Magnesium Metal Production in Canada

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Introduction

Over the last century, the primary magnesium industry in Canada has grown, peaking in the year 2000 with Canada as the second largest producer, and since then, has shrunk to a point where no primary magnesium is produced. The story is complex due to the fact that two competing commercial magnesium processes exist and that there has been a major global shift in the commercialization of these technologies. These two technologies are: (i) a high temperature thermal process where silicon is used to reduce magnesium oxide to magnesium metal and (ii) a more traditional light metal production route based on molten salt electrolysis, in this case the electrolysis of magnesium chloride.

Thermal Process

The source of magnesium oxide for the thermal process is typically calcined dolomite ($CaO \cdot MgO$) and the reductant is typically silicon in the form of ferrosilicon. There are some variants of the thermal reduction method that were practiced in the industry but they are all based on this basic process which is referred to as the “Pidgeon Process”. This process has a significant Canadian connection in that the process is named after its inventor, Prof. Lloyd Pidgeon, who developed the process in the late 1930’s at the National Research Council in Ottawa. The process was successfully piloted in January 1942 where its advantages of low capital cost, relatively simple reactor design, and ease of operation proved useful for war-time production of magnesium.

The Pidgeon Process uses finely powdered calcined dolomite and ferrosilicon that are mixed, briquetted, and charged into an externally heated retort made of nickel-chrome alloy steel as shown in Figure 1. The hot reaction zone portion of the retort is either gas fired, coal fired, or electrically heated to around 1,200ºC in a furnace, while the condensing section is equipped with water-cooled removable baffles. The magnesium that is formed in the vapour state is condensed on the cooled internal region of the reactor.

The condensed magnesium "crowns" are harvested, re-melted, and subsequently cast into ingots. Because of the vapour refining step intrinsic in this process, the metal produced can be of high purity (+99.95%), although because of the associated handling and re-melting steps, there is potential for subsequent oxide pickup.

Since its invention, this process and its variants have been exploited by a number of companies around the world, but the most significant activity has been in the last 15 years with the adoption and exploitation of the process in China. Currently, the vast majority of the magnesium production in China is based on the Pidgeon Process and China produces approximately 85% of the world’s magnesium.

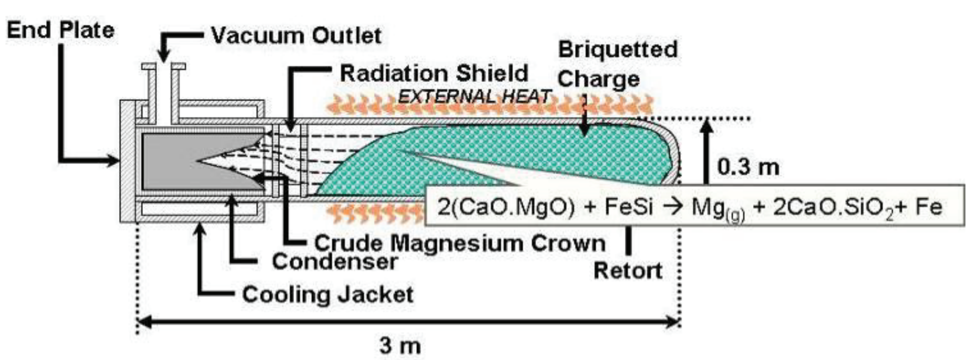

Figure 1. Pidgeon Reactor

Electrolytic Process

Electrolysis of molten magnesium chloride to make magnesium metal was first demonstrated by Bunsen in 1852, commercialized in Germany in the late 1800’s and the technology has undergone continued development ever since. Fundamental to this process route is a two-step process of first purification and dewatering of a concentrated aqueous solution of magnesium chloride to produce a nominally anhydrous magnesium chloride, followed by the second step of electrolysis. The use of an anhydrous feed for electrolysis is particularly challenging both in achieving efficient drying of the salt and in maintaining the salt in a dry state prior to electrolysis. A thermal process is used to remove the initial water with the subsequent introduction of HCl to completely dry the salt. Excess HCl is necessary to prevent significant hydrolysis (reaction of water with magnesium chloride to produce magnesium oxides and HCl gas) from occurring.

There are a number of variations in the approaches used commercially to obtain anhydrous magnesium chloride including direct chlorination which allows for distinction between the various magnesium plants around the world. The choice of technology for making the anhydrous magnesium chloride depends on the actual raw material source and access to technology. The first step of removing the water and all oxides from the magnesium chloride is an important consideration since any oxygen present in the feed to the electrolysis cell will react with and consume the graphite electrodes of the electrolysis cells, causing an increase in power consumption with the subsequent increase in the anode-cathode gap.

The second step, electrolysis, is based on a liquid chloride bath (containing some or all of NaCl, $CaCl_2$, LiCl, KCl and $MgCl_2$) at around 750°C. The magnesium chloride is electrolysed to produce molten magnesium at the cathode and chlorine gas at the anode. Because the metal is less dense than the electrolyte, it floats and is periodically tapped from the cell, alloyed and cast. The chlorine gas is either recycled and used for the preparation of the anhydrous magnesium chloride or sold – depending on the magnesium source and the chlorine balance. A cross section of a commercial electrolysis cell is shown in Figure 2. The electrolysis step requires between 10.5 and 14 MWh/t Mg, depending on the cell technology used.

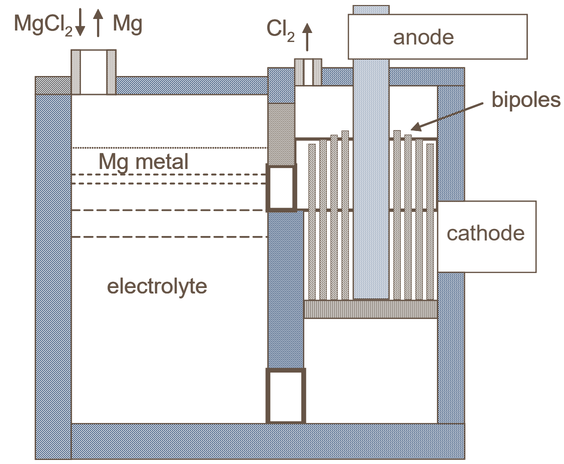

Figure 2. RTA Magnesium Multipolar Electrolysis Cell

Magnesium in Canada

Magnesium production in Canada spans almost a century - from the First World War to just after the start of the 21st century. In this time, a number of primary magnesium commercial operations existed in Canada (Table 1).

Although each plant in Canada has been based on either thermal reduction or electrolysis process routes, there is still a large variation in the details of the technologies used in each plant. This diversity in technology is common in the magnesium industry and identifies a significant contrast to the aluminum industry where there is relative standardization of technology for metal production. The choice of technology and plant locations can largely be explained by the combination of raw material sourcing, energy source availability and access to technology at the time of plant start-up.

Table 1. Magnesium Commercial Operations in Canada

Project Name	Date	Location	Comment	Capacity (ktpa)
Shawinigan Electro Metals Co.	1915-1919	Shawinigan, QC	Operated during WW1	< 0.15
Timminco	1945-2004	Haley, ON	Longest operating commercial operation in Canada	10
Aluminum Company of Canada	1951-1959	Saguenay, QC	Early commercial operation to meet Mg supply needs for Alcan Aluminum	6.5
Norsk Hydro Magnesium	1989-2006	Becancour, QC	Most productive commercial operation in Canada	48
Magcan	1990-1991	High River, AB	Started construction but never commissioned	12.5 (50 planned)
Magnola	2000-2003	Danville, QC	Most recent and largest commercial operation started in Canada	63

Shawinigan Electro Metals Co

The first magnesium production in Canada was in response to a shortage of magnesium created by World War I. Prior to World War I, most North American magnesium needs were supplied by Germany; however, the war resulted in a closure of this supply source and increased the demand for magnesium for such uses as metal powder for flares and tracer bullets. In response to this shortage, eight companies in North America started magnesium metal production, one of which was the Shawinigan Electro

Metals Co. in Shawinigan, Quebec. The plant was short lived, starting operation in 1915 and closing in 1919. During this time, it was actually the largest producer of magnesium in North America with up to 400 kg daily Mg production capacity in the context of world annual production in 1915 of 320 t Mg, rising to 1,200 t by 1918.

Timminco Ltd.

The origin of Timminco is the Dominion Magnesium Company, a Crown Corporation that commercialized the Pidgeon process in 1945 in Haley, Ontario. In 1967, the plant was sold to Falconbridge and then in 1971, sold to Chromasco which then changed the name to Timminco. The rationale for the Chromasco purchase was based on acquisition of a ferrosilicon plant in Beauharnois, Quebec with the original plan to shut down the Haley magnesium plant; however, because of a sudden up-turn in the magnesium market, Chromasco cancelled their plans two weeks before the scheduled shut down. In fact, Chromasco responded by investing in plant upgrades in the late 70's and 80's, increasing production to a peak of 10 kt/y capacity by 1989.

The raw material feed was calcined dolomite from their nearby, very high purity dolomitic limestone deposit and, after the sale of the Beauharnois ferrosilicon plant in the 80's, purchased ferrosilicon. The plant included calcination facilities for dolomite, feed preparation, reduction retorts, refining and casting of ingots and billets. The retorts were originally electrically heated but by the late 80's, all furnaces were converted to gas. At peak production in 1989, 16 furnaces with between 24 and 40 retorts per furnace were installed, resulting in about 475 operating retorts to meet production demand. By 1996, these numbers had decreased to 11 furnaces and around 330 retorts as production was scaled back. Secondary processing facilities at Haley include extrusion, magnesium billet and slab processing facilities and equipment to produce specialty magnesium metal and alloys. Timminco produced high purity metal up to 99.98% as well as alloys such as AX91E, ZK60 and HK31. Production was stopped in the Haley Plant in 2004; however, Timminco continued to process magnesium extrusions with purchased magnesium at their plant in Aurora, Colorado until 2009.

Aluminum Company of Canada Ltd.

The Aluminum Company of Canada (Alcan) built a 1 kt/y electrolytic plant in Arvida, Quebec in 1945 to produce magnesium to meet their aluminum alloy needs. The raw material for this plant was brucite ($Mg(OH)_2$) from a mine in Wakefield, Quebec which had a very high Mg content. The brucite was converted to anhydrous magnesium chloride using a shaft kiln in reaction with carbon and chlorine. The chlorine was sourced from a nearby Alcan caustic chlorine plant whose primary function was to produce caustic for a Bayer plant for alumina production and where the chlorine gas was a by-product. The anhydrous magnesium chloride was then electrolysed in cells which were adapted to operate without a diaphragm at 32 kA. In 1951, the plant capacity was increased to about 6.5kt/y using 56 monopolar electrolysis cells. Following the drop in magnesium demand in the years after the Korean War and a trade arrangement with Dow Magnesium to supply Alcan's magnesium needs, this plant was shut down in 1959. The specific energy consumption of these electrolysis cells at the time was around 20-22 MWh/t Mg.

After closure, the cell technology was licensed to Osaka Titanium Co., in Amagasaki, Japan for use in their titanium sponge production. This move provided a platform for Alcan's continued electrolytic cell development program. A series of patents describe the evolution of the magnesium cell technology, including the monopolar 40 kA (licensed to Oremet Wah-Chang in Portland, Oregon), the monopolar tapered cell (licensed to Timet in Henderson, Nevada for recycling $MgCl_2$ for titanium sponge production) as well as a series of multipolar cells (licensed to Noranda (see below) and the Australian Magnesium Corporation for their proposed Mg plant in Rockhampton, Australia). The multipolar cell development offered a significant breakthrough in magnesium metal production, improving the specific energy consumption to as low as 10.5 MWh/t Mg and increasing cell productivity to as high as 2.8 kt per cell per year. Both of these developments have significant impact on both the capital and operating costs for metal production, especially in environments of high labour and high energy costs. The multipolar technology continues to be developed and operated at the Osaka Titanium Company in Japan. Alcan (now Rio Tinto Alcan) also developed a magnesium chloride dehydration technology to prepare anhydrous magnesium chloride feed suitable for electrolysis. This technology is documented in a patent, but has not been commercialized.

Norsk Hydro Magnesium Inc.

Norsk Hydro had operated a magnesium smelter in Norway for many years and in 1985, Norsk Hydro initiated a feasibility study for an electrolytic magnesium plant based on sea water as the magnesium source to be located in an industrial park in Becancour, Quebec with a targeted production capacity of 60 kt/y Mg which was scaled down to 40 kt/y Mg later in the project. Availability and cost of the electrical power block required for the plant were largely responsible for the plant location. The plant was commissioned in 1989 and produced alloy, pure magnesium ingots, large round billets and alloy extrusion billet sows. In the early 90's a VDC caster was commissioned to produce T-bars. There were a number of operational issues in commissioning the plant which eventually resulted in a 48 kt Mg/y plant with the capacity to recycle 10-12 kt/y Mg. An aerial photograph of the plant is shown in Figure 3. The plant closed in 2006 and the technology and major components have been sold to Qinghai Salt Lake Group (QSLG) in China. Over its 18 years of operation, this plant was the most productive magnesium plant in Canada.

Figure 3. Norsk Hydro Magnesium Plant in Becancour, QC

The magnesium production route developed at the Becancour plant was based on the use of magnesite ($MgCO_3$) raw material sourced from China, Canada, Spain, and Korea which was crushed, calcined and leached to make concentrated $MgCl_2$ brine. This brine was then treated to remove sulfates, boron, and other impurities and then concentrated to around 50-55% $MgCl_2$ and then prilled. The prills were then converted to anhydrous magnesium chloride in a staged fluid bed reactor. The drying process involved air in the first stage followed by an atmosphere high in dry HCl in order to avoid hydrolysis reactions. The quantity of HCl circulating in the final stage of drying was very large in relation to the amount of magnesium chloride in the dryer.

Figure 4. Norsk Hydro Magnesium Electrolysis cells at Becancour, QC

The wet HCl from the fluid-bed dryers was recycled to the digestion section for the production of magnesium chloride solutions. The solid granular anhydrous magnesium chloride from the fluid-bed dryers was stored and transferred to 32 large, 435kA monopolar electrolytic cells (Figure 4). The electrolysis cells operated at an energy efficiency of between 13.0 and 14.5 MWh/t Mg. The chlorine from the electrolysis cells was recycled on site by burning with hydrogen in HCl synthesis units to make the HCl required for the dehydration step.

Magnola Metallurgy Inc.

In 1988, Noranda and Lavalin Industries established a 50/50 joint venture with the objective to evaluate the production of magnesium from asbestos tailings in the Eastern Townships of Quebec. Asbestos waste tailings are a mixture of magnesium silicates and other oxides and silicates, containing up to 24% magnesium.

A small pilot plant was built and operated at the Noranda Technology Centre in Pointe Claire, Quebec to develop a proprietary process for the production of anhydrous magnesium chloride based on aqueous HCl leaching of the tailings to make a concentrated solution of magnesium chloride. Most of the silica and iron was then removed by filtration of the brine. The solution was then neutralized with magnesia and treated with chlorine to oxidize the remaining impurities and further purified by ion-exchange to remove boron, nickel and manganese to separate magnesium chloride from the ore residue, resulting in a pure solution of about 27% $MgCl_2$. The solution was then dried to form $MgCl_2{\cdot}2H_2O$ prills and subsequently fully dehydrated using HCl gas in a molten salt chlorinator. The plan was to then electrolyse this anhydrous magnesium chloride in a molten chloride bath to make magnesium metal and chlorine gas which would be converted to HCl and recycled back to the leach and dehydration steps.

In 1995, Noranda constructed a demonstration plant in Valleyfield, Quebec with joint venture partners Aisin Seiki Corp Ltd. (Toyota) (16%), SNC Lavalin (16%), Société Générale de Financement du Québec (SGF) (16%) and Noranda Metallurgy Inc. (52%). The demonstration plant started in late 1996 at a rated capacity of 300 t/y and was shut down in 1998. The demonstration included the major process steps of leaching, molten salt chlorination and electrolysis. The electrolysis technology used for the pilot was licensed from Alcan and was a 1/6th slice of a commercial multipolar cell technology that had been developed for magnesium metal production in the titanium sponge industry. Eventually, both SNC Lavalin and Aisin Seiki dropped out of the venture, leaving Noranda (80%) and SGF (20%) as owners.

In late 1997, Noranda announced and built a 58 kt/y plant in Danville, Quebec, based on the raw material of serpentine asbestos tailings from the nearby Jeffrey Mine in Asbestos, Quebec (Figure 5). The plant production was eventually set at 60% alloy and 40% pure magnesium for a total metal capacity of 63 kt/y. Electrolytic production of magnesium metal using 24 cells of Alcan's most advanced and most productive multipolar cell technology was started in 2000 and the production increased over the commissioning stage up to a production level of around 30 kt/y. A number of technical problems were encountered during the commissioning, mostly related to the efficiency of the final stage of dehydration of the magnesium chloride.

Due to the extended time for commissioning and dramatic changes in the market for magnesium (principally intense competition from China), the plant was put on stand-by in 2003 with the expectation that a market turn around would result in a re-start of the facility. Noranda was subsequently absorbed into Falconbridge, which was then bought by Xstrata in 2006, at which time the decision was made to close the plant. Since then, the plant has been dismantled and major equipment components of the plant have been sold to various buyers, including magnesium producers in China.

Figure 5. Magnola Plant in Danville, QC

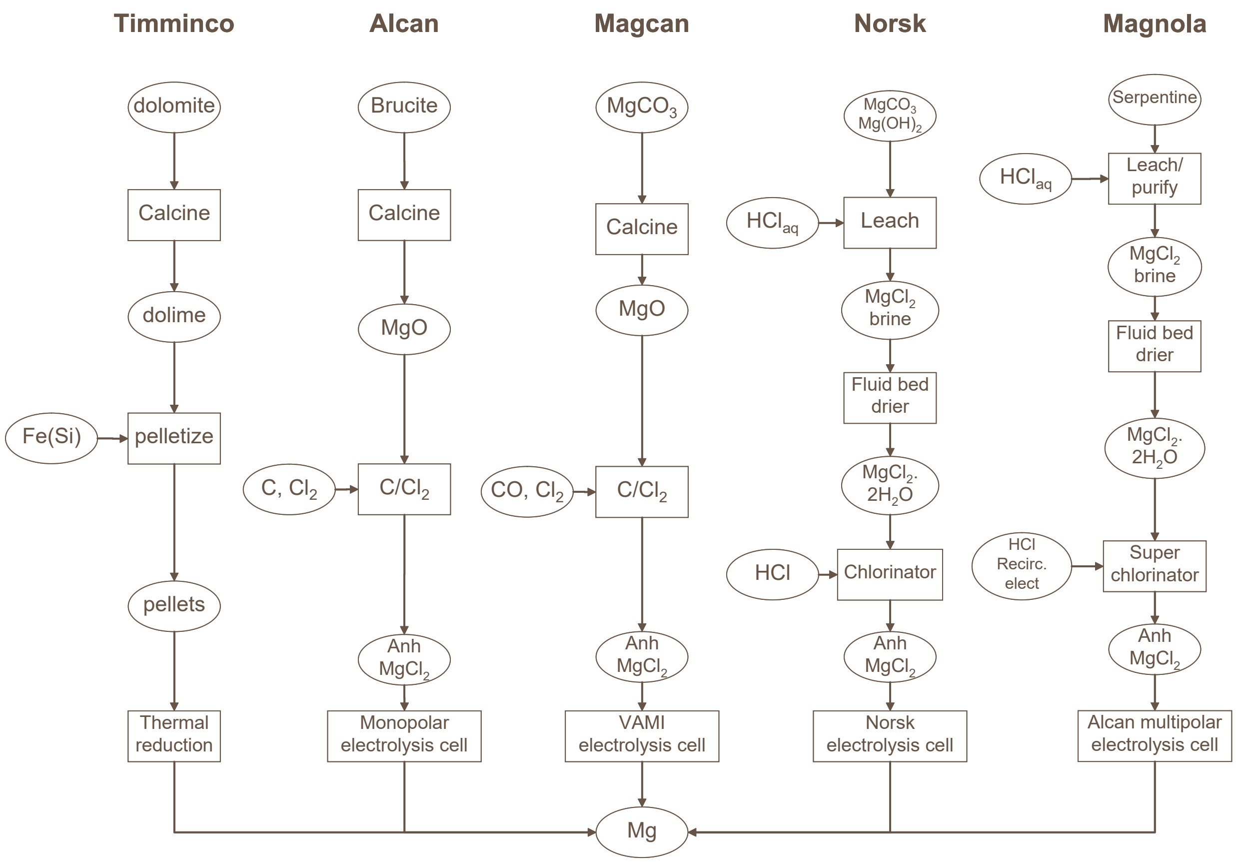

Figure 6. Side by side comparison of processes used in Canada

Other Canadian Projects

In 1986, Alcoa and Materials Processing Licensing Corporation announced a new 50 kt/y magnesium plant to be built in High River, Alberta. The first stage of the development was a 12.5 kt/y pilot. The plant used a unique one-step carbochlorination process to manufacture molten anhydrous magnesium chloride from magnesite. The magnesite ore was crushed into chunks and dumped into a reactor and reacted with carbon monoxide and chlorine in a shaft reactor that was heated by DC current. The resulting anhydrous magnesium chloride was then going to be fed to Russian designed VAMI electrolysis cells. The process apparently worked well on a very small pilot but the scale-up to the 12.5 kt/y pilot resulted in a number of technical problems that were never solved. The plant was started in early 1990 and closed in June 1991.

There have been at least four magnesium metal projects proposed in Canada, though none of these have progressed beyond the basic engineering stage. These projects include:

- The Cassiar Magnesium Project (electrolysis, based on using asbestos tailings, 2000-03, 90 kt/y production planned) in British Columbia
- The Cogburn Magnesium Project (artificial carnalite dehydration in HCl / electrolysis, based on magnesite raw material, 2002-03, 131 kt/y production planned) in British Columbia
- The Globex Mining Project (carbochlorination-electrolysis, based on magnesium-talc ore, 2001-02, 90 kt/y production planned) in Rouyn-Noranda, Quebec
- Gossan Resources (thermal process based on dolomite raw material, 2008-10, 50 kt/y production planned) in Inwood, Manitoba. Atmospheric reduction step (Zuliani Magnesium Process) developed for this project

Various issues have prevented each project from advancing, including issues with technology, funding, partnerships and changes in the market (in both demand and price).

World Magnesium Production

These commercial developments in Canada have been completed in the context of competing in a world market for magnesium. From WWII to 1997, world magnesium production was dominated by Dow Magnesium in the United States which was further complemented by plants in the United States, Kazakhstan, Russia, Norway, France, Israel and Canada.

About the time of Dow Magnesium's shutdown in 1997, there was the start of a shift in production from Western-based electrolytic production to Chinese silicothermal production using the Pidgeon Process. To emphasize this point, in 1994, less than 4% of the world's magnesium production was based in China compared to today, where over 80% of the world's magnesium is made in China. This shift in the production is a rare example where a more labour intensive production method (the thermal route) has displaced a less labour intensive route (electrolytic). The high labour, small unit output, low capital cost of the Pidgeon Process is very attractive to the economics of Chinese metal producers in comparison to the low labour, high unit production, high capital cost of the electrolytic process routes that are favoured by Western companies. In addition, the Western companies that have been involved in magnesium production have almost exclusively been large companies with main activities in a number of other metals or chemical products so that in the face of intense competition from low priced metal from China, the decision to abandon magnesium production was easier to make, instead of investing the capital required for modernization or modification of their plants for uncertain revenue.

The striking increase in magnesium production over the last 15 years and the fact that all of this increase has come from China is the most important factor that can be used to help explain the demise of much of Western based production (see Figure 7). This has been possible because of the overall small size of the industry (between 300 and 400 kt/y in the 1990's increasing to around 800 kt/y in 2010) and the small number of Western World producers. A second contributing factor to this changing demographic has been the continued imposition of duties on metal imports into the United States that have restricted Canadian and other producers' ability to enter the biggest consumer market for magnesium. Finally, the ability to secure long term contracts, particularly in automotive alloys, is a critical need of all magnesium companies to be successful. The closure of Norsk Magnesium was largely due to the two factors of loss of a long term contract with GM and the continued imposition of duty on their metal entering the United States. As well, Magnola failed to secure a long term metal sales contract which did not help it in its need to weather the onslaught of increased Chinese metal production that occurred at a very critical time in their plant startup.

While initial material exported from China in the early 90's was often devalued due to oxide or iron impurities, their processing methods have improved to the point that metal quality is now comparable to electrolytically produced metal.

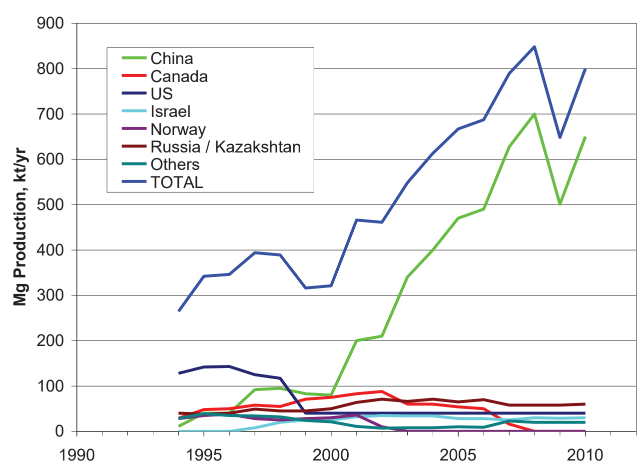

Figure 7. World Primary Mg Production (USGS)

The magnesium metal market is extremely volatile and idling of metal production based on the Pidgeon Process, such as in China, is much more easily achieved than can be done with electrolytic based production. This competition between these two technology routes has further complicated Western companies' ability to respond to the changes in the market.

Magnesium Processing

Most magnesium is used for aluminum alloying at around 41%, with castings and wrought products accounting for around 32% of the primary magnesium produced. Other uses of magnesium include iron and steel desulfurization (13%) and other products make up the remaining 14% of the market. The most significant magnesium alloy use is in die casting of automotive, aerospace and consumer products. Other, less significant, metal processing routes include rolling, extrusion and sand casting.

Canada continues to have a role in magnesium fabrication. The world's largest magnesium die casting company, Meridian Technologies Inc. (originally CAE Webster) established commercial die casting capabilities in Strathroy, Ontario in 1981 which have grown to an annual casting capacity of 16kt Mg with 21 die casting cells at their plant. Meridian has facilities around the world and is a leader in large size die castings for such automotive parts as instrument panels and front end supports. Another Canadian die caster of automotive components was Trimag (originally a joint venture with Haley Industries) which started production in 1996 in Haley, Ontario. The Trimag plant in Haley moved operations to Boisbriand, Quebec in 2007 and finally closed their Canadian production in 2009 due to the decrease in demand for automotive castings. A leader in sand casting expertise for both aluminum and magnesium, Haley Industries in Haley, Ontario, has been in business since 1952, casting complex components for the aerospace industry. As well, Mitchell Aerospace in Saint-laurent, Quebec is recognized as a long term, competent supplier of sand cast magnesium components for the aerospace industry. Another Canadian based fabrication activity included Timminco, who had extrusion presses in their Haley, Ontario facility until the plant was closed a few years ago and the equipment moved to the US.

In response to the need for fabrication support and development, the Institute of Magnesium Technology of Canada (ITMG) was set up by the federal and Quebec governments in the 1990's in Ste. Foy, Quebec to provide research, development, and technical services in cast and wrought product technologies. This group supported both Canadian and international companies through prototyping, training and technical support. At their peak, they supplied an important service to the industry. However, in the last few years, as growth opportunities in the automotive sector did not grow as fast as expected, ITMG assets were incorporated into Trimag and it is now closed. One highlight in a Canadian magnesium alloy development was the Magnola sponsored development of creep resistant AJ62 Al-Mg alloy for a composite engine block that was used by BMW. Unfortunately, the metal for this application has since been replaced with an all aluminum casting. A number of Canadian university professors and research institutions still have research programs on alloys (e.g. development of creep resistant alloys), casting, thermo-mechanical processing and magnesium alloy corrosion.

Summary

Canadian developments in the magnesium industry include the invention of the Pidgeon Process by Lloyd Pidgeon and its commercialization by Timminco, development and commercialization of the multipolar electrolysis cell by Rio Tinto Alcan and the development and commercialization of novel means to make anhydrous magnesium chloride from diverse raw material sources using HCl by both Norsk Magnesium and Magnola. In the context of a very volatile market, Canada has made significant contributions to the technology for magnesium production but in light of the changes in the global magnesium market, the country has moved from a position about 10 years ago of being a major supplier of magnesium metal to a position today where there is no longer any primary magnesium production.

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