

# FINAL REPORT

## An Assessment of the Greenhouse Gas Consequences the Proposed Batchelor Magnesium Project

*Prepared for*

### **Mt Grace Resources**

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Australia

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Mt Grace Resources propose to construct a magnesium production facility at Batchelor, in Northern Territory, known as the Batchelor Magnesium Project (BMP). Three stages of development are planned. The first stage would produce 12,500 tonnes per year of magnesium ingots. In the each of the second and third stages capacity would be doubled, subject to the market demand for magnesium. The final proposed magnesium production capacity would be 50,000 tonnes per year. This report considers the Greenhouse Gas (GHG) emission consequences of the project.

## 1.1 Environmental and Regulatory Context

The emissions of carbon dioxide (CO<sub>2</sub>), mostly from fossil fuel combustion, are increasing the concentration of CO<sub>2</sub> in the global atmosphere, which influences the global climate via the enhanced greenhouse effect. Other Greenhouse Gases (GHGs) including methane, nitrous oxide and fluorinated gases also influence the enhanced greenhouse effect.

Although the nature and extent of climate change effects is uncertain, the Kyoto Protocol, which was signed by Australia in December 1997, signals the acceptance by the international community that precautionary measures to control GHG emissions are necessary. Under the Kyoto Protocol, it is proposed that Australia would be required to control its GHG emissions so that the average Australian GHG inventory over 2008-2012 is no more than 108% of the 1990 level; or to offset the excess via carbon sinks (e.g. changing land use from scrub to permanent forest), or to offset the excess via compensatory activities in other countries.

The Australian Government has not yet indicated its intent to ratify the Kyoto Protocol, which would make Australia legally committed to meeting the Kyoto target. Nonetheless, in the Prime Minister's statement prior to the Kyoto meeting, and with the approval of the Commonwealth Cabinet, he stated *"We are prepared to ask industry to do more than they may otherwise be prepared to do, that is, to go beyond the "no regrets" minimal cost approach where this is sensible in order to achieve effective and meaningful outcomes"*.<sup>1</sup>

In the absence of any measures to reduce emissions of GHGs, Australia's "Business as Usual" emissions in 2010 are expected to increase by 43% from the 1990 levels. Australia as a whole is challenged to reduce GHG emissions by 24.5% from the predicted "Business as Usual" level in 2010 by implementing a combination of "no regrets" and "beyond no regrets" measures. This is equivalent to limiting greenhouse gas emissions in 2010 to 108% of Australia's 1990 levels.<sup>2</sup>

## 1.2 The Contribution of Magnesium to GHG Reduction

Magnesium components are increasingly being used in the automotive industry, where weight reduction is a cost effective means to further reduce fuel consumption, and consequently CO<sub>2</sub> emissions. In

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<sup>1</sup> Howard (1997) *Safeguarding the Future: Australia's Response to Climate Change* Prime Ministerial Statement

<sup>2</sup> Summary of the Australian Federal EPA response to the Greenhouse Gas issue.

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addition, reduction of vehicle weight results in energy savings in vehicle manufacture, with consequent CO<sub>2</sub> emission reductions.

Considerable work has been undertaken by the automobile industry on life cycle analysis of light materials as a replacement for iron and steel. More specific life cycle analysis on the use of magnesium as a replacement for iron, steel and aluminium in vehicles has been undertaken by Hydro Magnesium of Norway. The basic conclusions from the Hydro Magnesium studies<sup>3</sup> are that where magnesium components replace steel components, there is an average saving over the life of a passenger motor vehicle of 50 kg CO<sub>2</sub> per kg of magnesium used.

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<sup>3</sup> Ongstadt et al 1992, Albright and Haagenen 1997

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## 2.1 Process Summary

The following process summary is used as a basis for the development of a GHG emission inventory for the project.

Magnesite, comprising about 92%  $\text{MgCO}_3$  is mined on the site. The magnesite is converted to magnesia ( $\text{MgO}$ ) by calcining in a gas-fired kiln. The  $\text{CO}_2$  evolved from the magnesite will be discharged with the products of combustion of natural gas from the kiln stack.

The calcined magnesia, comprising about 86%  $\text{MgO}$ , is reduced in a Direct Current Furnace (DCF), where magnesium vapour is evolved. Ferrosilicon, comprising about 76% Silicon, is added to the kiln as a reductant to convert  $\text{MgO}$  to magnesium metal. Calcined lime ( $\text{CaO}$ ) is also added to the DCF as a fluxing agent. Approximately 38% of the  $\text{MgO}$  is reduced in the DCF furnace. The electric power consumption of the furnace is about 5.3 MWh/kg Mg produced.

The magnesium vapour evolved from the DCF is condensed into a crude magnesium metal, which is finally refined in an electrically heated crucible before casting into magnesium ingots.

The following derivation of GHG emissions is derived on the basis of emission per kg of refined magnesium metal.

## 2.2 On-site GHG Emissions

### 2.2.1 Magnesite Mining

The raw magnesite input to the calcining kiln is 13 kg of mined magnesite per kg of magnesium metal. The magnesite is mined with diesel powered equipment. It is assumed that the fuel consumption for mining equipment is on average one litre of diesel per tonne of raw material mined. Diesel use produces 2.6 kg of  $\text{CO}_2$  per litre. Therefore the GHG emissions from diesel use in mining operations will be 0.034 kg of  $\text{CO}_2$  per kg of magnesium product.

### 2.2.2 Magnesite Calcining

13 kg of magnesite is calcined in the magnesite kiln per kg of magnesium. When calcined this will yield 6.57 kg of calcined magnesite and release 6.21 kg of  $\text{CO}_2$  from magnesium carbonate and 0.04 kg  $\text{CO}_2$  from associated calcium carbonate in the raw magnesite per kg of magnesium. The magnesite kiln is estimated to require 4.0  $\text{GJ}^4$  of natural gas per tonne of magnesite calcined. The  $\text{CO}_2$  emissions from burning natural gas (in NT) is 51.7 kg  $\text{CO}_2/\text{GJ}$ , corresponding to 2.69 kg  $\text{CO}_2/\text{kg.Mg}$ . Consequently the total  $\text{CO}_2$  emission from the magnesite kiln is 8.94 kg/kg.Mg.

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<sup>4</sup> 7.5 MMBtu per US ton of dead burned dolomite

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### 2.2.3 Limestone Calcining

For Stages 1 and 2 it is proposed to obtain burnt lime (CaO) from a limestone calcining operation elsewhere. However, for Stage 3 it is proposed to obtain limestone to produce the required calcined lime with an on-site gas-fired lime kiln. The DCF requires 0.626 kg of calcined lime per kg of magnesium. Therefore 1.12 kg of limestone is required per kg of magnesium, which would release 0.494 kg CO<sub>2</sub>/kg Mg. The lime kiln is estimated to require 4.29 GJ<sup>5</sup> of natural gas per tonne of limestone calcined, which would produce 0.222 kg CO<sub>2</sub>/kg Mg. Consequently the CO<sub>2</sub> emissions from calcining limestone would be 0.72 kg per kg of magnesium.

### 2.2.4 Electrode Consumption

The electric current is delivered to the DCF furnace via carbon electrodes. The carbon electrodes are slowly burned to CO<sub>2</sub> in the DCF, thus providing a small part of the magnesia reduction requirement. From pilot plant trials it is reported that the consumption of carbon electrodes is 2 kg/MWh. The electricity consumption of the DCF is 5.3 kWh/kg.Mg. Therefore the CO<sub>2</sub> produced by carbon electrode combustion is 0.039 kg.CO<sub>2</sub>/kg.Mg.

### 2.2.5 Other GHG Emissions

Other minor sources of CO<sub>2</sub> on site will include staff vehicle movements and blasting operations at the minesite. These cannot be quantified until the project reaches a more advanced stage. However, they would be trivial compared with the CO<sub>2</sub> emissions from the magnesite kiln.

Other GHG emissions to be considered are methane, nitrous oxide, Hydrofluorocarbons, Perfluorocarbons and sulphur hexafluoride, which are specified in the Kyoto Protocol. The proposed process does not involve any of those fluorinated compounds so there is no potential for emission of HFCs, PFCs or SF<sub>6</sub>. The only potential sources of methane would be fugitive leaks from the natural gas supply system, which would be trivial.

Nitrous oxide (N<sub>2</sub>O) is a potential minor component of oxides of nitrogen from combustion processes. N<sub>2</sub>O is a potent greenhouse gas with a Global Warming Potential<sup>6</sup> of 310. Oil industry GHG inventories<sup>7</sup> provide an emission factor of 0.00022 kg N<sub>2</sub>O per kg of fuel for gas fired furnaces. It is noted that this emission factor is probably conservative and that actual N<sub>2</sub>O emissions are likely to be less. On the basis

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<sup>5</sup> 6.5 MMBtu per US ton of dead burned lime

<sup>6</sup> According to the Intergovernmental Panel on Climate Change (IPCC), the Global Warming Potential (GWP) is "an attempt to provide a simple measure of the relative radiative effects of the emissions of various greenhouse gases." The GWP of a gas reflects the cumulative radiative forcing of that gas over a specified period of time (or "time horizon"), beginning with the moment it is emitted. The GWP is expressed in terms of that gas' radiative forcing *relative* to the forcing associated with the same mass of CO<sub>2</sub> over the same time-horizon. The GWP of nitrous oxide is 310.

<sup>7</sup> Australian Petroleum Production and Exploration Association - 2000 Greenhouse Gas Emission and Action Plan Report

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of this emission factor and the GWP factor, the N<sub>2</sub>O from the magnesite kiln and the limekiln would contribute about 0.08 kg CO<sub>2</sub> equivalent per kg of magnesium. There is also the potential for minor amounts of N<sub>2</sub>O to be generated from the blasting operations, depending on the type of explosive that is used.

## 2.3 Off-site GHG Emissions

### 2.3.1 Lime and Limestone

As noted in Section 2.2.3, it is proposed that limestone would be calcined on-site in Stage 3, and off-site for Stages 1 and 2. From the point of view of the overall GHG inventory the actual location of the limekiln is immaterial. Therefore, the contribution for limestone calcination is considered as an on-site emission, as in the Stage 3 configuration. There will also be a CO<sub>2</sub> emission associated with limestone mining. On the basis of the assumptions in Sections 2.2.1 and 2.2.3, this will amount to 0.003 kg.CO<sub>2</sub>/kg.Mg.

### 2.3.2 Electricity

The electricity consumption of the DCF furnace is estimated to be 5.3 kWh/kg.Mg, corresponding to 7.6 MW for Stage 1 and 30.3 MW for Stage 3. There will be additional electricity requirements on site for the magnesite crushers, the magnesium refining crucible and other minor equipment. The power requirements for these additional pieces of equipment cannot be quantified until the project reaches a more advanced stage. Therefore a nominal allowance of an additional 2 MW for Stage 1, increasing to 8 MW for Stage 3, is assumed to cover the demands of ancillary equipment. Hence the total electricity requirement is estimated at 6.7 kWh/kg.Mg.

In the Darwin area electricity is generated from natural gas, with some high efficiency combined cycle capacity. The GHG emissions associated with power supplied via the NT grid is 0.55 kg.CO<sub>2</sub>/kWh<sup>8</sup>. Using this factor, the GHG emission associated with electricity use is 3.68 kg.CO<sub>2</sub>/kg.Mg.

### 2.3.3 Ferrosilicon

Ferrosilicon (FeSi) is used as a reductant in the DCF, at the rate of 1.48 kg per kg of magnesium. The smelting of FeSi is an energy intensive process requiring about 16.2 GJ/tonne<sup>9</sup> of FeSi. Therefore the use of FeSi effectively represents an energy input to the process of 6.7 kWh/kg.Mg. FeSi smelting is typically located adjacent to hydroelectric resources and therefore uses a renewable electricity resource with no CO<sub>2</sub> emissions. The FeSi will be imported because there is no manufacturing capacity in

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<sup>8</sup> Personal Communication – Trevor Horman, Manager Strategic Planning, NT Power and Water Authority.

<sup>9</sup> Assuming 115% of heat of formation from SiO<sub>2</sub> and Fe<sub>2</sub>O<sub>3</sub>

Australia. Accordingly, GHG emissions associated with the production of FeSi are excluded from this initial GHG inventory.

Conceptually, if FeSi were to be smelted with electricity generated in NT at (0.55tonnes of CO<sub>2</sub> per MWh), then the corresponding GHG emissions would be 3.7 kg.CO<sub>2</sub>/kg.Mg.

## 2.4 Summary of GHG Emission Data

From the foregoing estimates, the overall GHG inventory for the BMP is summarised in Table 2-1. The figures that are presented on a “per kg of magnesium product” apply to all Stages of the project because the processing technology is common. Table 2-1 also shows the actual annual GHG emissions for the full-scale operation that is planned for Stage 3.

**Table 2-1 Initial GHG Inventory for BMP**

	kg.CO <sub>2</sub> eq/kg.Mg	k.tonnes CO <sub>2</sub> -eq/year at Stage 3
<b>On-site emissions</b>		
Diesel use for mining operations	0.03	2
Magnesite calcining kiln	8.94	447
Limestone calcining kiln*	0.72	36
N <sub>2</sub> O from combustion in the kilns	0.08	4
Carbon electrode consumption	0.04	2
<b>Off-site emissions</b>		
Diesel for limestone mining	0.003	0.1
Electricity generation	3.68	184
Total	13.5	675

\* Lime kilns would be off-site for Stages 1 and 2

Table 2-1 shows that the GHG inventory is dominated by the calcining processes and the electricity requirements. In contrast, the minor unquantifiable emissions identified above are probably smaller than the uncertainty in those principal sources of GHG.

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### 3.1 Scope for improvement

The above estimates are based on process performance estimates, which are derived from assay data, pilot plant trials and experience in other industries. The BMP is a development from the commercial Magnatherm process, which is a batch process operating under vacuum. The BMP plant will operate continuously at atmospheric pressure and is the first of a kind using this process enhancement on a commercial scale. Accordingly, it is to be expected that process refinements and improvements would be identified in the Stage 1 plant and can be applied in the Stage 2 and Stage 3 plants. Such improvements are likely to result in the more efficient conversion of magnesite to magnesium.

It is noted that only 30% of the magnesium present in the raw magnesite reports as finished magnesium ingot. Whilst this conversion rate is essentially a limitation of the process technology, which requires a high magnesia content in the furnace slag, it indicates that there is scope for improvement in magnesia conversion efficiency.

Table 2-1 shows that most of the GHG emissions relate to the preparation of raw magnesia for the DCF. Therefore any improvements in the efficiency of conversion of magnesia will have a direct effect of reducing the GHG emissions from the kilns. In addition, the electricity demand for the DCF depends partly on feed flowrate and will also be reduced.

### 3.2 Comparison with Other Magnesium Plants

The principal GHG emissions for the BMP are compared in Table 3-1 with data presented in the Environmental Impact Statements for the Australian Magnesium Project (AMP)<sup>10</sup> at Stanwell in Queensland and the South Australia Magnesium Processing Facility (SAMAG)<sup>11</sup> at Port Pirie in South Australia.

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<sup>10</sup> Australian Magnesium Corporation Pty Ltd, Draft Environmental Impact Statement - Australian Magnesium Project, Stanwell, Central Queensland, Dames & Moore (December 1999)

<sup>11</sup> SAMAG Ltd Environmental Impact Statement for a Magnesium Processing Facility and Gas Fired Power Station, Port Pirie, South Australia, Sinclair Knight Merz (November 2000)

**Table 3-1 Comparison of GHG Emissions from Magnesium Production**

kg.CO <sub>2</sub> -eq/kg.Mg	BMP	AMP	SAMAG
On-site emissions	9.8	7.4	3.8
<i>Electricity requirement (kWh/kg.Mg)</i>	6.7	16	21.7
Power generation	3.7	25.2*	6.9
Total	13.5	32.6	10.7
Data adjusted to a common energy basis :- natural gas with power generation at 0.55 kg CO <sub>2</sub> /kWh			
Total GHG emissions on common basis	17.2	20.1	15.7

\*Includes supply of steam from coal fired power plant

Table 3-1 shows that the comparison of GHG emissions between the differing magnesium production technologies is heavily influenced by the energy supply system that is used.

In the case of BMP the electricity is supplied from gas-fired plant in NT at 0.55 kg.CO<sub>2</sub>/kWh, but also about half of the energy is supplied by renewable hydroelectricity in the form of imported Ferrosilicon.

In the case of AMP the electricity is supplied from the adjacent coal fired power station and in addition the EIS reports a large amount of energy supplied as steam from the coal fired power plant.

In the case of SAMAG the electricity is supplied from a new high efficiency combined cycle power plant to be built alongside, which would emit 0.32 kg.CO<sub>2</sub>/kWh.

Also shown on Table 3-1 is a comparison between the three plants when considered on the common basis of using natural gas to supply energy and power at 0.55 kg.CO<sub>2</sub>/kWh. In this case the electricity used to smelt FeSi is included in the BMP assessment. This conceptual comparison indicates that the three technologies have similar GHG emissions in the region of 15-20 kg.CO<sub>2</sub>/kg.Mg when compared on a consistent energy supply basis.

### 3.3 Overall GHG Comparison

As noted in Section 1, the replacement of steel components in motor vehicles by magnesium components is estimated to reduce life cycle GHG emissions by 50 kg CO<sub>2</sub> per kg of magnesium used. The foregoing assessment shows that the overall GHG emissions attributable to the BMP would be 13.5 kg.CO<sub>2</sub>/kg.Mg. Therefore, if more than 27% of the output from the BMP is used to replace steel in motor vehicles, there will be an overall GHG benefit.

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Mt Grace Resources intends to participate in the Commonwealth Greenhouse Challenge Programme with the BMP.

The Greenhouse Challenge program has been established by the Commonwealth Government to assist in meeting Australia's obligation to abate GHG emissions in line with the Kyoto Protocol. The Greenhouse Challenge involves the development of voluntary cooperative agreements between industry and Government. Under these agreements, companies commit to taking action to abate GHG emissions by improving efficiency in energy use and processing, and by undertaking actions which would result in the enhancement of sinks and the more effective use of resources.

The steps that prospective participants in the Greenhouse Challenge have to undertake are as follows: -

- Establish and inventory of emissions. That would be an improvement and refinement of the outline GHG inventory presented in this report.
- Develop an Action Plan to minimise GHG emissions;
- Forecast expected reductions in GHG emissions that would result from the implementation of the Action Plan;
- Sign an agreement with the Commonwealth committing to the actions outlined in the Action Plan;
- Monitor emissions against forecasts; and
- Provide annual reports on progress.

The types of policies and measures that could be included in an Action Plan for the BMP include: -

- Capital projects that improve energy or chemical conversion efficiencies;
- Operating procedures that improve energy or chemical conversion efficiencies;
- Management initiatives and improvement programs that make "small step" GHG benefits;
- Use of alternative or renewable energy technologies; and
- Research and Development projects with the potential to reduce GHG emissions.

Where a conventional economic analysis of the measure indicates that there would be an economic benefit or no significant impact on the economics of the operation, then those measures would be categorised as "No-regrets" measures. They would be included in the Action Plan, subject to capital availability.

Where a conventional economic analysis of the measure indicates that there would be a significant cost to the operation of pursuing the measure, then those measures would be categorised as "Beyond no-regrets" measures. They may be considered for possible inclusion in the Action Plan, subject to the following considerations:-

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- Capital availability;
  - Acceptability of a long pay back period;
  - Long term strategic objectives;
  - Social and environmental objectives; and
  - Perceived long-term trends in carbon control legislation and carbon trading.

This on-going GHG emission review programme, under the Greenhouse Challenge, is consistent with the Prime Minister's undertaking "*...to ask industry to do more than they may otherwise be prepared to do, that is, to go beyond the no regrets minimal cost approach where this is sensible in order to achieve effective and meaningful outcomes*"