Developments in the Zuliani Process for Gossan Resources' Magnesium Project

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ABSTRACT: As the world's lightest structural metal, magnesium is poised for unprecedented growth to meet accelerating global demand for lighter weight materials in transportation and for portable devices.

To become the light-weight material of choice, magnesium must become cost competitive with other lightweight materials, particularly aluminum. In view of its weight saving advantage, magnesium's competitive position improves dramatically if its production cost is maintained at less than about 1.3 times the production cost of aluminum. Sustainable future growth also requires that magnesium producers utilize process technology that provides an environmentally attractive life cycle assessment.

This paper provides an update of the Zuliani Process currently being developed by Gossan Resources for its magnesium production project to be located at Inwood, Manitoba Canada. Process efficiencies and Greenhouse Gas emissions as determined from thermodynamic modeling and experimental testing will be compared to existing magnesium production processes. Based on the results, Gossan is confident that its magnesium project will realize the operating cost and environment objectives needed to support strong future growth. The paper will also outline the next phases to be undertaken to bring the project to full commercialization.

Introduction

Escalating fuel costs and tighter emission standards in the transport sector along with the development and widespread demand for increased portability in electronics, tools and sporting goods are dramatically accelerating the demand for light-weight materials.

To seize this opportunity, magnesium must become cost and environmentally competitive with other lightweight material options, particularly aluminum. In view of its weight saving advantage, magnesium's cost competitive position improves dramatically if it's per unit weight production cost is maintained at less than about 1.3 times the production cost of aluminum. Long-term future growth also requires environmental competitiveness. Magnesium producers need to utilize process technology that provides a much more environmentally attractive life cycle assessment than can be achieved with current production methods.

Magnesium Production Technology

Magnesium production processes can be classified into two main groups; electrolytic and thermal.

Magnesium electrolysis as originally practiced by Dow Chemical (USA), Norsk Hydro (Norway & Canada), US Magnesium (USA), Dead Sea Magnesium (Israel) and a few Soviet Union based companies is a large scale, continuous process employing electricity to reduce magnesium chloride containing molten salt to molten crude magnesium metal for subsequent refining and casting into commercial forms. Electrolysis process technology is generally complex involving many independent process steps. Very specialized electrolytic cell technology together with high purity anhydrous MgCl or equivalent is necessary to achieve acceptable electrical efficiency and energy costs. Because of process complexity, CapEx for a modern plant can approach or exceed $1 billion. Achieving an adequate return on capital requires plant production capacities of the order of 50,000 tpa or higher. Today, only US Magnesium, Dead Sea Magnesium and a few former-Soviet based producers, like Solikamsk and Avisma, continue to employ electrolysis technology.

Thermal reduction technology originally practiced by Timminco (Canada), Bolzano (Italy), Pechiney (France), Alcoa (USA), RIMA (Brazil) and Ube (Japan) and piloted by Mintek (South Africa) use readily available magnesium containing ores and generally known and understood thermal methods. In general, mixtures of calcined dolomite ore and ferro-silicon reductant are heated in solid or in molten state under vacuum to produce magnesium vapor which condenses as solid crude magnesium for subsequent melting, refining and casting into commercial products. Typically, commercial thermal technology suffers from being labor and maintenance intensive, from poor raw material utilization efficiencies, from a large volume of by-product waste, from high energy consumption and from additional costs & yield losses associated with the melting and refining of the crude solid magnesium condensate. However, because of their relative simplicity and lower CapEx, thermal plants can be built in much smaller increments of the order of 10,000 tpa or less. Today, Chinese producers and RIMA continue to employ thermal production methods.

Two Fundamental Paradigm Shifts Affect Magnesium Production Cost & Pricing

Within this technology backdrop, the magnesium producing industry has undergone two major paradigm shifts over the last two decades.

The first paradigm shift started about 1990 when China began to produce magnesium metal employing rather outdated 1940's thermal reduction technology originally developed in Canada by Dr. Lloyd Pidgeon **[1]**. The low CapEx, raw material, energy & labor intensive *Pidgeon Process* was ideally suited to late 20th century China where labor costs were low and environmental regulations were lax.

The net result of this development was an exponential growth in Chinese production, and correspondingly, a dramatic decline in magnesium market prices which had been previously averaging between US $3,100-$3,800 per tonne. By 1996, magnesium prices had fallen sharply to $2,500 per tonne and continued their relentless decline to less than $2,000 by the turn of the century. The resulting dramatic price shock led to the eventual curtailment and shut-down of many western electrolysis and thermal magnesium facilities. Today, just under 80% of the world's magnesium is produced in China using the *Pidgeon Process*.

The second major paradigm shift started to become evident in about 2007. China's rapid industrialization and move towards a freer market economy combined with rapidly accelerating inflation and a sharp spike in world oil prices resulted in a dramatic and fundamental step change in Chinese magnesium production and delivery costs. As shown in the table below, these demand pressures have resulted in a sharp escalation in energy, labor and raw material costs used in magnesium production.

As early as 2007, industry observers were coming to the conclusion that "the days of exceptionally low magnesium prices were indeed coming to an end" **[2]**.

Table 1: Change in raw materials, energy & labor costs in China between 2005 and 2011 – taken from various published sources

Commodity	% Increase (2005 - 2011)
Thermal Coal	~ 450%
Electricity	~100%
Ferrosilicon	~ 60%
Labor Hourly Rate	> 250 – 350%

Chinese inflation has had a dramatic impact on magnesium production cost and market pricing. Since 2005 the direct cost of producing magnesium in China and landing it in western markets as determined using a detailed Pidgeon Process cost model has increased by between 1.7-1.9 times from about US $1485 per tonne to between US $2530-$2830 per tonne by the end of 2011.

Because Chinese producers tend to establish market prices marginally above their "cash cost", the free market "floor price" of magnesium has correspondingly increased by about 1.7 times over the same period from about US $1,800 per tonne in the mid-2000's to just over US $3,000 per tonne by the end of 2011.

Economic Prospects for Magnesium

After about 10 years of low and stable prices, magnesium customers suddenly experienced a sharp price spike in 2008 which has subsequently leveled out at a new "floor" price that is ~1.7x pre-2008 levels. This unstable situation has no doubt raised customer concerns about what the future may hold. As discussed previously, it is very likely that the era of low magnesium prices is over due to the fundamental and dramatic upwards shift in energy, materials and labor costs in China.

Looking forward; since ferro-silicon (FeSi) represents almost 50% of the Chinese magnesium production cost, the Chinese magnesium price has typically trended between 2 - 2.5 times the Chinese FeSi price. Hence, projections for FeSi demand and pricing can be expected to largely determine magnesium's future production cost and pricing dynamics.

The vast majority of the world's FeSi is produced in China. FeSi is a major alloying element used in the production of steel hence FeSi demand is fundamentally tied to the demand for steel.

Between 2001 and 2010 world steel production grew from about 850 million tonnes to 1,417 million tonnes with Chinese steel production increasing over the same period from 152 million tonnes to 627 million tonnes **[3]**.

According to a recent CRU publication **[4]**, the current economic slowdown in China is expected to result in a slight pause in steel demand until about Q2 2012 at which point Chinese domestic steel demand will continue to grow. CRU is forecasting that between 2010 - 2015, Chinese steel demand will grow at near GDP levels of about 6 - 7% per annum. Hence, domestic Chinese FeSi demand can also be expected to grow at a similar 6 - 7% per annum.

Electricity is the major cost component impacting on the Chinese FeSi price. Based on a recent EU Commission Study **[5]**,

Figure 1: Trends in Free Market Mg Price

assuming a conservative average Chinese GDP growth going forward of about 6.5%, demand for electricity is expected to increase annually by about 7.2% which in turn will impact significantly on the demand for coal. The EU commission projected that by 2025, China would consume over 6 billion tonnes of coal annually or nearly three times the production and consumption in 2005. Even a far more conservative forecast by the International Energy Agency projected Chinese coal consumption to more than double by 2025. Importantly, coal is the primary energy source for Chinese Pidgeon Process magnesium production.

Figure 2: Chinese Steel Demand [4]

Given the expected annual growth rates of between 6-7% for steel, FeSi, and electricity together with the rapidly accelerating demand for coal, once the current economic slowdown in western markets diminishes, inflationary pressures in China can be expected to resume for the foreseeable future. Even though the current slowdown has resulted in a slowing in Chinese growth and a corresponding pause in magnesium price pressure, magnesium production costs and market prices are likely to feel significant upward pressure once Chinese energy, raw material and labor costs continue to increase.

Simply put, Chinese profit margins on magnesium are far too low to absorb any significant increase in production costs so western magnesium consumers should expect magnesium prices to continue upwards on a parallel path with the Chinese energy, materials and labor cost inflation rate.

Magnesium's Competitive Position with Aluminum

Figure 3 shows magnesium's competitive price point based on weight savings over aluminum.

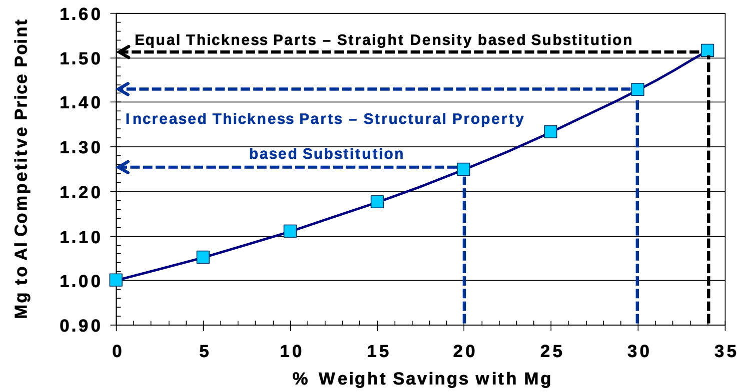

Figure 3: Effect of % Weight Savings on the Mg to Al Competitive Price Point

As shown in this figure, the often quoted 1.5 competitive price point really only applies to parts of equal thickness used in non-structural applications. To attain comparable mechanical properties in structural parts, magnesium components need to have thicker cross sections thereby reducing weight savings most often to between about 20-30%; a good rule of thumb for many structural applications is a 25% weight savings which corresponds to a competitive price point of 1.33 not 1.5.

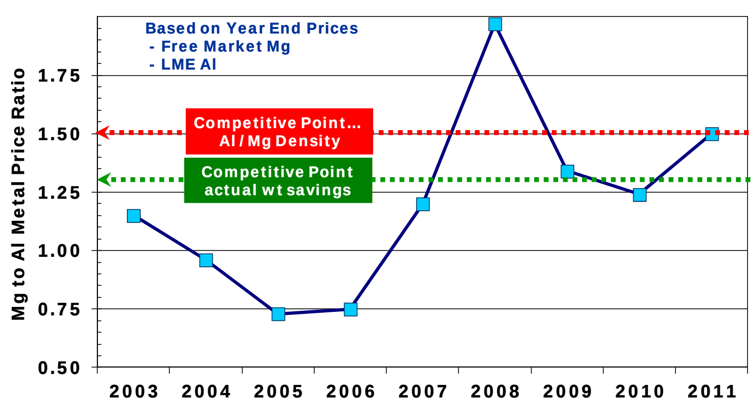

Figure 4: Recent Trends in Mg to Al Price

Figure 4 shows recent trends in the Mg to Al Price ratio. Up to about 2007, the Mg to Al price ratio was very favorable leading to unprecedented growth in Mg demand – during the period between 2000 to 2007 magnesium production grew from about 400,000 tpa to almost 600,000 tpa on the strength of competitive magnesium pricing stemming from the low operating cost structure in China. However, as discussed above the recent sharp rise in Chinese production costs and the corresponding price increases have significantly diminished magnesium's competitive position compared to aluminum. The net result is that growth in magnesium production and demand has been significantly curtailed in recent years.

Looking forward - for magnesium, with about 80% of the world's production being concentrated in China having production cost and pricing pressures that are not largely shared by the world's more diversified aluminum production base, there is a significant risk going forward that continued upward pressure on magnesium prices arising from increasing FeSi, labor and energy costs in China will lead to an increasingly uncompetitive position vis-à-vis aluminum.

Magnesium's Life Cycle Analysis (LCA)

In order to seize the lightweight opportunity, magnesium must not only be cost competitive but it must also be environmentally competitive. Table 2 provides a summary of the Global Warming Potential (GWP) which represents a summation of the "direct plus indirect" kg CO_2 for various processes/plants.

For comparison purposes, the world average GWP for aluminum ingot is 12.7 kg CO_2 /kg **[6]** but it is highly regionally dependent; 9.8 in North America, 11.0 in Europe and 24.7 in China.

Table 2: GWP for Mg ingot produced with various processes [11]
******indicates plants not in operation today

Magnesium Production Process (Location)		GWP
THERMAL	Bolzano (Brazil)	13.8
	Magnetherm (France)**	17.6
	Pidgeon (China)	43.3
ELECTROLYSIS	Norsk Hydro (Canada)**	16.1
	AM (Australia)**	27.9

About 95% of Chinese producers employ the Pidgeon Process to supply essentially 80% of the world's magnesium **[8]**. Hence, for the vast majority of magnesium applications the GWP per kg Mg ingot is 43.3 kg CO_2.

It should be noted that RIMA Brazil (Bolzano Process) accounts for about 3% of the world Mg production [**10**]. While the Bolzano and Pidgeon processes use different furnace configurations, both involve solid state reduction of calcined dolomite by FeSi under vacuum to produce a solid, crude Mg condensate that needs to be melted prior to refining and ingot casting.

As shown in Table 5, both the Pidgeon and Bolzano processes have essentially the same raw materials utilization efficiencies. Hence, the environmental benefits reported in Table 2 cannot be attributed to improved process efficiencies but instead are primarily due to RIMA's specific locational situation involving the use of hydroelectricity and charcoal produced from renewable eucalyptus trees grown in Brazil which provides a net GHG biofuel credit for the production of Mg and FeSi.

It should also be noted that the shuttered Norsk Hydro Canada plant employed hydroelectricity and can be considered representative of about the lowest CO_2 emissions potential for electrolysis production as evidenced by AM Australia having a GWP of 27.9.

Given today's dominance of Chinese magnesium produced essentially with the Pidgeon Process, and that its GWP is 3.4 times higher than the average for Al ingot production, the LCA for magnesium in automotive applications would not appear to be very favorable.

For example, D'Errico et al. **[11, 12]** reported that the LCA for 100 kg weight savings from the replacement of steel with 42 kg of magnesium components produced from Chinese Mg ingot indicated a typical vehicle would have to travel a distance of 290,000 km before the CO_2 emissions saved from its reduced weight would breakeven with the additional CO_2 generated from the production of components with Chinese magnesium. Importantly, the 290,000 km breakeven travel distance is well beyond the average vehicles expected lifetime of 200,000 km.

Gossan Resources Breakthrough Magnesium Project

Gossan Resources Limited a Canadian public company (TSX Venture – GSS) has entered into an arrangement that provides an exclusive option to secure worldwide rights to the highly efficient ZULIANI Magnesium Process which is currently under development.

In September 2008 Gossan received a final National Instrument 43-101 Report on its 1635-hectare Inwood dolomite property located in south-central Manitoba, Canada which is in close proximity to major magnesium markets within NAFTA countries.

As indicated in Figure 5 **[13],** Manitoba also has abundant, stable and low priced electricity generated almost exclusively from hydro. Manitoba electricity prices are very stable and amongst lowest in the industrialized world.

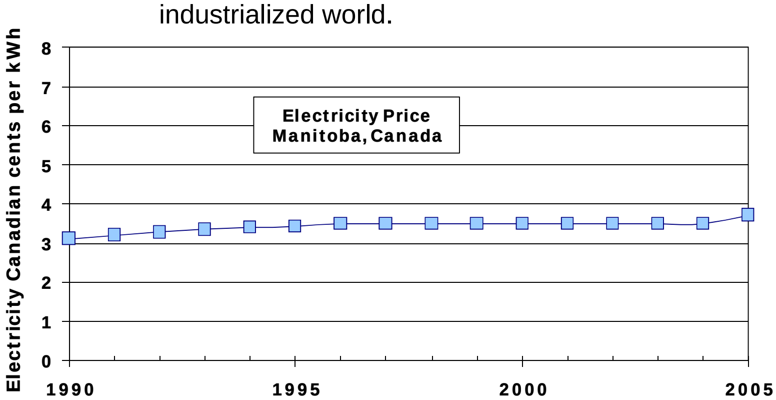

Figure 5: Manitoba Electricity Rates (1990 - 2005)

In 2007, Watts, Griffis & McOuat independently calculated a National Instrument 43-101 compliant resource based on the results from a 27-hole 2006 drill program and 25 holes previously drilled on the property. The program targeted 80 hectares of the Fisher Branch Formation which typically outcrops at surface and extends to a depth of about 12-15 meters

WGM's resource estimates are summarized in Table 3.

Based on process efficiencies from the work to date, the Measured Resource alone would support over 100,000 tonnes of magnesium metal production for 30 years.

Table 3: Watts, Griffis & McOuat Limited (WGM) NI43-101 Mineral Resource Estimates

Formation & Zone	Classification	Tonnes	MgO (wt%)	CaO (wt%)
Fisher Branch	Measured	28,819,000	21.15%	30.91%
Fisher Branch	Indicated	5,057,000	21.40%	30.66%
Fisher Branch	Inferred	131,236,000	21.64%	30.51%

In addition, Gossan has secured several quartz properties that are believed to be capable of supporting backward integration into FeSi production which should be very commercially attractive given Manitoba's favorable electricity rates.

Process Development Results - A new breakthrough thermal magnesium process is under development by Dr. Douglas J. Zuliani who holds a Ph.D. in Metallurgical Engineering from the University of Toronto and formerly worked for 16 years in senior management at Timminco Ltd., a former world leader in high purity magnesium metal production using the Pidgeon Process.

The ZULIANI PROCESS (the PROCESS") utilizes electricity to produce magnesium metal from calcined dolomite and FeSi. It has been designed to specifically address the main constraints that have unfavorably impacted operating cost, productivity and GHG emissions with all known thermal magnesium processes.

The objectives of this development are:

- To maintain sustainable profitability by realizing a 20-30% direct production cost advantage of over existing magnesium producers in China;
- To spur market growth by realizing a direct production cost that will be cost competitive with aluminum (~≤ 1.3 x Al Cost). Industry estimates indicate electricity represents ~1/3 of

the production cost of aluminum **[14]**. Assuming an average rate of about $0.04 per kWh and power consumptions of 12,500-15,000 kWh per tonne, under normal circumstances aluminum production costs can be expected to range between ~$1500 - $1800 per tonne. Under these assumptions the target competitive magnesium production cost should range between ~ $1,950 - $2,340 per tonne (1.3 x Al cost);

- To achieve a Life Cycle Assessment competitive with aluminum.

To date, independent thermodynamic modeling and bench scale experimentation have been conducted to verify the chemical and raw materials utilization efficiencies of the PROCESS.

Thermodynamic Modeling Results - In 2007 Dr. Arthur Pelton, of THERMFACT Ltd. and a Professor at Ecole Polytechnique in Montreal, Quebec was contracted to develop a thermodynamic model of the PROCESS using the FactSage integrated thermodynamic databank system which calculates the conditions for multiphase, multi-component equilibria in complex gas-slag-metal systems.

Dr. Pelton's analysis and confidential report were issued in September 2007 with the main findings being as follows:

1. The PROCESS is capable of producing magnesium vapor at atmospheric pressure in the desired temperature range of 1550-1650^{o}C. As such the PROCESS will not require the use of a vacuum as employed in other thermal methods.

2. The report confirms that unlike other thermal processes which produce crude solid magnesium which requires melting before refining and casting into commercial grades, molten magnesium condensation is feasible with the PROCESS. An assessment of the composition of the magnesium vapor phase confirmed that Gossan's Manitoba dolomite is of sufficient purity to produce better than 99.8% commercial grade magnesium metal.

3. The report confirms the boundary conditions where the PROCESS will operate at a high thermodynamic efficiency. Although the study focused principally on process thermodynamics, the report also indicates that it is expected that the PROCESS will demonstrate excellent kinetics for producing magnesium compared to other thermal magnesium processes using dolomite and FeSi.

Bench Scale Experimental Results - In 2009, Gossan retained Process Research ORTECH Inc. (ORTECH) of Mississauga, Canada, an independent pilot lab with recognized metallurgical expertise to conduct bench scale testing of the PROCESS to extract magnesium metal from dolomite and confirm process thermodynamics and kinetics.

The ORTECH bench scale tests were carried out in three phases with final results reported in September 2011.

Figure 6: Experimental Apparatus used in ORETECH's Bench Scales Tests

The following was concluded based on a constructed mass balance derived from ORTECH's bench scale experiments:

1: The PROCESS produces magnesium metal vapor at 1 atmosphere in the desired temperature range. Atmospheric production will avoid the need for using costly and complex vacuum systems and is an important prerequisite for molten magnesium condensation.

2: The efficiency and chemical effects of varying FeSi grade in the range between 30-75% were consistent with that previously predicted by Dr. Pelton's FactSage thermodynamic model.

3: There is exceptional agreement between the experimental mass balance developed using the measured initial raw material chemistry, measured raw material weights and measured final slag weight and chemistry as determined in the ORTECH tests and Dr. Pelton's thermodynamic model.

In a subsequent independent analysis of the results, Dr. Pelton reviewed and verified that there is excellent agreement between the ORTECH experimental mass balance and the FactSage thermodynamic modeling predictions.

This excellent agreement indicates that the high efficiencies predicted by the thermodynamic model are confirmed by actual experimentation. The results confirm significant efficiency improvements when compared to all other commercial thermal production methods currently in commercial use.

Environmental Considerations – ORTECH was also contracted to carry out an independent environmental assessment of the PROCESS to determine the GWP and LCA implications.

ORTECH developed a detailed mass and energy balance method to calculate the GWP associated with magnesium production. As a methodology check, ORTECH determined that the GWP for Chinese magnesium produced using the Pidgeon Process is 42.0 kg CO_2 per kg Mg ingot which compares very favorably with previously published GWP of 43.3 **[8]**.

Table 4: Comparison of Bench Scale Mass Balance Results & FactSage Thermodynamic Modeling Predictions to produce 1 kg magnesium vapor

	ZULIANI PROCESS		
Process Efficiency Factors	**FactSage MODEL**	**MASS BALANCE EXPERIMENT**	**AT 100% EFFICIENCY**
Kg Mg Vapor per Kg Si Used	**1.630**	**1.633**	**1.730**
kg Mg Vapor per kg Dolime Used	**0.225**	**0.227**	**0.244**
Kg By-Product per kg Mg Vapor	**3.851**	**3.862**	**3.571**
Magnesium Vapor Recovery	**92.3%**	**92.9%**	**100.0%**
Si Utilization Efficiency	**94.2%**	**94.4%**	**100.0%**

Table 5: Thermal Process Efficiency Factors to produce 1 kg magnesium Ingot

THERMAL PROCESS Efficiency Comparison	@ 100% Eff	Pidgeon CHINA	Bolzano BRAZIL	Zuliani CANADA
PROCESS DYNAMICS	-	Solid State	Solid State	Molten State
Energy Source	-	Coal	Hydro & Charcoal	Hydro & Nat Gas
Reaction temperature, °C	-	1200	1200	1600
Mg vapor pressures, atm	-	0.045	0.045	$\geq$ 1
Vacuum	-	Yes	Yes	No
Mg condensate	-	solid	solid	molten
EFFICIENCY FACTORS				
Kg Si used per kg Mg ingot	0.578	0.89	0.81	0.63
Kg dolime used per kg Mg ingot	4.13	5.36	5.84	4.55
Kg by-product per kg Mg ingot	3.9	5.5	5.9	4.4
% Mg Recovery (Dolime to Ingot)	100%	77.1%	71.4%	90.7%
% Si Efficiency	100%	64.9%	71.4%	91.8%

Using similar heat and mass balance methodology for FeSi and magnesium produced with the highly efficient PROCESS in Manitoba using hydroelectricity and natural gas for calcining dolomite, the GWP of Gossan magnesium (direct & indirect emissions) has been determined as 9.1 kg CO_2 per kg Mg ingot which is 28% less than the 12.7 GWP for average aluminum ingot production.

Using the LCA approach together with the more efficient magnesium component manufacturing methods described by D'Errico **[11,12]**, a lightweight vehicle design that replaces 381 kg of iron, steel and aluminum with 154 kg of Mg components according to USAMP design predictions **[15]** would begin to generate net GHG savings after a travel distance of only 69,500 km. This compares to a breakeven distance of 275,600 km before a net CO_2 benefit starts if Chinese magnesium were employed - the vehicle CO_2 savings from a weight savings of 227 kg would be 2.46 kg per 100 km travelled. The kg of CO_2 generated from the production of 154 kg of parts from Gossan magnesium would be 1,709 kg versus 6,776 kg from Chinese magnesium.

Such performance is clearly advantageous compared to Chinese magnesium however most importantly it would place Gossan's magnesium ingot in a much more favorable environmental position vis-à-vis aluminum which has a somewhat higher GWP and provides on average between 20-30% less weight savings than magnesium.

Economic Considerations - On the basis of the modeling and experimental work carried out to date, a continuous process route and flow sheet has been established for the continuous production of molten magnesium metal. This process route has been examined independently and favorably reviewed by a third party metallurgical company with direct expertise in magnesium production. A US Provisional method patent has also been filed in June, 2011.

A detailed direct cost model has been developed and indicates that with the exceptional raw materials efficiency and the use of stable and low priced hydroelectricity in Manitoba, Gossan's direct operating cost to produce magnesium metal is projected to be significantly below (20-30%) of the cost to deliver Chinese magnesium into western markets.

Most importantly, the direct cost also appears to be well within the target range set out to be competitive with aluminum thereby enabling magnesium to remain in a highly competitive position even when market conditions fluctuate.

SUMMARY & NEXT STEPS

As described above, the magnesium industry has undergone two significant paradigm shifts in the last twenty years – the first shift was the start-up of low cost production in China that ultimately reduced market prices by about 50% resulting in many western producers exiting the business. As a result of this first paradigm shift, favorable pricing resulted in significant market growth during the first decade of the 21st century and Chinese share of world magnesium production went from essentially zero in 1990 to about 80% today.

The second paradigm shift occurred in about 2007-08 when China's rapid industrialization and move towards a freer market economy combined with rapidly accelerating inflation and a sharp spike in world oil prices resulted in a dramatic and fundamental step change in Chinese magnesium production and delivery costs. Between 2005 and 2011, the cost to produce magnesium in China and deliver it to western markets increased by ~1.7 to 1.9 times. This fundamental upwards shift in Chinese production costs resulted in a corresponding and dramatic 1.7 times increase in the free market price.

Most importantly, during this period the Mg to Al price ratio increased from a very favorable range of between 0.75 – 1.25 before 2008 to about 1.5 by the end of 2011. The net result of the rising Mg to Al price is that growth in magnesium production and demand has been significantly curtailed compared to the high growth period prior to 2008.

While the recent WTO ruling against China's export tax pricing mechanism may result in some short term downward shift in magnesium free market prices, based on an analysis of longer term prevailing economic conditions in China including growth prospects for steel, FeSi, electricity and coal, it is predicted that the cost to produce magnesium in China will continue to experience ongoing upward pressure especially once the effects of the current economic slowdown diminish.

Importantly for magnesium, with about 80% of the world's production being concentrated in China having production cost and pricing pressures that are not largely shared by the world's more diversified aluminum production base, there is a significant risk going forward that continued upward pressure on magnesium prices arising from increasing FeSi, labor and energy costs in China will lead to an increasingly uncompetitive position vis-à-vis aluminum.

From an environmental perspective, the direct and indirect emissions associated with Chinese magnesium production contribute to a Global Warming Potential of between 42 – 43.3 kg CO_2 per kg Mg ingot which is highly uncompetitive compared to aluminum ingot produced with an average GWP of 12.7.

To avoid the uncompetitive operating cost and GWP risks associated with such a strong reliance on Chinese magnesium production, the industry needs a more geographically diverse production base and a breakthrough process that will make a step change improvement in raw materials utilization and related energy efficiency.

Results to date on the Zuliani Process currently being developed by Gossan Resources confirms exceptional agreement between independently conducted thermodynamic modeling and bench scale experimentation. When compared to other thermal process technology (Pidgeon, Bolzano and Magnetherm and Mintek), the Zuliani Process has demonstrated the potential to:

- Significantly increase FeSi utilization efficiency;
- Dramatically reduce dolomite consumption and the amount of associated process waste;
- Produce magnesium vapor at atmospheric pressures and thereby avoid the complexities and cost of using a vacuum;
- Condense magnesium in molten form to avoid additional energy and melt losses associated with the refining step;

When these process efficiencies are factored in, a detailed direct cost model indicates that with the use of stable and low priced hydroelectricity in Manitoba, Gossan's direct operating cost to produce magnesium metal is projected to be significantly below (20-30%) the cost to deliver Chinese magnesium into western markets. Importantly, the direct cost also appears to be well within the target range set out to be competitive with aluminum thereby enabling magnesium to remain in a highly competitive position even when market conditions fluctuate.

An independent environmental analysis also determined that Gossan's Manitoba magnesium project would produce magnesium with a GWP of only 9.1 kg CO_2 per kg Mg ingot which is 4.6 times lower than for corresponding magnesium production in China and 28% less than the average for aluminum ingot production. A corresponding Life Cycle Analysis indicates that for a lightweight vehicle design (replacing 381 kg of iron, steel and aluminum with 154 kg of Gossan magnesium) "net GHG savings" would begin after a travel distance of only 69,500 km.

Such performance would position Gossan's magnesium in a very favorable economic and environmental position vis-à-vis aluminum which on average provides between 20-30% less weight savings.

The fundamental thermodynamic and kinetic aspects of the Zuliani Process have been confirmed by the modeling and experimental work conducted to date. The next step which is now underway is to undertake larger scale experimentation needed to support the design of the continuous reactor specifically to verify molten bath mass flow characteristics and to confirm the efficiency of the molten magnesium condenser.

The results from this next phase of work will enable detailed design engineering and will support financing for the first commercial stage which is envisioned to be a 5,000 tonne pilot/demonstration scale plant.

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