag in the ratio 4.6:3.2:1 would result in the compositional changes shown in Table I. By reference to the appropriate sections of the phase diagram, it is readily confirmed that these slags have a near constant liquidus temperature (and hence magnesia activity) which may be approximated to 2,223K.

Predictions of the other slag activities, as previously outlined, reveal that the activity coefficients of the slags listed in Table I are little changed during the process. *It can be shown that the process* thermodynamics may, to a first approximation, be analyzed on the basis of the following values of activity coefficient: $\gamma_{MgO} \sim 2.8$; $\gamma_{CaO} \sim 0.6$; $\gamma_{Al_2O_3} \sim 1 \times 10^{-2}$; and $\gamma_{SiO_2} \sim 5 \times 10^{-3}$.

The positive deviation from ideality exhibited by MgO in these slags is in marked contrast to the negative deviations of the remaining components (particularly SiO_2). *This favors the* production of high-purity magnesium and low silicon contents.

The activity coefficient data may be used in conjunction with the activities reported *for the* Magnetherm slag[9] to compare the equilibrium silicon levels associated with the spent reductant of the two processes. Assuming that the plasma generates a temperature of 2,273K at the reaction site, and taking the final slag composition of Table I as representative, a silicon activity of 3×10^{-3} is predicted from Equation 1. The equivalent value for the Magnetherm process is 0.01 at the operating temperature of 1,823K and would increase at higher *temperatures. The new process should,* therefore, make more effective use of the silicon content of the reductant.

PILOT TRIALS

Initial trials have been conducted in Billiton Research's 600 kVA transferred-arc plasma reactor. The reactor is similar to that shown in Figure 1. The trials were carried out in two stages.

During the first stage, 150 kg of slag having a composition 25 wt.% MgO, 42 wt.% Al_2O_3 and 33 wt.% CaO was charged and melted. Subsequently, 65.2 kg of ferrosilicon (75 wt.% Si), 189 kg of calcined dolomite and 83 kg of calcined magnesite were added. *The surface* temperature of the slag was held at approximately 2,223K which corresponded to bulk slag temperatures of 1,973–2,053K. No attempt was made to condense the magnesium vapor which was combusted. The dust was collected in a baghouse where it was sampled to enable determination of its magnesia content. The slag was also sampled to follow the progress of the process. At the end of this stage, the silica content of the slag was determined to be 27.8%, which compares with a theoretical 27% for complete consumption of the silicon reductant. Analysis of the residual metal indicated a silicon content of 1.2%. This data strongly supports the contention that the plasma process is vastly superior to the Magnetherm process with respect to utilization of the reductant.

The *second stage of the trials was* conducted with surface-slag temperatures of approximately 2,123 and 2,023K in order to assess the feasibility of lower temperature operation. Atmospheric pressure magnesium production was demonstrated to take place with silicon contents of as low as 9% in the metal phase. Analysis of the combusted magnesium vapor collected during both stages of the trials indicates that magnesium having a purity greater than 98% is obtainable. Since this figure will have been influenced by entrainment of dusts from the feedstock materials, it is anticipated that the process is ultimately capable of better than 99% purity.

CONCLUSIONS

Since magnesium vapor is produced at atmospheric pressure and in the absence of other gases such as carbon monoxide, the product losses associated with vacuum condensers or gas quench technologies are circumvented by the plasma process. This advantage, coupled with the near-99% silicon consumption, will dramatically enhance the economic competitiveness of the pyrometallurgical route to magnesium production.

It is anticipated that the process will be suited to operation in plasma reactors currently being installed to treat waste *steel plant dusts. Since magnesium is* increasingly employed by the steel industry as a desulfurizing agent, the process may be attractive for low tonnage exploitation by the ferrous industries. The simplicity of the process should also ensure its suitability for scale-up by primary magnesium producers.

References

1. A.M. Cameron, A. van Hattem and V.G. Aurich, "Extractive Metallurgy of Magnesium," *Magnesium Technology* (London: Inst. of Metals, Nov. 1986), pp. 7–17
2. G.K. Bhat, "Potential, Problems and Innovations of Plasma Heat Applications in the Metallurgical Industry," *Pure and Applied Chem.*, 56 (2) (1984), pp. 209–214.
3. A.M. Cameron, "Magnesium Production," International Patent Application PCT/GB88/00560, Publication Number WO89/0063 (Jan. 1989).
4. F.J. Hansgirg, *The Iron Age* (Nov. 18, 1943), p. 57.
5. F.J. Hansgirg, *The Iron Age* (Nov. 25, 1943), p. 52.
6. T.A. Dungan, "Production of Magnesium by the Carbothermic Process at Permanente," *Trans AIME*, 159 (1944), pp. 308–314.
7. A.M. Cameron, J.P. Lotens and V.G. Aurich, "Carbothermic Production of Magnesium," *Pyrometallurgy '87* (London: The Inst. of Mining and Metallurgy, 1987), pp. 195–222.
8. C. Faure and J. Marchal, "Magnesium by the Magnetherm Process," *JOM* (Sept. 1964), pp. 721–723.
9. R.A. Christini, "Equilibrium Among Metal, Slag and Gas Phases in the Magnetherm Process," *Light Metals* (Warrendale, PA: TMS, 1980), pp. 981–995.
10. J. Szekely et al., "An Assessment of Magnesium Primary Production Technology," U.S. Dept. of Energy Report (Feb. 1981).
11. W.H. Gauvin and H.K. Choi, "Plasmas in Extractive Metallurgy" *Mater. Res. Soc. Symp. Proc.*, vol. 30 (1984), pp. 77–89.
12. "Arc Plasma Processes," *U.I.E. Arc Plasma Review* (Paris: International Union for Electroheat, 1988).
13. N.A. Barcza et al., "Thermal Production of Magnesium," U.S. patent no. 4,699,653 (Oct. 1987).
14. D.A.R. Kay and J. Taylor, *Trans. Farad. Soc.*, vol. 56 (1960), pp. 1372–86.
15. R.H. Rein and J. Chipman, *Trans. Met. Soc. AIME*, vol. 223 (1965), p. 415.
16. H. Gaye, "A Model for the Representation of the Thermodynamic Properties of Multi-Component Slags," University of Strathclyde Metallurgy Dept. Centenary Conference (June 1984).

ABOUT THE AUTHORS

A.M. Cameron received his Ph.D. in metallurgy from the University of London in 1981. He is currently a lecturer in process metallurgy at the Manchester Materials Science Centre, UMIST, Manchester, U.K.

D.L. Canham received his Ph.D. in metallurgy from the University of Cambridge in 1979. He is currently project leader for plasma-related processes at Billiton Research Arnhem.

V.G. Aurich graduated Dr.rer.nat. from the University of Braunschweig, West Germany. He is currently head of process development at Billiton Research Arnhem.

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MAGNESIUM AS A STRUCTURAL METAL: CAN THE DREAM COME TRUE?

SUPPLY/DEMAND CONDITIONS NECESSARY TO ENCOURAGE THE STRUCTURAL USE OF MAGNESIUM

Patricia T. Foley
Commodities Research Unit
57 Union Place, Suite 207, Summit, NJ 07901
and
Ken Gilbert
British Sulphur Consultants
31 Mount Pleasant, London, England WC1X 0AD

To see the widespread use of magnesium in structural applications appears to be the collective dream of the industry, although not everyone shares this vision. Magnesium alloys were widely used in structural applications during the second world war and in the Volkswagen Beetle in the 1960s and 1970s, but over the past decade, some 80-90% of magnesium usage has been in chemical applications, most importantly aluminum alloying. However, structural markets are seen as the most important area of future growth.

Can the dream come true? Can magnesium alloy parts be produced at a cost comparable to steel castings, aluminum castings and mass produced plastics? And if the price is right, are magnesium producers and die casters able to meet demand?

This paper looks at the demand and supply conditions necessary to encourage the structural use of magnesium. We consider the use of magnesium alloys in die casting applications and the price and other conditions needed to encourage demand growth. We examine the industry cost curve and the price needed to support supply growth. We evaluate the gap between the demand and supply prices to assess whether the dream can become a reality.

Structural Uses of Magnesium

Magnesium is used both as a structural material and a chemical, but in recent years non-structural uses have predominated. Early efforts to develop magnesium markets began in Germany in the 1920s and focused on structural applications in the fledgling automotive and aerospace industries. The Germans had some success in selling magnesium and magnesium alloys to the automakers and during the 1930s magnesium alloy die castings were used in oil pump housings, engine cooling fans, blower impellers, and gearboxes. Aircraft manufacturers used magnesium alloys in tail wheels, brake shoes, brake levers, and pistons. Magnesium alloy die castings were also used in a number of office equipment and electric motor applications.

During the second world war magnesium was used as a *structural metal on a large scale. In addition to its use in* aircraft landing gear and engine components, it was used in a German jeep, the forerunner of the Volkswagen Beetle.

In the 1950s, 1960s, and 1970s, Volkswagen was a major consumer of magnesium and magnesium alloys at its casting shops in Germany, Brazil, and Mexico. In 1971, the company consumed 42,000 tonnes of primary magnesium — one quarter of western world production at the time and more than is used today in all structural applications. Over the 1965-81 period, VW used some 40% of Norsk Hydro's output, and in *some years this figure was as high as 70%.*

However, a new generation of Volkswagen cars was introduced in the mid 1970s. At the same time, magnesium prices increased sharply and Volkswagen's German consumption fell to 9,000 tonnes by 1975. Today, Volkswagen still uses magnesium alloys for replacement parts and other applications, but it consumes very much less than in the 1960s and early 1970s.

US magnesium development efforts prior to the war had *not progressed* as far as the German work; however, US magnesium and magnesium alloy usage in structural applications increased sharply in the 1940-45 period only to fall back to pre war levels in the late 1940s. As a result of a large amount of technical development work done in the 1950s and 1960s, magnesium was adopted in structural applications including materials handling equipment, automotive uses, lawnmower decks, chain saws, and other power tools.

From 1960 to 1974, demand for magnesium in non-structural applications, in particular, aluminum can stock, grew rapidly. Although demand in structural uses also increased, by the mid-1970s sales to non structural markets began to outstrip sales for structural applications.

Structural uses represented 44% of western world consumption in 1970, but only 16% in 1991. While most of the decline in Western Europe and Latin America was due to decisions made by Volkswagen, shipments in the North American market also fell by 50% between 1970 and 1985. Although shipments of magnesium and magnesium alloys for structural applications were lower in 1990 than in 1980 (see Figure 1), by 1983 the downward trend had stopped.

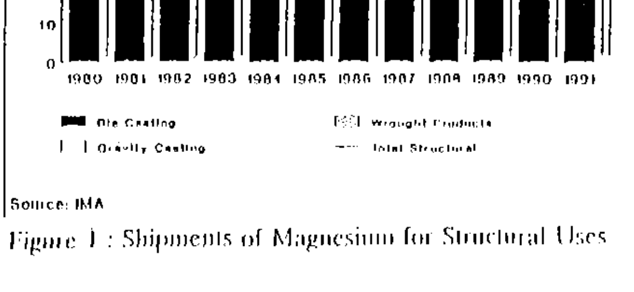


Figure 1 : Shipments of Magnesium for Structural Uses

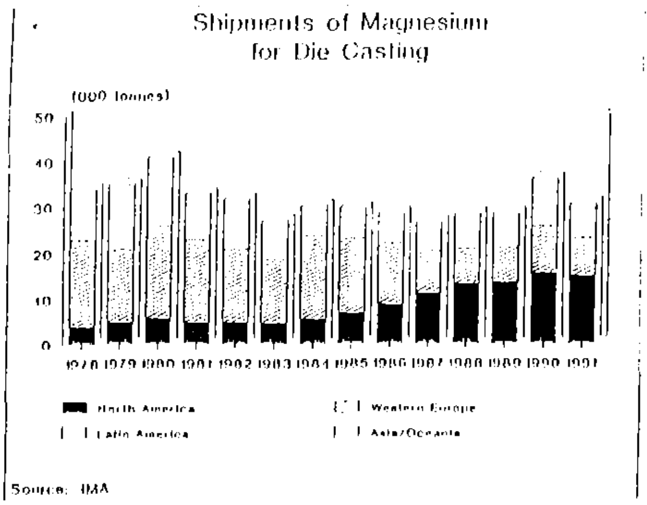


Figure 2 : Shipments of Magnesium for Die Casting

Structural magnesium and magnesium alloy products include die castings, gravity castings (i.e., sand, investment, and permanent mould castings), and wrought items (i.e., extrusions, forgings, plate, etc.). Die castings dominate this category accounting for over 75% of shipments.

Die Casting Applications

Primary magnesium shipments to the die casting market totalled some 31,000 tonnes in 1991 and accounted for just 13% of western world demand. Although die casting currently represents only a small percentage of the total market, it is one of the few areas where magnesium producers can affect consumption.

Figure 2 shows the pattern of western world magnesium consumption in die casting applications. Although the North American market grew rapidly over the 1978-91 period, Western European and Latin American consumption declined sharply. This reflects both strong promotion efforts in the United States and the demise of the Volkswagen Beetle.

Currently, some 50% of the primary magnesium consumed in die casting applications is used in North America. Western Europe takes over 27% of the total, against 19% in Latin America and about 5% in Asia/Oceania.

Our research revealed important differences in the market and applications for magnesium alloy die castings in North America, Western Europe, and Japan, along with variations in foundry practices and costs, the alloys and product forms used, the structure of the die casting industry, and recycling practices.

In the mid and late 1970s, very little magnesium alloy was used by North American automakers, but by the mid 1980s magnesium alloys began to make small inroads into this market as a result of technical advances both in the alloy composition and in foundry practices. Moreover, announcements of new production capacity in the late 1980s eased consumers' fears concerning availability and price and further encouraged demand.

On the technical side, the first and perhaps most important advance was the development and demonstration of new alloys. These include the high purity corrosion resistant alloys (i.e., AZ91D and AZ91E) that were developed in the early and mid 1980s and the high ductility alloys (i.e., AM20 and AM50) that were demonstrated in the late 1980s, mainly in Western Europe. The high purity alloys allow magnesium castings to perform as well as or better than other metals in terms of resistance to general surface corrosion. The high ductility alloys allow magnesium to be used in applications that require a high degree of bending and flexibility during a failure mode while in operation.

One reason that the high purity alloys have been successful is the use of fluxless melting at foundries. In addition, advances in both hot and cold chamber casting technology have increased the competitiveness of magnesium alloys and lowered total product costs.

The development of hot chamber die casting and its application to magnesium alloys has reduced the cost of producing small- and medium-sized castings both in absolute terms and vis a vis aluminum. Furthermore, hot chamber casting is well suited to producing thin-walled parts that take advantage of the good castability of magnesium alloys. An important advance in cold chamber casting in the mid 1980s was the development of a gravimetric metal transfer system which eliminated the need for hand ladling. This also allowed more consistency in cold chamber castings, both in terms of temperature and cycle time. It improved yields and provided for more reliable castings.

The North American Market

In 1991, the size of the North American market for magnesium alloys in die casting applications was some 20,000 tonnes, calculated on a gross weight basis, and including secondary as well as primary magnesium alloys. The market grew at an 11.6% rate during the 1980s, with particularly strong growth in the 1984-1990 period.

Automotive products is the largest market for magnesium alloy die castings, and in North America it accounts for some 65-70% of the total. This market fuelled the rapid growth in magnesium shipments to die casters in the late 1980s, as the North American car manufacturers -- led by Ford -- introduced new parts and programs that utilized magnesium alloys.

North American car production peaked in 1985 at 9.3 million units, but fell by 30% to 6.5 million units in 1991. During this period primary magnesium shipments to die casters grew by nearly 130%, from 6,900 tonnes in 1985 to 15,800 tonnes in 1990 and only declined by 600 tonnes in 1991 (see Figure 3).

Ford produced some 2.7 million cars, vans, and light trucks in 1990 and consumed some 9,500 tonnes of magnesium alloys. Average usage per vehicle was 3.5 kg.

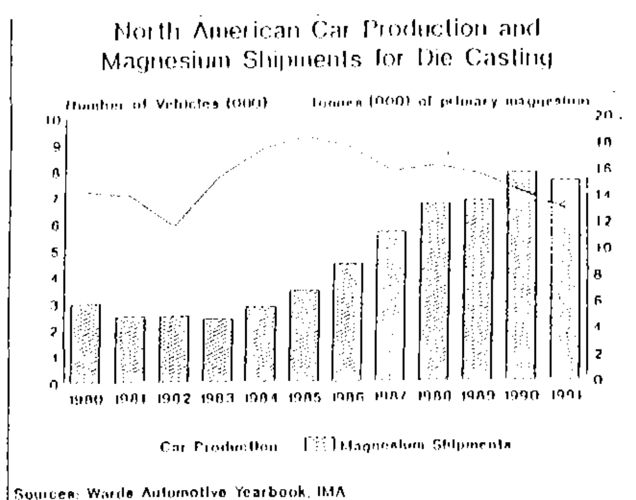


Figure 3 : North American Car Production and Magnesium Shipments for Die Casting

Table 1 : Magnesium Alloy Parts Used by Automobile Manufacturers

North America	Europe	Japan
Steering column lock housing	Gear box	Steering column assembly
Clutch housing	Instrument panel support beam	Steering wheel cores
Pedal support brackets	Cylinder head covers	Valve covers
Seat supports	Seat frames	Cylinder head covers
Transfer case	Cam covers	Inmani top cover
Armrest support	Oil pumps	Inmani chamber
Accessory drive brackets	Oil pan bottoms	Motorcycle wheels
Engine accessory brackets	Wheels/systems	
Valve cover	Transmission housing	
Steering column brackets		
Induction system housing		
Cam cover		
Oil filter adaptor		

Source: CRU

although some products, such as the F-series trucks, used considerably more. Chrysler's average unit usage in 1990 was about 1.6 kg/vehicle while GM used less than 0.5 kg/vehicle. All three companies increased their unit usage in 1991 and have plans for additional applications.

Table 1 lists some of the magnesium alloy parts used by the major North American automobile manufacturers. Most of the current uses fall into the categories of supports, brackets, housings, or covers. These are applications where the automakers can take advantage of magnesium's low density, high stiffness-to-weight ratio, and good castability. In the North American market, magnesium alloys have not made inroads into moving parts or the engine itself, except in high performance or racing cars. To date, North American manufacturers have not used magnesium alloys in large structural components, such as instrument panels or seat frames, although they are studying these applications. Magnesium alloy wheels often are specified on performance vehicles, but have limited applications in the mass production market.

An important factor behind the increased use of magnesium alloys in US automobiles has been the CAFE regulations, which require automakers to meet certain corporate average fuel economy standards or face penalties. Tighter CAFE standards will certainly encourage the further use of magnesium alloys in automotive application, but they alone will not make the market grow. On the other hand, provided there are no adverse changes in the availability or price of magnesium alloys in the United States and that the magnesium alloy supply industry, i.e., primary producers and die casters, continues to support technical and market development work, magnesium alloys will continue to be an attractive material for automotive applications even if weight savings do not strictly "pay".

The European Market

In 1991, the size of the Western European market for magnesium alloys in die casting applications was some 12,500 tonnes on a gross weight basis and including secondary as well as primary magnesium alloys. The market declined at a 7.4% rate during the 1980s.

The former West Germany is by far the largest European consumer of magnesium alloy for die casting applications, as most of the important die casters serving the automotive market are located there. Sweden is the second largest consumer, and here Electrolux is a major user of magnesium alloys for chain saw parts. Outside of these two countries, the markets are small and fragmented.

Automotive products is the largest market for magnesium alloy die castings in Western Europe, and accounts for some two thirds of the total. However, unlike the North American market, which showed a strong increase in consumption in the late 1980s, the Western European market declined steadily throughout the mid and late 1980s, before increasing by a surprising 31% in 1990. At the same time as magnesium alloy use was declining, European vehicle production was growing, albeit quite slowly (see Figure 4).

The pattern of magnesium alloy usage in automotive applications is very different in Western Europe than in North America. Although for many years Volkswagen was by far the largest consumer of magnesium alloys, today there is no leader in the European market. Several of large automobile manufacturers consume 1,000-2,000 mtpy of magnesium alloys, but for most companies unit usage per vehicle is still less than 1 kg. Although Mercedes Benz, BMW, and Audi have all been innovators in the European market, particularly in terms of the use of large magnesium alloy castings in new applications, these companies account for only a small portion of the European car market.

As Table 1 shows, the magnesium alloy parts used by the major European automobile manufacturers are quite different from those used by their North American counterparts. Although magnesium alloy castings are used by several European manufacturers for cylinder head covers and various brackets and supports, in Europe, magnesium alloys are also *used in large structural components such as the Audi* instrument panel and Mercedes Benz seat frames. BMW uses magnesium alloy castings in engine parts such as oil pumps.

In the 1980s, the European vehicle manufacturers did not face the same pressure to produce lighter cars that was evident in North America. To start with, most European cars were already considerably lighter than their US counterparts owing to high petroleum prices throughout Europe. Secondly, there were no CAFE standards or other government regulations mandating fuel efficiency. European producers were not in the market to "buy" weight reduction, at least not to the same extent as North American manufacturers.

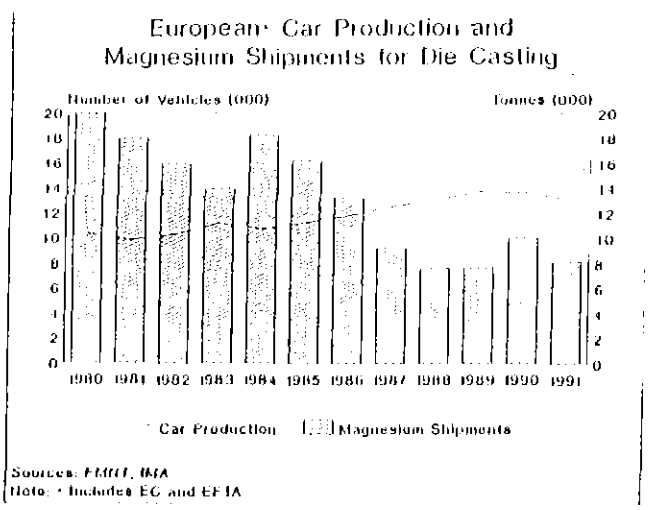


Figure 4 : European Car Production and Magnesium Shipments for Die Casting

During the 1990s, European producers have begun to feel more pressure to reduce the weight of their vehicles. This is evident in the luxury car market, where consumers now want lighter cars with better handling. In response, the luxury car producers, such as Mercedes Benz, Audi, BMW, and Volvo, are looking at ways to reduce weight. Emission control standards, improvements in fuel efficiency, and more consumer comfort features are the main forces behind the move to even lighter mass market cars, such as Volkswagens, Fiats, and Peugot/Citroens. In Europe, it is likely that magnesium alloy parts will be introduced first in the larger, heavier, "high end" cars, and if they prove cost effective, they will be used further down the product line.

The Japanese Market

In 1991, the size of the Asian/Oceanic market for magnesium alloys in die casting application was some 2,100 tonnes on a gross weight basis and including secondary as well as primary magnesium alloys. Most of this market is in Japan, and there was little growth in shipments during the 1980s.

As in North America and Western Europe, automotive products is the largest market for magnesium alloy die casting; however, in Japan, it accounts for only about 50% of the total. Average unit usage of magnesium alloy in Japan was only 0.1 kg/vehicle in 1990, against 1.1 kg/vehicle in the United States and 0.6 kg/vehicle in Western Europe.

Currently, Toyota is the only Japanese carmaker that is using magnesium alloys to any significant extent. In the mid and late 1980s, Honda included magnesium alloy parts in its mass market Accords and Civics, but today the company uses magnesium only in its low-volume NSX sports car.

Japanese carmakers cite fuel economy, US CAFE standards, and the need to produce lighter cars as the main reasons for considering magnesium alloys. Although tighter CAFE standards may not be an issue in 1992, the Japanese automakers anticipate that requirements will be tightened in the mid to late 1990s. As the Japanese producers move away from small cars to luxury models, CAFE requirements become more of a concern. Moreover, as automakers add more comfort, convenience, and safety features to their cars, they must reduce the weight of current parts and components.

In addition to US CAFE standards, the Japanese have domestic goals for improved fuel economy and reduced emissions. The Japanese target is to improve fuel economy by reducing vehicle weight by 35% by the year 2001. Many Japanese carmakers are looking first to aluminum for their weight reduction program, but most believe that magnesium alloys also have a role to play.

The Latin American Market

In 1991, the size of the Latin American market for magnesium alloys in die cast applications was some 6,500 tonnes on a gross weight basis and including secondary as well as primary magnesium. The market declined at 7.2% annual rate during the 1980s, although shipments rebounded from 3,900 tonnes in 1987 to 8,700 tonnes in 1990 before falling to 5,800 tonnes in 1991.

Nearly 90% of the magnesium alloy castings shipped in Brazil are for automotive castings. Agricultural products, mainly chain saw parts, accounted for some 8-9% of the market with portable engines making up the remainder.

Autolatina, a joint venture between Volkswagen and Ford, is the main Brazilian consumer of magnesium alloy for die casting. Autolatina and Volkswagen Mexico use magnesium alloy engine blocks and transmission cases in several models. The average use of magnesium alloy per vehicle is 11.7 kg, but this varies by model.

In 1990, magnesium alloys were used in engine blocks for the domestically produced VW Combi and in engine blocks that were exported to Mexico to be used in VW Beetles. The Beetle has not been produced in Brazil since 1986, although a large number of replacement engines are produced. Brazilian consumption of magnesium alloys is expected to decline, and the future of the VW Beetle in Mexico is uncertain as production has already continued beyond its expected deadline. In 1991, VW Mexico began producing the Golf, and this is expected to hasten the demise of the Beetle. The loss of this market could be partially offset by the Brazilian production of transmission cases for VW's German cars, but this is unlikely before 1995.

Impediments to Magnesium Alloy Usage

In mid and late 1991, we interviewed primary magnesium producers, die casters, and automakers in North America, Western Europe, Japan, and Latin America about the main impediments to the increased use of magnesium in automotive applications. The individuals we spoke with cited two types of limitations: those affecting the use of currently available alloys in known applications and factors that prevent magnesium from expanding into new applications.

They cited four main impediments to current usage including:

- raw material costs;
- raw material availability;
- processing costs; and
- the die casting supply base.

Additional factors that will affect future usage include:

- technical concerns such as corrosion protection and elevated temperature properties, availability of physical and mechanical data;
- CAFE or other standard regarding fuel economy, weight, or emissions; and
- developments in the scrap market

This paper concentrates on the current impediments to demand as many of the other presentations at the IMA meeting are concerned with the factors affecting future usage.

Raw Material Costs

Raw material costs and the cost of primary magnesium compared to aluminum are often cited as stumbling blocks to the further usage of magnesium alloys. However, over the past two years, magnesium prices declined by 25-40% from \$1.60-1.80/lb in 1989 to \$1.00-1.20/lb in late 1991. This sharp decline is reflected in Figure 5, which shows the value of imports into the United States, Germany, the Netherlands, and Japan. Although prices have increased since late 1991, we do not expect that they will return to pre-1989 levels in the next five or so years. This is based on our analysis of production costs and structural overcapacity, and is discussed below in more detail.

Although alloy prices declined in the past two years, the fall has not been as sharp as that for pure magnesium. Press reports indicate that AZ91D prices fell from \$1.40/lb. in 1989 to \$1.25/lb in late 1991, although they too have rebounded in 1992. The important point to note about alloy prices is that in the late 1980s alloys sold at about a 10% discount to pure magnesium on a contained metal basis; however, by late 1991

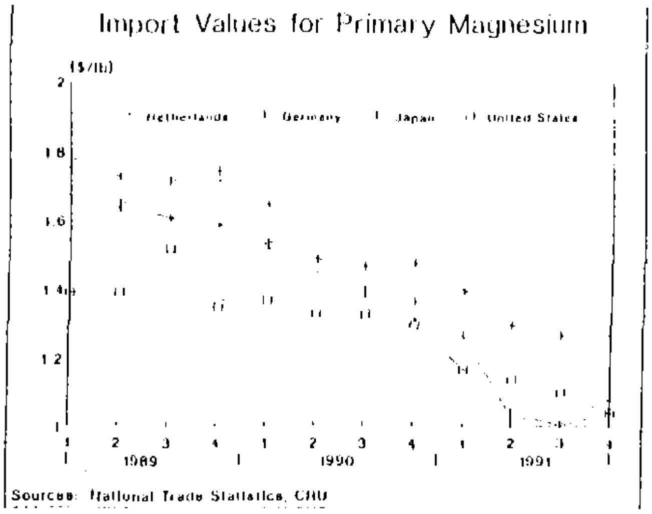


Figure 5 : Import Values for Primary Magnesium

and even in today's market, that discount has become a premium of some 10-15%.

With magnesium prices in the $1.25 to $1.40 range and alloys selling at about a 5-10% discount reflecting the metal value, we do not expect raw material cost to be a major impediment to demand growth in structural applications.

Raw Material Availability

Fundamental changes in primary magnesium availability and the structure of the raw material supply base is behind the dramatic fall in magnesium prices. Important changes included:

- the opening of new capacity;
- new ownership at Magcorp;
- increased international competition;
- a swing in East-West trade;
- growing merchant/trader involvement; and
- strong growth potential in price sensitive markets.

The opening of the 45,000-mtpy Becancour plant raised total industry capacity by more than 15%, and also increased the competition among existing producers for sales and market share. The North American market was the natural outlet for metal from Becancour, and Norsk stepped up its marketing efforts in North America even before the plant opened. In the late 1980s, this was not a difficult task as the market was relatively tight and consumers welcomed a new supplier. However, when the market eased in 1990, producers began to compete more vigorously for sales, and soon this competition took the form of lower prices.

At the same time that the Becancour plant was being built, Amax decided to withdraw from the magnesium business and sell its Rowley, Utah, plant. After much wrangling, the plant was sold to Renco, an investment group. The purchase was financed largely by debt. Amax is basically a metals and raw materials company and it took a long term view of the magnesium market. In the mid 1980s, Amax devoted considerable effort to market development. However, with the sale to Renco and the establishment of Magcorp as the operating company, the company's position and strategy changed. Magcorp is now a relatively high cost producer with a large debt burden and is owned by an investment group. The company is in a position where it has to keep its production and sales high to maintain cash flow and service its debt. This has been difficult in the over supplied North American magnesium market.

In view of Norsk's increased presence in the North American market and severe price competition there, in early 1991 Dow announced that it was strengthening its marketing efforts in Western Europe and Japan where it was already competing actively with Norsk Hydro. The presence of at least two strong suppliers in the three main markets has served to bring regional prices closer together (see Figure 5).

Over the 1988 to 1991 period, the Eastern Bloc has shifted from a net importer of about 3,300 tonnes of magnesium to a net exporter of about 2,600 tonnes. In 1991 the increased availability of material from the former Soviet Union brought more traders into the market, thus giving consumers an additional source of supply. Generally, traders offer more flexible pricing terms than primary producers. Their concern is maximizing the margin between the price at which they can buy material and their sales price, and thus they care very little about the costs of producing magnesium or the profitability of primary production. The low prices quoted by traders in 1991 were widely reported and had a strong negative impact on market sentiment prices.

As the capacity of the industry has grown, the major producers have become more interested in expanding the markets for magnesium. Traditional markets, such as aluminum alloying and chemical applications, are not very exciting as there is little the producers can do to affect consumption. Instead, the producers have focused on the more price-sensitive markets, such as magnesium alloy die castings and to a lesser extent desulphurization, as a source of future growth. Price competitiveness and pricing flexibility is an important consideration of automakers evaluating the use of magnesium alloy die castings.

We believe that these factors will continue to have a strong impact on the market in the 1990s, and that they will keep constant dollar prices below the levels of late 1980s.

Processing Costs

Raw material costs are only one component of total parts cost, albeit an important one. However, when design engineers evaluate the use of magnesium in a specific application, it is the cost of the part rather than the raw material that is critical. Processing costs vary by part depending on the size and complexity of the part, the amount of machining that is needed, etc. To get a rough idea of the importance of processing costs, we asked die casters what percentage of their total cost was raw materials and what percentage was processing. Among experienced magnesium die casters in North America and Europe, raw materials represent 30-60% of the total, depending on the product mix. In Japan, and among less experienced die casters, processing costs are a larger percentage of the total (see Table 2).

One way to increase the competitiveness of magnesium alloy parts is to lower per part processing costs vis a vis aluminum and other materials. Some of the larger and more experienced die casters are working on equipment design and technical advances to minimize costs at their operation.

Table 2 : Processing Costs for Magnesium Alloy Part

	Typical Processing Costs*	Per Part Costs
North America	40-65%	$2.10-3.60/lb
Western Europe	50-70%	$2.50-4.20/lb
Japan	60-80%	$3.50-7.00/lb

Source: CRU
Note: * As a percent of total costs

These die casters must continue to seek the best operating practices at all stages of the production process. At the same time, the less experienced and weaker foundries must strive to introduce best practice at their operations. In addition to lowering average processing costs across the industry, this would serve to increase the number of high quality, low cost die casters.

Die Casting Supply Base

Almost all the producers, die casters, and automobile manufacturers we spoke with during the course of our study cited concern about the die caster supply base as a major impediment to the future use of magnesium alloys. This was particularly true in Japan, but similar comments were given by North American and European firms.

In our fieldwork, we identified 35 North American die casters that work with magnesium, and we were able to obtain sales figures for 25 companies. Of these 25, 21 had annual sales below $50 million. Of the four with sales above this level, only one depends on magnesium alloy casting for a large portion of its business.

We consider five of the 35 to be important suppliers of magnesium alloy castings to the automotive market (see Table 3), and in addition there are another 3 or 5 smaller suppliers. We identified four companies that focus on communication, computer, and aerospace applications and four captive die casters.

The remaining 17 companies we considered to be "dabblers". Their main focus is either aluminum or zinc, but they are capable of working with magnesium alloys. Some of these companies are quite large and very experienced in their own area and could move into magnesium alloy casting as the market grows and they gain experience.

The magnesium alloy die casting industry is perceived by both the automakers and the primary magnesium suppliers as a risky, low margin business. The die casters are generally small, and they produce only a limited number of parts. Because of their small size and narrow focus, many of the die casters are highly susceptible to changes in the design and production program by the automakers or other consumers. The cancellation of a major part or program can have severe consequences for the die casters. As a result, the die casters often go through periods of financial instability. This instability and turmoil often limits the die casters' access to risk capital for development programs.

The die caster looks to both the primary magnesium producers and the automakers for assistance in product development. This has important implications for both funding and design work. It implies that development programs for new magnesium parts must be jointly supported by the automakers, the die casters, and the primary magnesium alloy suppliers.

In North America, the automakers will supply funds for the die casters to design, test, and often prototype a new part. This has the advantage of bringing the die casters into the design process at an early stage and helps to insure castability and to minimize processing costs. Also, when the automakers work closely with potential suppliers, they are less reluctant to "single source" a specific part. This in turn leads to better machine utilization and lower costs at the die casters.

The primary magnesium alloy producers are called on to assist in alloy development and evaluation and provide basis data on alloy characterization and properties. Although this system has worked well in many cases, the US auto companies still bemoan the lack of suitable supply base for magnesium alloy die castings.

Table 3 : Die Caster Supply Base - Main Automotive Die Casters

North America	Europe	Japan
Magnesium Products Ltd.	Stihl	Tokai Rika (Toyota)
Die Makers	Mahle	Tosei
Harvard Industries	Volkswagen	Teisan
Spartan	Others	Nippon Light Metal
Lunt		Nippon Kinzoku
Others		Others

Source: CRU

We identified about 15 European die casters that work with magnesium alloys, mainly in West Germany, the UK, and Sweden. However, there may be other small firms in France, Italy, Switzerland, Austria, and elsewhere. The largest die casters in Western Europe are Stihl and Mahle. Both are big companies with sales of more than $300 million.

The relationship between the carmakers and die casters in Western Europe appears to be more distant than in North America and Japan. Western European die casters generally are not involved with the automakers in the design process. Rather, the car producers will come to them with a part already designed and ask for bids. "Castability" and "manufacturability" from the die casters point of view generally are not considered before the design is final. As a result the automakers may not take full advantage of the physical and mechanical properties of magnesium alloys, and may pay more than they have to for a magnesium alloy part.

The Japanese magnesium alloy die casting industry is less developed than those in North America and Europe. We identified 13 Japanese die casters that work with magnesium alloys. In addition to the main die casters listed in Table 3, several of the large aluminum die casters have begun using magnesium on a trial basis.

In addition to the relatively small number of die casters in Japan, most of the existing producers have small machines, which limits the size and complexity of the parts they can produce. Moreover, Japan has few die casters with experience in cold chamber casting of magnesium alloy parts. There are a large number of aluminum die casters and adequate cold chamber capacity, but these producers are still near the bottom of the learning curve for magnesium alloy castings.

Often, Japanese die casters are associated with large companies that supply many automotive components. In contrast, North American die casters are generally small, independent firms. In Japan, the die casters are better able to undertake their own development programs. Major companies have their own laboratories and research centers, and are able and willing to fund development work and to bear some of the risk in magnesium alloy market development.

Currently, Japanese companies are installing new die casting equipment without firm orders for parts. These investments are based on promised future growth, rather than contracts already in hand and are a good indication of likely market growth for magnesium alloys. Despite the current lack of die casting capacity in Japan, and the small size of the machines and equipment, Japanese die casters are confident that they can meet any increase in the demand for magnesium alloy castings.

Future Demand in Structural Applications

Unlike aluminum, copper, nickel, and other mature metals where demand is determined mainly by economic activity in important end-use markets, future demand for magnesium alloys will be determined primarily by actions taken by magnesium producers and die casters. We believe that work devoted to overcoming the main impediments to magnesium usage along with overall strong promotion efforts and attractive pricing will be main determinants of future consumption in structural applications.

Producers and die casters must work to lower processing costs and improve the global die casting supply base, and all interested parties, including automobile manufacturers, must work together to improve industry practices and to ensure optimal design and minimum cost of magnesium alloy parts.

In addition to addressing the current impediments to magnesium alloy usage, supply industry must find or develop "across-the-board" applications for magnesium alloys. Currently, magnesium alloys are selected on a part-by-part basis, and there is no single application that "belongs" to magnesium. In part, this results from the fragmented structure of automobile manufacturers, but it is also a result of the small size of the current market for magnesium alloy die castings and the lack of resources among the magnesium alloy supply industry, especially when compared to suppliers of competing materials such as aluminum or plastics.

When aluminum castings began to be used in automotive applications in the mid-1970s, they too were introduced gradually on a part-by-part basis. Today, however, aluminum has virtually 100% of the market for parts such as pistons, transmission cases, intake manifolds, etc.

The magnesium alloy supply industry needs to emulate this behavior by selecting a part or number of parts -- for example, valve covers, steering lock housing, clutch housing, instrument panels, wheels, etc. -- and then develop these parts to the point where magnesium alloys are used across-the-board. Such development programs would include perfecting casting techniques, coating technology, and other production related factors as well as finding ways to minimize costs.

Much of the literature regarding magnesium alloy usage refers to magnesium to aluminum price ratios rather than the absolute levels of magnesium alloy prices. In part, this is due to fear of US antitrust violations. The magnesium business is still a small, oligopolistic industry with only a few large sellers. Magnesium is not traded on a futures market and until large scale Soviet exports began in 1990, there were few traders active in this market. In addition, the magnesium business tends to be very secretive. Price information is not widely reported.

We are not convinced that the industry is well served by a continued reliance on the magnesium to aluminum price ratio as a measure of magnesium's competitiveness. Firstly, magnesium competes with materials other than aluminum. Secondly, the price ratio measures raw material costs, and raw materials make up only 40-60% of the total cost of a die cast part. Focusing on changes in the raw material cost ratios overtime masks the advances made in lowering processing costs. Thirdly, aluminum prices are a moving target, but magnesium prices have been more stable. It may not be in the best interest of the magnesium alloy industry to have consumers continually evaluate the competitiveness of magnesium in terms of aluminum prices. Particularly now that secondary aluminum will be traded on the London Metal Exchange. Finally, the reliance on a price ratio assumes that the two materials have equal properties. This makes it more difficult for a potential consumer to weigh fully the properties of each material and the overall advantages and disadvantages.

Rather than focusing on the magnesium to aluminum price ratio, the industry needs to consider the substitution possibilities and the demand for magnesium alloys at different price levels. For example, if annual average alloy prices were \$1.10/lb rather than \$1.25/lb would demand be 30,000 mtpy, 60,000 mtpy, or 90,000 mtpy, and what if prices were \$0.90-1.00/lb, what effect would this have on demand? This is a difficult question to answer, but it is a crucial question for current magnesium alloy suppliers as they set pricing policy and decide on an appropriate level of market development funding. It is also an important question for potential new suppliers as they compare their production and capital costs with the price needed to stimulate demand in the die casting sector.

We have not studied this aspect of demand in great detail, but indications are that magnesium alloys are competitive with aluminum, steel, and plastics at prices in the \$1.25-1.35 range or about current levels.

Since the mid 1970s, much emphasis has been placed on weight reduction and fuel efficiency and the role that magnesium could play in helping automakers achieve these goals. While it is certainly true that magnesium alloys offer weight savings and that in some instance car companies are willing to "pay" for weight reduction, we do not believe the need for weight savings, or fuel efficiency is going to drive future magnesium demand.

Intermaterial competition in the weight reduction game is fierce, and some kinds of substitution -- for example, the use of aluminum rather than steel body panels -- will have a far greater effect on automobile weight than the use of magnesium alloys in small parts. In addition, material substitution competes with body and engine design changes as a way of improving overall fuel efficiency.

While the magnesium industry should stand ready to take advantage of future CAFE requirements or other weight reduction or fuel savings regulations, the industry must not count on this as a source of future growth. It is up to the producers to create their own future by working to remove the current impediments to alloy usage, by designing and promoting parts that take advantage of magnesium properties -- including its low density -- and by offering its products at a price level that supports future demand growth.

Because future demand depends heavily on actions taken by the industry, it is difficult to forecast. Based on discussions with producers, die casters, and automotive companies, we have assumed that the current interest in magnesium is real and that producers and others will continue to support development efforts and maintain attractive prices at least through the mid 1990s. Based on these discussions, we are forecasting demand growth in die casting applications of 12% per annum through the 1990s. This implies expansion of western world shipments from 36,000 tonnes in 1990 to 101,000 in 2000, but average worldwide consumption still less than 3 kg/vehicle. Figure 6 summarizes our regional growth projections for the structural market.

Cost Analysis

Our demand analysis indicates healthy growth in consumption in structural application at demand prices in the \$1.25-1.35/lb range. Is the possible? Is the supply price of magnesium compatible with the demand price?

In analyzing metals and materials, the short-run supply price of a commodity is generally defined as the operating cost at the highest cost producer that must operate to meet demand. The long-run supply price is the total cost of bringing new capacity on-stream.

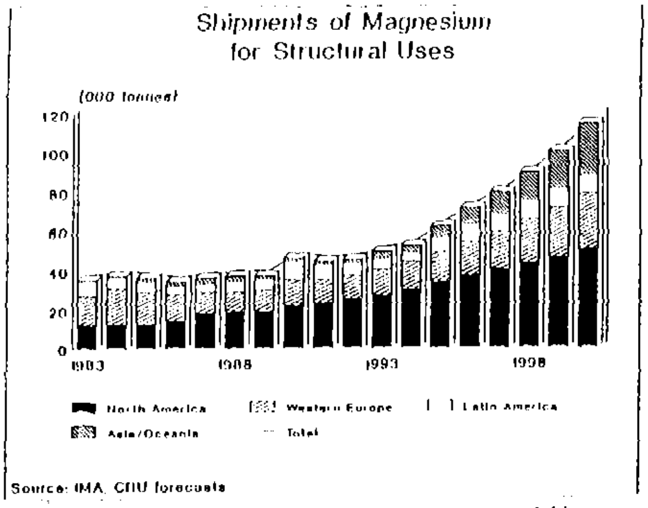


Figure 6 : Shipments of Magnesium for Structural Uses

To determine the supply price of *magnesium*, we calculated the fixed, variable, and total operating costs at existing operations. We then estimated current production on a plant-by-plant basis and forecast future output. We calculated operating rates and then used these to estimate actual operating costs in 1991 and forecast costs in 1995. We then ranked the producers from lowest-cost to highest-cost and drew an industry cost curve (see Figure 7). Table 4 summarizes the basic methodology we used in estimating costs and Table 5 shows the individual cost elements we considered.

Interpreting the Short-Run Cost Curve

The cost curve is a tool CRU uses in analyzing supply and prices in the aluminum, copper, lead, zinc, ferroalloy, and other metal industries.

The cost curve in Figure 7 shows direct operating at magnesium smelters that operated in *1991*, *based on our* estimate of their fixed and variable costs and operating rates. The curve shows that about half of the producers had direct operating costs below $1.00/lb in 1991 and were profitable on an operating cost basis, although these plants may have shown losses on a total cost basis, i.e., when sales and financial charges were considered. The curve shows that about 50,000 tonnes of production, or roughly 20% of the total, had costs above $1.25/lb and were probably not profitable in 1991, even on an operating cost basis.

The high-cost end of the curve includes production that has since been closed or curtailed -- i.e., SAIM and Northwest Alloys, as well as smelters that operate for reasons other than accounting *profitability. For example, for some companies* employment, foreign exchange earnings, or downstream integration may justify operating losses.

Table 4 : Cost Methodology

Understand Production Process
Calculate Unit Inputs
Calculate Local Input Costs
Convert to US Dollars
Calculate Fixed and Variable Operating Costs at Different Production Rates
Calculate Total Costs

Source: CRU

Table 5 : Elements of Variable, Fixed, and Total Costs

Variable	Fixed	Total
Raw Materials	Labor	Variable
magnesium chloride	Maintenance	Fixed
magnesite	*Plant overheads*	Capital costs
dolomite		Depreciation
alumina		Capital charges
chlorine		*Loan payments*
hydrochloric acid		
ferrosilicon		
coke		
Processing chemicals		
Utilities		
electricity		
gas		
steam		
other		
Electrodes		
Byproducts		
chlorine		
other		

Source: CRU

The cost curve does not directly take into account closure costs. Some companies will incur short-term losses if they believe prices will soon recover and the losses sustained are less than the costs of shutting and restarting operations. Although the cost curve is a useful forecasting tool, it is not *foolproof and has to be interpreted* cautiously.

Generally speaking, in markets where there is structural overcapacity -- *meaning capacity in excess of that needed in* the next cyclical upturn -- the tail of the cost curve indicates the floor price for a metal, although actual prices may fluctuate around this level.

Costs in 1995

We have used our magnesium cost database to forecast operating costs in 1995 and draw the 1995 cost curve. In doing so we made assumptions about demand, operating rates, inflation, and exchange rates. As Figure 8 shows, our projections indicate that the cost curve will be flatter in 1995 than in 1991 as high cost operations close and lower cost smelters *increase their operating* rates. This implies that the floor price for magnesium will be lower in 1995 than in 1991.

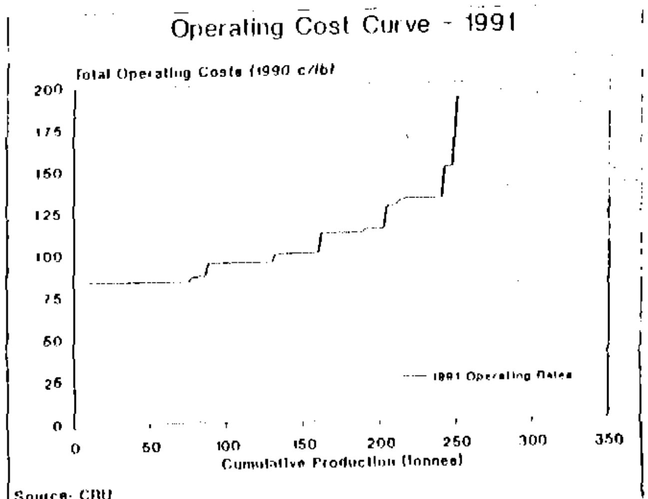


Figure 7 : Operating Cost Curve - 1991

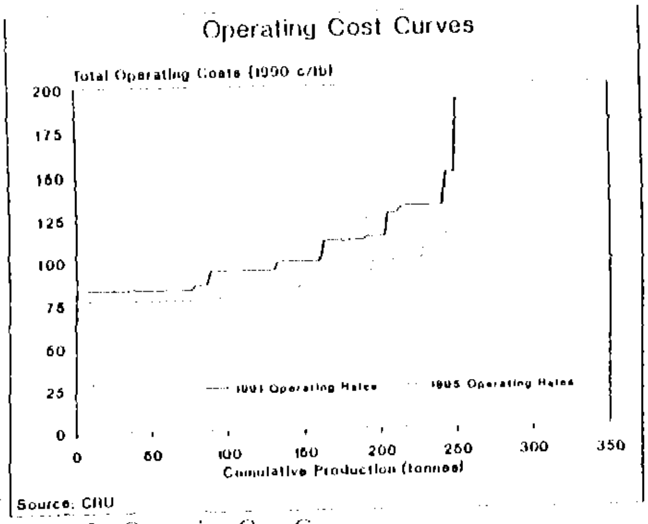


Figure 8 : Operating Cost Curves

although this does not necessarily mean that profitability at the low-cost plants will suffer. Our projections indicate a floor price of about $1.25/lb in 1995. Actual prices will depend on the amount of excess capacity in the industry and the prices necessary to bring this production on stream.

Some 90,000 tonnes of magnesium capacity was shuttered in the 1989-92 period (see Table 6), but we believe that a large portion of this capacity can be brought back at prices in the $1.25-1.40/lb range. An additional 40,000-80,000 mtpy of production is available from improved operating rates and incremental expansions at existing facilities. If demand is steady and inventories are under control most of this production is also economic at prices below $ 1.40/lb. The availability of 130,000-170,000 mtpy of additional production (above first half 1992 levels of some 220,000 mtpy) at costs below $1.40/lb will provide an upper limit on prices.

As a result of this cost and supply assessment, we believe the magnesium market will be amply supplied through the mid-1990s and prices will fluctuate in the $1.25-1.40 range (in constant 1990 dollars). These supply prices are consistent with the development of the market for magnesium alloys in structural applications. However, by the late 1990s, if the demand grows as we have assumed, the industry will once again be faced with capacity constraints. New capacity will be needed to support further demand growth. The important question then becomes, what is the cost of new capacity, i.e., can it be added at prices consistent with magnesium alloy use in structural applications?

Table 6 : Announced Cutbacks

Time Period	Sites	Amount (tonnes)
1989 - 2H	Norsk Porsgrunn	15,000
1991 - 1H	Magnohrom, Magcan Timminco	16,000
1991 - 2H	Norsk Porsgrunn, Becancour	30,000
1992 - 1H	Northwest Alloys, SAIM	26,000
Total		87,000

Source: CRU

Table 7 : Costs at a 60,000-mtpy Greenfield Electrolytic Magnesium Plant

Cost Element	Cost/Pound (1990 US$)
Variable Costs	$0.40
Fixed Costs	$0.36
Capital Charges*	$1.00
Total	$1.76

Source: CRU
Note: * Based on total capital costs of $470 million, 20% real interest rates, 10 year loan
= US$7,833 per annual tonne

Long-Run Costs

In our cost estimates, we have considered a new 60,000-mtpy greenfield electrolytic magnesium smelter located in Australia. We have assumed that production would be based on locally available magnesite and that it would incorporate best available technology. Our fixed, variable, and total cost estimates are shown in Table 7. It is likely that a new plant will have operating costs comparable to the lowest-cost existing operation; however, in our analysis capital charges for a new plant represent over 50% of total costs.

We have calculated capital costs from a banker's point of view. We assumed that total capital costs would be $470 million and that the project would have to offer a 20% real rate of return over a 10-year period. This indicates capital charges of $1.00/lb of magnesium and total costs of $1.76/lb. This cost is far above the $1.25-1.35/lb demand price, and if magnesium is to be considered competitive in the long run, ways must be found to close the gap.

Short of dramatic new developments in processing, we believe that little can be done to reduce the variable operating costs. We have assumed that a new greenfield plant would be able to negotiate favorable energy and raw material contracts, employ low-energy cost cell technology, and minimize maintenance costs.

Per pound fixed costs vary with the size of the plant, and larger plants generally mean lower costs; however, the small size of the market limits the amount of new capacity that can be absorbed in any one year without upsetting prices.

The most promising area for improvement is finance charges. It may be unwise to reduce capital costs, since this could then translate into higher operating costs, but there is considerable scope for negotiating attractive financial charges.

Although the availability of government sponsored concessionary financing may be limited, consumer financing or guaranteed off-take contracts may provide other ways of reducing risk. If the effective real rate of return can be lowered to 10% and the investment period extended to 20 years, the finance charge would fall to $0.49c/lb (see Table 8). With total costs of $1.25/lb for new capacity, the long-term outlook for the magnesium industry looks much brighter.

Can the Dream Come True?

The short- and medium-term outlook for magnesium alloys in structural applications is bright, provided the magnesium alloy supply industry, i.e. the producers and die casters, work together both to overcome the main impediments to demand and to promote market development in key areas. In addition, producers must maintain reasonable pricing policies and die casters must work aggressively to lower processing costs. To a large extent, short- and medium-term demand depends on the action taken by the industry.

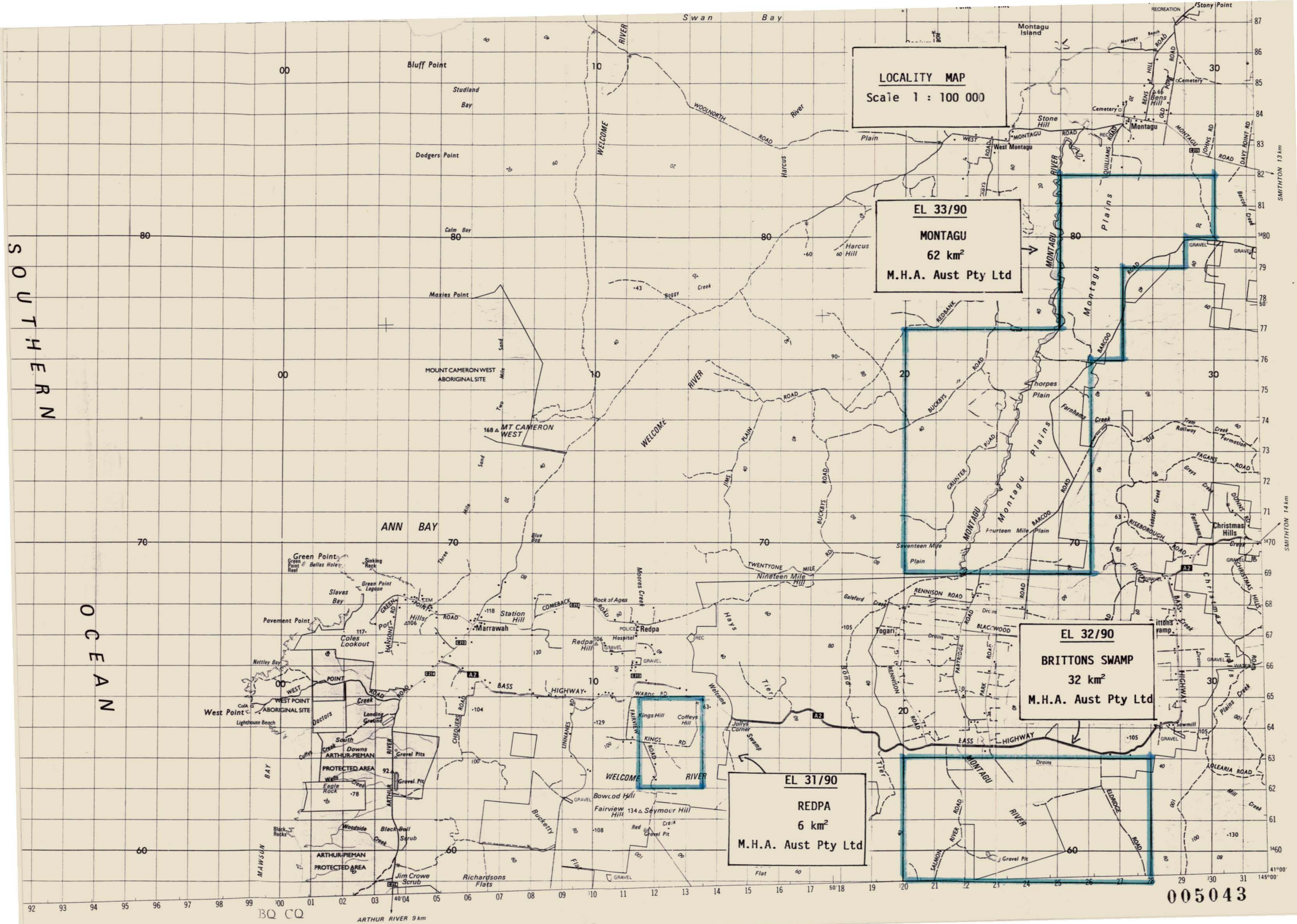
Table 8 : Financing Charges at Various Real Interest Rates and Payback Periods

Interest Rate	10 Year Loan ($/lb)	20 Year Loan ($/lb)
5%	0.54	0.34
10%	0.68	0.49
15%	0.83	0.67
20%	1.00	0.86
25%	1.17	1.06

Source: CRU

In the longer term, there is the question of capacity constraints and the cost of adding new capacity. Here the most important issue appears to be the availability and cost of capital for new production, and again its up to potential new producers and interested consumers to seek advantageous arrangements.

Can the dream come true? We believe it is possible, but not inevitable. It depends not only on exogenous factors like CAFE requirements or interest rates but on actions taken by individual companies and the industry working together to shape their own future.



LOCALITY MAP
Scale 1 : 100 000
EL 33/90
MONTAGU
62 km²
M.H.A. Aust Pty Ltd
EL 32/90
BRITTONS SWAMP
32 km²
M.H.A. Aust Pty Ltd
EL 31/90
REDPA
6 km²
M.H.A. Aust Pty Ltd
SOUTHERN
OCEAN
Swan Bay
ANN BAY
Bluff Point
Studland Bay
Dodgers Point
Calm Bay
Maxies Point
MOUNT CAMERON WEST ABORIGINAL SITE
MT CAMERON WEST
Green Point
Pavement Point
Coles Lookout
Marrawah
Station Hill
Redpa
Kings Hill
Coffeys Hill
West Point
WEST POINT ABORIGINAL SITE
ARTHUR-PIEMAN PROTECTED AREA
Montagu Island
Stony Point
Montagu
West Montagu
Stone Hill
Bens Hill
Harcus Hill
Thorpes Plain
Montagu Plains
Togari
Christmas Hills
Seymour Hill
Bowcod Hill
Fairview Hill
Richardsons Flats
Jim Crowe Scrub
Black Bull Scrub
BASS HIGHWAY
WELCOME RIVER
MONTAGU RIVER
ARTHUR RIVER 9 km
SMITHTON 13 km
SMITHTON 14 km

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