MAGNESIUM INDUSTRY GROWTH IN THE 1990 PERIOD

Robert E. Brown
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Abstract

Electrolytic magnesium production has been the mainstay of the world’s magnesium industry since magnesium was first discovered by Davy in 1808. Many of the early workers developed small advances until the electrolysis of anhydrous magnesium chloride became the standard method of production. From the very first days, the importance of anhydrous magnesium chloride has been recognized. It remains the major problem area of economic and efficient electrolytic magnesium production.

There has been a dramatically increased usage of magnesium in the past ten years by the automotive industry. This usage is projected to continue a large growth as automakers continue to strive for better fuel economy with reduced emission. The use in die casting alone has been projected to increase at 10-15% per year for the next 10 years.

Cost of magnesium and its alloys is constantly compared to aluminum and its alloys by the automakers on all continents. Magnesium usually loses this battle, in spite of the different densities. Aluminum is 50% heavier than magnesium, hence for the same casting shape a pound of magnesium would make three castings while a pound of aluminum would make only two. Automakers feel that to be fully competitive, magnesium should be priced at 1.5 times the price of aluminum. This only takes into account the densities and not the other advantages offered by magnesium such as damping capacity and strength and rigidity.

In recent years, the interest in magnesium has grown dramatically and there is a great deal of basic research and pilot plant work going on to identify better and more economic ways to produce electrolytic magnesium metal. There is more technical brainpower being applied to magnesium than ever before at anytime in history. The work has no boundries or restrictions and can be found on all the major continents (except maybe Antarctica).
ELECTROLYTIC MAGNESIUM HISTORY

Magnesium as an element was discovered by Sir Humphry Davy in 1808. There is no record showing that Davy ever isolated magnesium as a metal. The first actual production of pure magnesium metal in the metallic form has been credited to the French scientist Bussy, who fused anhydrous magnesium chloride with metallic potassium. The German scientists Liebig and Bunsen and the French scientists St. Claire Deville and Caron all worked on methods of producing magnesium from anhydrous magnesium chloride. Michael Faraday is credited with producing the first magnesium by electrolysis of molten magnesium chloride salt. A major step toward the mass production of magnesium was made by Robert Bunsen, the German scientist, who made a small laboratory cell for the electrolysis of fused magnesium chloride in 1852. Graetzel and Fischer, also German scientists, started investigating the use of carnallite from Stassfurt as the raw material for electrolytic production of magnesium.

The original electrolytic cells that were developed by Chemische Fabrik Griesheim-Elektron used a cell feed of molten carnallite (MgCl₂·KCl·6H₂O). The dehydration of carnallite is much easier than the dehydration of pure magnesium chloride solution (MgCl₂·6H₂O). Most of the electrolytic magnesium production cells operating today are derivatives of the original Chemische Fabrik which became part of I. G. Farben in 1927.

Up until 1915, Germany was the only magnesium producer. When WWI started in 1914, there was a shortage of magnesium for pyrotechnics in military ordnance. Magnesium had long been used for flares and for tracer bullets. The price of magnesium was $5.00 to $6.00 per pound. Eight companies in North America went into the production of magnesium metal. As soon as the war ended, the number of companies dropped off to two, Dow in Midland, Michigan and American Magnesium Corporation (Alcoa) at Niagara Falls, NY.

Dow Chemical had gotten into the production of magnesium from underground brines at the Midland, Michigan plant. Dow could not solve the anhydrous problem and developed a special process that fed ‘wet’ feed (MgCl₂·5H₂O) to the Dow-designed electrolytic cell. American Magnesium Corporation used the oxide fluoride process developed by Harvey. This process was similar to the aluminum production process in that it was electrolysis of magnesium oxide in fluoride melts. However, the slight solubility of magnesium in the fluoride created many problems, including high operating temperatures, and high specific gravity of the eutectic mixtures (largely barium fluoride) which caused the liberated magnesium to immediately rise to the top of the bath and oxidize.

The Dow process was cheaper and gave more pure magnesium; so American Magnesium Corporation ceased production in 1927. AMC costs of production were 43 cents per pound in 1927 while Dow’s were 22.5 cents per pound. AMC negotiated a purchase agreement with Dow to purchase all their magnesium requirements from Dow and ceased production. It was an 18 month contract and a new five year contract was signed in 1928. The prices paid by AMC were below the market and decreased even more as the Dow total sales increased.

For most of the 1930 period, Dow Chemical in the US and MEL in England and two companies in France continued to produce and market magnesium metal in small quantities.

It took the start of hostilities in Europe for the US to become aware of the need for strategic materials. To assist in a build up, the US created the Defense Plant Corporation. This group had the job of building plants for production and fabrication of strategic materials. Magnesium was a strategic material. The US increased its magnesium production rapidly by building 6 new electrolytic plants and 7 silexothermic plants.

Most of these plants were shut down after the war and eventually Dow found itself in the US as the sole producer. The electrolytic plant in Michigan was closed and all of the magnesium metal production concentrated in Texas.

Magnesium production appears to be quite simple. This is merely a deceptive appearance that has trapped many of the world’s foremost metals companies and several junior companies. A normal question would be, ‘“If it is simple why aren’t more people doing it”?’ For some reason that idea has not seemed to cause second thoughts among too many experts, who usually feel that they can solve the problem of profitable magnesium production that few people have ever been able to solve.

It is the “profitable” part that has given the most problems. There have been many plants and many processes that have produced magnesium, but not very many that have produced profits.

Since 1950, there have been many projects attempted as is shown in Table 1. See Appendix attached.

NEW MAGNESIUM PROJECTS BEING DISCUSSED

There are 18 new magnesium projects under consideration somewhere in the world. They range from new smelters to expansions to feasibility studies. Surprisingly, in the USA, there are no new magnesium projects being discussed. The largest and oldest US producer, Dow Chemical, shut down their total magnesium operations in 1998, removing 65,000 tons per year of magnesium production from the market. This metal supply has been picked up by many of the other magnesium production sources.

NORTH AMERICA

The leading new project is the Magnola project of Noranda Magnesium being constructed at Asbestos, Quebec (see LMA Feb 1998). The C$733 million project includes a total facility to produce anhydrous magnesium chloride cell feed from asbestos tailings (serpentine) using a proprietary process. Alcan electrolytic cells will be used to convert the magnesium chloride to 63,000 metric tons per year of magnesium metal. Design and engineering is approximately 98% complete with construction about 70% complete. The plant is presently on schedule to start producing magnesium metal by mid-2000 with commercial production by March 2001. Hatch Engineers did the process work on the project and plant design and engineering and construction is by SNC-
Norsk Hydro Canada Inc has plans to expand its primary magnesium plant at Becancour, Quebec. Plans are to take the 45,000 metric ton per year plant to 85,000 metric tons per year in two phases. The decision to start construction has on the first phase has been postponed because of economic problems at the parent company. It had been expected to produce metal by 2001. The plant uses imported magnesite from the Pacific Rim for its feed and converts it to anhydrous magnesium chloride by a proprietary process. Norsk Hydro also has a proprietary electrolytic cell design which operates at over 400 kA.

The plant expansion will make use of much of the infrastructure already in place. The existing dehydration units will be modified to accommodate the first phase. The project includes new electrolytic capacity and technological improvements leading to higher productivity per cell. Other changes, recently identified will lead to reduced energy consumption and increased throughput in various units in the plant.

Gossan Resources continues to work on their high purity dolomite property at Inwood, Manitoba, 50 miles north of the city of Winnipeg. Metallurgical testing was carried out by Hazen Research of Golden, Colorado in mid 1997. Hatch and Associates of Montreal were engaged to carry out a prefeasibility study on the Inwood magnesium project. The report indicated that a 50,000 metric ton per year magnesium metal production plant using off-the-shelf technology of a sintering plant would be about US$0.89 per pound and US$1.13 per pound after financing. Gossan is working on a market study for magnesium metal that would be produced from this project.

Minroc Mines Inc. has started shipment of high-grade chrysotile product from the Cassiar operation in British Columbia, Canada, utilizing the company’s own proprietary wet process technology. Minroc has recently announced that it will proceed with investigations and work on a project at the Cassiar Mine for the production of magnesium metal from the existing tailings source at the mine. The high purity of the chrysotile at Cassiar, with its low iron content, they feel is a prime requirement for economic and competitive production. The Cassiar chrysotile feed is 23% magnesium and 5.5% iron. This compares with the Noranda Chrysotile project in Quebec which is announced at 21%-23% magnesium and 4%-8% iron. The Minroc Cassiar Magnesium project is being evaluated at production rates of 30,000 and 60,000 mtpy. The project has been assured of competitive rates for power, which is the key factor in costs and economics of any magnesium project.

Minroc also signed a memorandum of understanding with a division of the Korean automaker, Hyundai. The latest plans say that the magnesium plant will produce 90,000 mtpy of magnesium and the Aluminum Company of Korea (a Hyundai company) will be entitled to as much of the product as it may require with the remainder to be made available for sale to the international markets. Aluminum of Korea may acquire a 35% interest in the project in conjunction with an initial $25 million financing under the agreements, and could acquire a 65% interest in the project by providing additional project funding.

A preliminary assessment report by Kilborn/SNC Lavalin suggests that the mine’s reclamation pile contains enough magnesite for 100 years of production. SNC Lavalin is assisting the company in securing financing. Detailed tests for producing magnesium metal will take place simultaneously with the reclamation activities.

A great new future for Newfoundland-Labrador was discussed at the 11th Annual Mining Conference in Baie Verte, Newfoundland. The Minister of Mines, Chuck Furey said, “A new industry is being investigated for the old asbestos mine site. Geotech Survey Ltd was given permission by the government a few months ago to determine if it’s feasible to produce magnesite from the old asbestos ore tailings.

The Northwest Alloys (Alcoa) plant continues to operate the modified Magnetherm process at Addy, Washington. The plant is is rated at 41,000 mtpy. Production is of high purity magnesium used for alloying in Alcoa aluminum plants. In recent years, there has been an interest in the production of diecasting alloy at this plant. The plant has been upgraded over its entire life and further work to improve the process has been announced. NWA will work with Mintek of South Africa at developing a modified reduction reactor at Addy. The original plant had nine furnaces rated at 4,000 mtpy each. In later years, the plant has increased its rated capacity while reducing the number of furnaces in service.

Magnesium Corporation of America at Rowley, Utah is investing $46 million to evaluate new electrolytic magnesium cell technology and to install a new magnesium DC caster. The new cells when installed will have the potential to provide manufacturing efficiencies and reduce costs of magnesium production. With improved efficiencies, the production of the plant at Rowley could increase its capacity from the present announced rating of 41,000 mtpy. The new caster enables MagCorp to produce various sizes, shapes and weights of magnesium ingots and billets at lower cost. It can also produce T-Bar ingot which is used for aluminum alloying and offers a void-free, large shape.

AUSTRALIA

Australia has a number of magnesium projects being actively discussed and studies for magnesium metal plants are being conducted in all of the 6 major states. Tasmania and Western Australia have two each. The first large magnesium metal production project and the one that is further along is the project in Queensland which was originally developed by Queensland Metals as one of the end uses of its large high-purity magnesite deposit at Kunwarara, north of Rockhampton. It has been incorporated as Australian Magnesium Corporation (AMC).

Australian Magnesium Corporation is a company that is owned by Queensland Metals (50%) and Normandy Mining (50%) subject to financial support and a 5% interest held by Fluor Daniel for engineering services. Normandy also holds a 36.85% interest in QMC. AMC is the most advanced of the potential new producers in Australia and has a partner (Normandy) which is financially sound. Ford invested AS$40 million to assist the project into a pilot plant stage. Ford has also signed a long term off-take agreement for one-half of the planned production of 90,000 metric tons per year. AMC is operating a 1500 tpy demonstration plant to prove the process and gather operational data to complete the feasibility study. The construction of the commercial plant slated for completion by mid 2002 with commissioning and commercial operations by the end of 2002. The plant uses a process patented by CSIRO, an Australian Government Research arm, for production of...
anhydrous magnesium chloride from magnesite. Alcan electrolytic cells will be used in the commercial plant. The plant is expected to cost A$780 million including working capital.

The demonstration plant consisting of the CSIRO feed process and one full-scale Alcan Multipolar cell has been run since August 1999. The cash cost of producing magnesium is estimated to be A$0.65.

The electrical contract was signed at 20 mls which is somewhat less than the original number that was used in their feasibility calculations. The new plant site at Stanwell is near the power station, near a major gas pipeline and only a short distance from a major ocean port.

Crest Magnesium was one of the leading projects, but recently seems to be struggling to keep all of the partners working to get a plant built. Located on a very good deposit of magnesite in NW Tasmania, the project seemed to be going quite well until late in 1999. Discussions with a potential JV partner, Xstrata of Switzerland, were broken off.

The project as originally planned had Crest with the exclusive rights for Australia and New Zealand to use technology developed by the Ukrainian National Research and Design Titanium Institute and VAMI JSC over 20 years. There was talk of doubling the plant capacity in three stages over an 11 year period – taking production to 190,000 mtpy. The large Australian engineering and construction firm, Multiplex and Hatch Associates Limited of Canada were reviewing the technology in conjunction with Hatch or other approved consultants, and would provide a performance guarantee as to the nameplate operation of the plant (95,000 metric tons per year). The Tasmanian government will act as an intermediary for the supply of all energy: gas, electricity and commercial steam at a price that meets the indicative price already supplied by Duke Energy. Electrical costs are estimated to be 40% of the total cash production costs and Crest estimates an electrical cost of US$0.28 to produce each pound of magnesium.

Crest and Multiplex agreed to dissolve their JV partnership in October 1999.

Golden Triangle Resources NL, which was originally investigating the possibility of another magnesite project based on another section of the Main Creek Magnesite Deposit (adjacent to the Crest/Multiplex section), six to seven kilometers south of the Savage River Iron Ore Mine. The projects lie southwest of Burnie in northwest Tasmania. Golden Triangle exercised an option to acquire this portion of the Main Creek Magnesite Resource (47 million tonnes) from Savage Resources Limited in September 1998. First stage bench scale hydrometallurgical test work by Oretest Pty Ltd in Perth has now been augmented by Lakesfield Research Limited of Canada who have begun work on the second phase of laboratory test work that will lead to a pilot plant program. This project has been deferred in favor of the Woodsreef project.

Bass Resources, a Tasmanian mining company has announced that it has identified the site for a new magnesium production plant at Bell Bay. Bass Resources is planning to develop an arrangement with Pasminco which will provide access to a mineral resource based on the Main Creek magnesite deposit. If that proceeds, Bass Resources would be in a position to obtain access to Golden Triangle Resources’ exploration results and process technology.

Golden Triangle now intends to make the development of the magnesite project, the “Woodsreef” project in New South Wales, its main focus. Drill testing of the 24 million tonne Woodsreef asbestos tailings dump, located in Northern New South Wales has been completed. This is similar to the resource being developed in Canada by Noranda Magnesium.

In January 1999 Golden Triangle announced that it had awarded a contract to carry out “Comparative Magnesium Production Scoping Study” between the Tasmanian and New South Wales magnesite projects to South African engineering group, Bateman Brown and Root. The Bateman Group has some recent magnesium experience, having worked with the Israeli Chemical Industries in the development of the Dead Sea Magnesium Project. Golden Triangle has engaged the services of Mintek, South Africa’s national minerals-research organization, which is separately involved with the development of Plasma magnesium processing technology.

Pima Mining N.L. is a mineral exploration company. In September of 1998, Pima’s 80% owned subsidiary, South Australian Magnesium Corporation (SAMAG) acquired a 100% interest in a number of magnesite deposits in the Leigh Creek area of Australia, and plans to establish a magnesium metal production plant at Port Augusta, South Australia. Magnesite has been mined intermittently in South Australia’s Flinders Ranges since 1919. Currently, SAMAG is proceeding towards the development of a proposed magnesite mine in the Willouran Ranges, North West of Leigh Creek. Their estimated mineral resources total 205 million tonnes of magnesite, with 16 million tonnes being in the “measured” category.

SAMAG has recently announced that they purchased Dow manufacturing process and plant design. Plus they purchased the research records from Dow and hired several top Dow technical employees from Texas Division. The key component is electrical energy at a competitive price. This power situation has become a problem and recent statements from South Australian power officials indicate that project power costs of about 2 cents per Kwh may not be obtained.

Hatch Associates have completed a pre-feasibility study of the Port Augusta magnesium metal project, based on Dow electrolytic cell technology. SAMAG indicates that the study confirms that there is significant potential to produce magnesium metal at a cash operating cost of less than the US$0.61 per pound originally stated. Pima recently stated that, “The SAMAG project should produce 52,500 tpa of magnesium or magnesium alloys.” A detailed study on this project by Hatch has confirmed the low projected costs of production. First commercial production is scheduled for the first half of 2003.

In the Northern Territory, Mt. Grace Gold Mining NL acquired a 100% interest in the Batchelor Magnesite Deposit in late 1998. The company has reported extensive occurrences of magnesite in their tenement near Batchelor, some 85 kilometers south of Darwin. The company has now initiated a metallurgical testing program to demonstrate that Bachelor magnesite is amenable to beneficiation by flotation and is suitable for the production of magnesium metal. The stated aim is to construct a 50,000 tpa magnesium metal smelter with commissioning by July 2002. Energy may be available from a proposed development of Timor Sea natural gas together with the existing natural gas
pipeline infrastructure crossing Mt. Grace’s reserve.

Mt. Grace had retained DevMin Consultants to do a pre-feasibility study which will lead to a six to 12 month bankable feasibility study to prove the project’s viability.

Mt. Grace has signed an agreement with Magnesium Developments International to use the Heggie process for their magnesium production plant. The Heggie process is a thermal process.

Pilbara Magnesium Metal Associates (PMMA) is a joint venture based on Onslow Salt deposits in Western Australia. It was reported that HCC Pty Ltd and Multiplex Construction were part of this project. The plant would use bitterns from existing salt operations for the source of magnesium credits. This would require technology somewhat similar to that used in Israel or the Great Salt Lake. It has been reported that Uri Ben Noon, the former CEO of Dead Sea Magnesium, is a consultant to this project. An Israeli engineering company is providing a preliminary feasibility study. It is also reported that test work is being conducted in Russia and Israel. The venture proposes a 50,000 metric ton per year magnesium plant.

CRA in conjunction with Fluor Daniel Australia and St. Joe Minerals conducted testing and pre-feasibility work in this same area in 1985-86 with the intention of using by-product magnesium-rich liquor from the CRA gypsum operations. At that time, the anhydrous magnesium chloride feed production process investigated was the NaIco process. There was an earlier 1970’s feasibility study for a magnesium metal production plant done by CRA and Ube Industries Ltd of Japan.

Electrolytic magnesium production plants produce more pounds of chlorine than they do magnesium. Shell and Dow are considering an integrated chemical plant in the same region and could possibly use the chlorine by-product stream for chemical production. With good sound basic technology for magnesium chloride production and an efficient electrolytic cell, the metal cost could be competitive with the other Australian projects.

It has been rumored that PMMA is in discussions with the Solikamsk magnesium production facility in Russia to obtain the latest electrolytic magnesium production technology.

Hazelwood Power is again investigating the possibility of recovering magnesium metal from fly ash. Hazelwood Power is a 1600 MW brown coal fired electricity generator located in the LaTrobe Valley of Victoria. The Victoria state power commission looked at recovering magnesium from fly ash in 1970’s. The private company (Hazelwood) is working with HRL Technology Ltd to conduct pre-feasibility studies into the possibility of using a magnesium chloride feed liquor produced from flyash for magnesium metal production. It has been reported that there is sufficient fly ash available to supply a 30,000 metric ton per year smelter for 30/40 years. The big advantage would be transmission-free energy contracts, excellent water resources, and waste disposal potential. The study was based on the Alcan process for the production of anhydrous magnesium chloride and Alcan electrolytic cells.

Anaconda Nickel has announced an AS1 billion magnesium smelter will be built near a magnesite deposit they discovered when looking for nickel. The project development plans have not been clearly established at the present time. Shortly after the announcement of the magnesium project, Anglo American bought 23% of Anaconda Nickel and are said to be very interested in magnesium.

A summary of some of the planned magnesium projects was presented by Chris Laughton of Golden Triangle at a magnesium meeting in Sydney, Australia in June 1999. See Table 2.

**REPUBLIC OF CONGO (Brazzaville)**

Magnesium Alloy Corporation (MAC) commissioned SNC-Lavalin in Montreal to perform a feasibility study for the Kouilou hydroelectric site conditional upon certain financing arrangements by SNC-Lavalin. Upon completion of the study SNC-Lavalin may assist MAC in the financing and/or construction of the Kouilou hydroelectric site in Congo. SNC-Lavalin with its engineering expertise in hydroelectric facilities as well as its extensive construction experience in Africa, makes an important addition to MAC’s technical team. MAC has an option to develop the Kouilou hydroelectric site as a potential low-cost energy source for this extraction plant. The Kouilou River site lies 50 km north of Pointe Noire.

The lead contractor for the feasibility study is Salzgitter Anlagenbau GmbH (SAB), an engineering and general contracting division of Preussag AG of Germany. Kavernen Bau-und Betriebs (KBB), another member of the Preussag Group, has extensive experience in all phases of solution mining including modeling of reserves, solution mining simulation, drilling production wells together with brine extraction and transport.

VAMI, SAB and KBB, the principal contractors along with several sub-contractors have done detailed studies. VAMI and Ukrainian State Titanium Institute have been performing evaluation of advanced and improved modifications to proven magnesium extraction technologies. VAMI and the Titanium Institute took part in the design and implementation of the magnesium extraction technology for the Dead Sea Works Magnesium facility. They also took part in the technical design for the proposed magnesium facility in Iceland in conjunction with Salzgitter. VAMI developed the technology and took part in the design and construction of all the magnesium plants in the former Soviet Union (Berezniki, Solikamsk, Kalush, Zaporozhe, Ust-Kamenogorsk).

Preliminary reviews of the MAC project, subject to low energy costs as currently indicated, indicate very low cost magnesium production. MAC anticipates a first phase annual production rate of 58,000 metric tons with a second phase of 16,000 tons. Production decision due in 1999 with production possible by 2001.

**NETHERLANDS**

The Dutch development of the magnesium project for the Northern Netherlands is proceeding at this time. The project is part of the Antheus public-private project organization charged with developing the metal business climate in Northern Netherlands. The Magnesium Development Project Delfzijl (MDPD) project team is led by Reinder Rentema as chairman. A plan for a magnesium metal production plant of 40-60,000 metric tons per year has been presented to interested magnesium producers and magnesium users and the investment community.
It has an estimated installed cost of US$400 million. A study run by Hatch Associates of Quebec, Canada recently evaluated and compared the “Antileus” option with existing magnesium-producing technologies. That study shows that thanks to the high purity brine and other favorable production factors the planned region can offer a proposition that will feature one of the lowest cost structures of all existing and planned magnesium producing plants worldwide.

The exact technology to be used has not been chosen, but the planned project location has operating magnesium chloride solution mines that are presently being mined at a rate of 200,000 tons of magnesium chloride per year. Hydro Terra of Canada is working on a feasibility study for this project. Ample electrical energy is available and power deregulation in Europe in 2002 will help keep costs competitive. The brine is reported to be very pure. Long term plans call for a combined plant that will use the chlorine by-product of the magnesium operations to combine with ethylene to make ethylene dichloride. One of the partners is Nedmag, a former Biliton Company.

NORWAY

The original Norsk Hydro magnesium production plant in Norway was built at Porsgrunn during World War II using I.G Farben technology. This plant has been upgraded and modified to reach the present capacity of 40,000 mtpy. Presently, this plant uses seawater and dolomite to produce its anhydrous magnesium chloride cell feed. The plant has been upgraded to take care of environmental concerns and additional 10,000 tons of recycling capacity has been added in recent years. Further details will be available from a more detailed presentation by Norsk Hydro.

FORMER SOVIET UNION (FSU)

Now the oldest magnesium production operation in the world is the Solikamsk facility in Russia. It has been in operation since 1934. Solikamsk has installed a magnesium powder production plant and has a contract with GM for magnesium alloy. Solikamsk produces about 10,000 tpy of primary metal and 10,000 tons of alloy. The new magnesium granule plant is rated at 2,000 tpy with potential to expand to 8,000 tpy. Solikamsk also produces recycled magnesium. There have been plans and discussions to double the size of the primary magnesium plant. It was reported in 1998 that Solikamsk would participate in a project to use asbestos tailings from Uraltbest. The plans were to double the Solikamsk production of primary metal and alloy. Estimated project costs were reported at US$300-500 million.

Avisma which is the magnesium plant at Berezniki produces an estimated 15,000 mtpy and no immediate plans were known about expansion.

In Kazakhstan, the magnesium plant at Ust-Kamenogorsk produced an estimated 10,000 tons in 1998 with no announced plans of expansion.

In the Ukraine, there are two magnesium plants: Zaporozhe which did not operate in 1998 and Kalush produced an estimated 10,000 tons of primary magnesium in 1998. No plans for expansion have been seen although there have been several announcements made about start-up plans.

ICELAND

The Iceland Magnesium Project has been around in various forms since 1971. Promoted by the Sudawes Heating Corporation, a producer of heat and electricity from geothermal steam, the project has had new life. A consortium of Salzgitter, Magnit (VAMI and UTI), and Alumag met a feasibility study for a 50,000 metric ton primary magnesium metal production plant. The proposed plant used an electrolytic process with cell feed produced using VAMI technology. The study confirmed the technical viability of such a project. Both seawater and imported magnesite were reviewed. Again the potential supply of low cost electricity made the production costs attractive.

In 1998, Australian Magnesium Investments purchased a 40% share in the Icelandic Magnesium Project. No decision has been made as to when the design and construction will start. AMI is part of the Australian Magnesium Corporation and the acquisition presumably gives them the access to the Russian-Ukrainian technology or they could possibly use the technology that is being developed in Queensland. No immediate decision to proceed is expected until AMC gets the final results of the feasibility study based on demonstration plant operation.

ISRAEL

Dead Sea Magnesium has struggled to get into full production. In 1998, they produced 25,000 mt. Israeli Chemical Limited, the parent of DSM will put up $50 million more for debottlenecking work. It was reported that this money will be used to improve equipment serving the DSM electrolytic reduction plant. It was said that the present auxiliary equipment can only process 27,000 tpy, but DSM hopes to develop a capacity of 35,000 tons. The latest $50 million is in addition to the $460 million already spent.

The board of directors of Israel Chemicals (ICL) and its subsidiary Dead Sea Works Ltd have authorized the deal (on October 18, 1999) in which the magnesium unit which was a subsidiary of Dead Sea Works will be transferred to Israeli Chemicals. ICL Joseph Rosen reported recently, "Dead Sea Works hold a 65% stake in the unit, while Volkswagen AG holds 35% of the joint venture. After the deal, ICL will hold 65% of the magnesium unit.

ICL, a chemical holding company will inject $63 million into the magnesium unit to promote growth and sales. Offered from Volkswagen and ICL, have agreed on a joint business plan to invest $100 million into the magnesium unit to promote growth and profitability. According to the plan, Volkswagen will invest $35 million into the unit.

JORDAN

The Jordan Magnesia Company has built a US$70 million magnesium oxide plant. The project has a planned production of 50,000 metric tons per year of high quality magnesium oxide and 10,000 tons of specialty products from Dead Sea brine. The plant will be near the potash project. The Jordan Magnesia Company is owned by Arab Potash and JODICA.
The Near East Group is currently involved with the Arab Potash Company and is working to develop a magnesium production project using Dead Sea brine as a raw material. The plant will be a 25,000 ton per year facility. The Arab Potash group had signed an agreement to use Russian and Ukrainian Technology for the magnesium production facility. A major sponsor or partner is being sought by NEEC.

ALBANIA

Albania has found a magnesium hydroxylate deposit of Crystotil – Antigorite type, formed by tectonic mylonitization of ultramafic rocks and their hydrothermal elaboration. The deposit has enormous reserves (over 100 million tones). There is strong interest in building a magnesium metal plant near the deposit.

UNITED ARAB EMIRATES

Construction of a Dh734 million magnesium alloy plant is being planned for Sharjah’s Hamran Free Zone. The smelter project is being promoted by the Sahari Group of Abu Dhabi and Normans of Albania. This project is currently owned 50:50 by the two partners. The group is seeking European and Gulf partnership and funding. The ownership profile will be changed then according to spokesmen. The plant will have an initial capacity to produce 20,000 tons per year of magnesium products, to be increased to 60,000 ton plant upon completion in the next 24 months. For the Sharjah project, raw material will come from Albanian mines which are estimated to have reserves of over 400 million tons. Magnesium products made at the plant will be sold to buyers in Japan, the United States and Europe.

CHINA

China has more installed magnesium production capacity than any country in the world. The exact capacity and how much is actually producing at any one time is unknown, because the bulk of the production is from small and widely scattered silicothermic Pidgeon process plants (i.e. small, horizontal steel retorts charged with briquettes of calcined dolomite and ground 75% ferrosilicon as a reductant). There are 24 magnesium production plants with larger than 3000 tons per year production (three are electrolytic, the others thermal).

Fifty plants have capacities of 1,000 to 2,000 mt. There are announced plans for expansion by several of the larger thermal plants. One of the large electrolytic smelters, Minhe, has also made announcements about expansion, but there has been no confirmation that this move is happening. The continued internal competition to sell magnesium has caused the Chinese to lower the selling price CIF their ports to very low numbers. In 1999, pure magnesium was available in port of Tanjan for US$1650 per metric ton. An internal group has attempted to establish a minimum export price of $2150 per metric ton. These efforts have not been completely successful.

The small plants can be shut down and started up relatively quickly. So as the price goes up, the country’s production will increase. It has been speculated that the very small plants need a price of US$1800 to break even, but based on the transaction prices the break even must be closer to $1400. It is very subjective and varies widely according to plant and location.

PERU

One company in Peru has been reported to have a pilot plant running using Epsomite/Magnesium sulfate heptahydrate (Epsom Salt). A company called TRC Technologies was looking for someone to prove a lump sum, turnkey plant in 1998. There has been no further announcements from this area.

COLUMBIA

Over the past several years, there have been reports that Columbia was investigating magnesium containing ore bodies with the idea of producing magnesium metal. This has not been updated in the last two years.

BRAZIL

Brasmag has operated a modified Ravelli silicothermic process in Minas Gerais for a number of years. On and off there have been announcements for expansions. At this time, nothing has been actually done to increase the 7,000 metric ton capacity.

GENERAL DISCUSSION

During project evaluation and feasibility studies, there are several key items that must be in place. Power costs must be competitive. The source of magnesium feed for any process must be readily available and free of any of the contaminating elements that could adversely affect the production process. There must be a sufficient differential between the production costs and the selling price to produce profit.

Australia and Quebec have power prices that are among the lowest in the world. The prefeasibility studies on new plants in these areas are indicating production costs that are lower than the estimated production costs of the present magnesium producers. The selling prices that have been used in the studies have been adjusted downward to reflect the impact of increased production. It appears from this quick summary that all is rosy.

Unfortunately there are a few areas that are not being addressed or referred to very often. The newest operating magnesium project, the Dead Sea Magnesium plant, had trouble getting production up to the design production levels. Costs for the facility tended to overrun the original budget. Final product quality was reported to be substandard for almost a year. The costs of production are not available, but are known to be higher than originally budgeted. This plant uses the Russian/Ukrainian magnesium production process, which has been proven to successfully produce magnesium using carnallite as a feed stock, but is still fairly complicated.

The Noranda Magnola project has had their design, build, construct costs increase to C$733 million while planned production went from 58,000 mt per year to 63,000 mt per year. Design engineering is complete and construction is about 50% complete. This plant is using proprietary technology to produce anhydrous magnesium chloride from asbestos tailings. Alcan electrolytic cells will be used to produce the magnesium metal. The process was proven in a pilot plant operation, but the design scale-up is very large.
The Australian project that is furthest along is the Australian Magnesium Corporation work in Queensland. A modified Naico process was developed (AM process) by the Australian Magnesium Research and Development project and Australian patents obtained. AMC has built a 1500 metric ton demonstration plant at Gladstone, in Queensland. This plant uses the AM process to produce anhydrous magnesium chloride from Queensland magnesite from Kunwarara. A single full scale Alcan electrolytic cell is installed to produce magnesium metal and data for the feasibility study. There have been numerous problems in starting up and running the demonstration plant, including major electrolytic cell operating problems caused by initial introduction of iron contaminated feed. The cell has been cleaned, modified and is restarted and has now produced the first magnesium metal. Much of the feasibility study has been completed. The demonstration plant will supply operational data that are needed to verify the initial conclusions. The development work for this project will have taken 13 years and expended almost $100 million by the time sufficient data for a go or no-go decision is accumulated. It is hard to believe that there are many projects or many companies that would be willing to spend this amount of money on development.

The major stumbling block to magnesium production is the lack of a standard proven commercial technology. There is also a very limited experience base. For most processes, the experience lies in the hands of the present producers and most do not want to share or license their technology.

There are basically two processes, electrolytic and thermal. Each of these has many sub-groups or sub divisions. The electrolytic is based on converting magnesium credits to some form of magnesium chloride and breaking the bonds to create magnesium metal and chlorine gas. There are several versions of this technology, but the predominant is reduction of anhydrous magnesium chloride in a version of the I.G. Farben sealed cell which produces magnesium metal and chlorine gas.

The thermal process converts magnesium credits to magnesium oxide and removes the oxide by use of a reducing agent. There are many types of these processes being used. The most widely used is the silicothermic process, which utilizes ferrosilicon as the reducing agent.

The Australian projects are mainly looking at electrolytic reduction for their process. One project is looking at a thermal type plant. AMC uses the AM (Australian) process for production of anhydrous magnesium chloride and uses the Alcan cell for reduction. Crest has signed to use the VAMI/ukrainian technology. SAMAG has signed to license Dow technology for the cell feed and the reduction areas. Golden Triangle has retained Bateman Brown and Root and is looking at some new technology for feed production, with an Alcan cell being mentioned for reduction. Hazelwood mentions Alcan technology for their process to convert fly ash to magnesium metal. Batchelor has signed an agreement with Magnesium Developments International to license the Heggie thermal magnesium process. PMA is reportedly working with some Israeli engineers with no specific mention of the process. It has been mentioned that Solikamsk technology is being discussed. No process was mentioned for Anaconda Nickel.

A summary of projected costs and returns is shown in Table 3 (attached).

This summary shows that there is profit in magnesium projects. These figures are basically taken from preliminary company announcements. As the projects develop further, the costs will be more accurately presented. However, it can be quickly seen that the rate of return is good if the projects are built and operated for the budget numbers. It can also be seen that there is some advantage in larger scale plants, if they run according to plan. There are a lot of IF’s in all the Australian Projects (perhaps Dreams would be a better choice of word) and, for that matter, in all the new proposed magnesium developments around the World.

No one has ever designed or built a 90,000 metric ton per year plant. A plant that size will require a large amount of special design engineering and special construction. It will require special crew training and a long start up period. Unfortunately, the magnesium cells run in series and when you start one line, you must run them all. The cost of designing a plant where each cell could be electrically isolated by switching would be cost prohibitive. The cells must be charged with molten magnesium chloride, which must come from a special melter or from cells already on line.

The estimated rate of return on the thermal process that is planned for Mt. Graces’ Batchelor Project is surprising. Of course, that is the main great attribute of the thermal process. Low construction costs and the fact that small plants can be built and justified. Modular construction can be used to expand the plants in a fairly simple fashion, compared to an electrolytic plant.

Future Needs

For magnesium to be highly successful, especially in the automotive area, the price must be lower than the published prices of today. The ideal price ratio discussed is a magnesium price that equals the price of aluminum x 1.6. As mentioned in other places, this is only to take into account the density differences. There are some additional value-added properties of magnesium other than weight savings. These include machinability, die casting speeds, rigidity, and damping capacity, die wear. It has been mentioned by Ford that 1.8 x the price of aluminum would be acceptable while GM, Fiat, VW, Toyota and others suggest a much lower ratio. Accepting that price is the most critical factor there is also the absolute need for longer term price stability, longer term alloy development efforts, physical and chemical data on the alloy performances and a marketing effort that would provide assistance in the design and development of magnesium parts for specific vehicle platforms.

NEW TECHNOLOGY

The search for new and better efficient magnesium production is being carried on by major companies and small private research firms. Government sponsored programs can be found in most of the industrialized countries. Any researchers with a sound idea and the ability to present this idea will find funding easier now than ever before. There is great need for a simpler and more efficient electrolytic process and there are a large number of very talented technicians and scientists working on the problems. A major breakthrough could come most any day.
Table 1: MAJOR MAGNESIUM PROJECTS SINCE 1950

<table>
<thead>
<tr>
<th>Startup</th>
<th>Company</th>
<th>Location</th>
<th>Mg Source</th>
<th>Process</th>
<th>Type</th>
<th>Initial Capacity</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1951</td>
<td>Norsk Hydro</td>
<td>Porsgrun</td>
<td>Sea Water</td>
<td>Electrolyt</td>
<td>I.G. Farb</td>
<td>18,000</td>
<td>1.</td>
</tr>
<tr>
<td>1959</td>
<td>Alabama Met</td>
<td>Selma, AL</td>
<td>Dolomite</td>
<td>Thermal</td>
<td>Pigeon</td>
<td>7,000</td>
<td>X 2.</td>
</tr>
<tr>
<td>1960</td>
<td>Furakawa</td>
<td>Japan</td>
<td>Dolomite</td>
<td>Thermal</td>
<td>Pigeon</td>
<td>5,000</td>
<td>X 3.</td>
</tr>
<tr>
<td>1964</td>
<td>Pechiney</td>
<td>France</td>
<td>Dolomite</td>
<td>Thermal</td>
<td>Magneth</td>
<td>9,000</td>
<td>4.</td>
</tr>
<tr>
<td>1964</td>
<td>Ube Kosan</td>
<td>Japan</td>
<td>Dolomite*</td>
<td>Thermal</td>
<td>Pigeon</td>
<td>5,000</td>
<td>X 5.</td>
</tr>
<tr>
<td>1969</td>
<td>Nat. Lead</td>
<td>Utah</td>
<td>Brine</td>
<td>Electrolyt</td>
<td>Modif IG</td>
<td>40,000</td>
<td>6.</td>
</tr>
<tr>
<td>1970</td>
<td>Am Magnes</td>
<td>Texas</td>
<td>Brine</td>
<td>Electrolyt</td>
<td>Modif IG</td>
<td>25,000</td>
<td>X 7.</td>
</tr>
<tr>
<td>1975</td>
<td>NoWst Alloy</td>
<td>Addy WA</td>
<td>Dolomite</td>
<td>Thermal</td>
<td>Magneth</td>
<td>36,000</td>
<td>9.</td>
</tr>
<tr>
<td>1985</td>
<td>MagCan</td>
<td>Canada</td>
<td>Magnesite</td>
<td>Electrolyt</td>
<td>MPLC</td>
<td>12,500</td>
<td>X 10.</td>
</tr>
<tr>
<td>1992</td>
<td>Norsk Hydro</td>
<td>Canada</td>
<td>Magnesite</td>
<td>Electrolyt</td>
<td>Norsk</td>
<td>45,000</td>
<td>11.</td>
</tr>
<tr>
<td>1994</td>
<td>Noranda</td>
<td>Canada</td>
<td>Asbestos</td>
<td>Electrolyt</td>
<td>Alcan</td>
<td>63,000</td>
<td>12.</td>
</tr>
<tr>
<td>1997</td>
<td>AusMagCorp</td>
<td>Queensld</td>
<td>Magnesite</td>
<td>Electrolyt</td>
<td>Alcan</td>
<td>1500</td>
<td>13.</td>
</tr>
</tbody>
</table>

Comments:
1. Plant expanded and process improved. Output in 1998 at 43,000 tpy + 10,000 tpy recycling
2. Pigeon process plant was put out of business by Dow lowering price from 36 to 30 cents
3. Plant became uneconomical. Labor, electricity, and process costs became too high
4. Plant at Marginal has been expanded to 20,000 tpy cap but electrical costs are high
5. Made dolomite from seawater magnesia and calcined limestone. Process became too costly. Moved plant to China in a joint venture
6. National Lead sold to Ammax who sold to Renco. Plant is looking at expanding to 60,000 tpy
7. Mag plant cells were not good. Bought Russian technology, had environmental problems, fixed much of that, then evaporation ponds flooded. Sold out to MPLC
8. Dow built a Mag-Chlor plant to produce magnesium and strong chlorine, it did not run well and was closed and demolished in one year.
9. Alcoa established a magnesium production plant using Pechiney technology. The plant is located just north of the old WWII magnesium plant that used the same dolomite deposit. Plant efficiency and capacity have been expanded by Alcoa applied research. Also looking at Mintek process.
10. MagCan was designed and built to process magnesite using a carbo-chlorination process developed by MPLC and piloted in England. The plant used the modified Russian electrolytic cells developed by American Mag. Failed due to combination of technical and partner reasons.
11. Norsk Hydro built a new plant in Canada to use magnesite. Process was developed in Norway. The plant was late and over budget and the operations took a long time to get running well. The plant was built in North America to access the auto industry and aluminum alloying. Anti dumping charges virtually barred the shipment of magnesium from this plant to the US, causing the plant to run at half capacity for several years and lose money. Plans to expand are on hold.
12. Noranda has been working on a process for asbestos for many years. The process was piloted and now a commercial plant is being built in Danville, Quebec. Work on the process development took about ten years before the pilot plant operation. Hatch did process, SNC is doing design and construction.
13. Australian Magnesium (Queensland Metals) has been working on the magnesium process for producing magnesium from magnesite for over 10 years. A 1500 tpy demonstration plant is in operation and is producing several tons of magnesium per day to prove the process and provide data for the feasibility study to be completed by end of 1999. The commercial plant is planned to produce 90,000 mt/yr and Ford Motor has signed an off-take agreement for ½ of the production for 5 years with an option to renew for another 5. Base price is said to be US$1.30. Ford also put A$40 million into the project to help build the demonstration plant.
### Table 2. Electrolytic Magnesium Producers – Current and Proposed

<table>
<thead>
<tr>
<th>Location</th>
<th>Plant/Company</th>
<th>Capacity</th>
<th>Operating Cost*</th>
<th>Capital Cost US$ Million</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA **</td>
<td>Magcorp</td>
<td>45,000</td>
<td>94</td>
<td>N/a</td>
</tr>
<tr>
<td>USA</td>
<td>Dow</td>
<td>60,000</td>
<td>91</td>
<td>N/a</td>
</tr>
<tr>
<td>Norway</td>
<td>Norsk Hydro</td>
<td>44,000</td>
<td>85</td>
<td>N/a</td>
</tr>
<tr>
<td>Israel</td>
<td>Dead Sea</td>
<td>55,000</td>
<td>81</td>
<td>460</td>
</tr>
<tr>
<td>Canada</td>
<td>Norsk Hydro</td>
<td>68,000</td>
<td>74</td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>SAMAG</td>
<td>52,000</td>
<td>71 (60-65)</td>
<td>420</td>
</tr>
<tr>
<td>Canada</td>
<td>Magnola</td>
<td>58,000</td>
<td>66</td>
<td>515</td>
</tr>
<tr>
<td>Australia</td>
<td>QMC</td>
<td>90,000</td>
<td>66</td>
<td>520</td>
</tr>
<tr>
<td>Australia</td>
<td>Crest</td>
<td>95,000</td>
<td>65</td>
<td>561</td>
</tr>
<tr>
<td>Australia</td>
<td>GTR (Main Creek)</td>
<td>80,000</td>
<td>62</td>
<td>421</td>
</tr>
<tr>
<td>Australia</td>
<td>GTR (Woodsreef)</td>
<td>80,000</td>
<td>57</td>
<td>423</td>
</tr>
</tbody>
</table>

* Derived from a variety of sources **Now closed

### Table 3. Proposed Magnesium Projects with Estimated Costs

<table>
<thead>
<tr>
<th>Company</th>
<th>Mtpy</th>
<th>Est Op cost/lb</th>
<th>Capital cost US</th>
<th>Capital cost/tn</th>
<th>Operate cost/tn</th>
<th>8%-15* yr Loan</th>
<th>Total cost/tn</th>
<th>Cost/lb $US</th>
<th>%ROI @ 1.50</th>
<th>%ROI @ 1.20</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAMAG</td>
<td>52,000</td>
<td>$0.61</td>
<td>$420M</td>
<td>8000</td>
<td>1542</td>
<td>917</td>
<td>2259</td>
<td>1.024</td>
<td>12.0</td>
<td>4.5</td>
</tr>
<tr>
<td>recent</td>
<td>Sep 99</td>
<td>$0.59</td>
<td>$375M</td>
<td>7142</td>
<td>1300</td>
<td>819</td>
<td>2119</td>
<td>0.96</td>
<td>15.12</td>
<td>6.72</td>
</tr>
<tr>
<td>AMC</td>
<td>96,000</td>
<td>$0.66</td>
<td>$520M</td>
<td>5416</td>
<td>1452</td>
<td>570</td>
<td>2022</td>
<td>0.917</td>
<td>21.5</td>
<td>10.45</td>
</tr>
<tr>
<td>Crest</td>
<td>95,000</td>
<td>$0.65</td>
<td>$561M</td>
<td>5905</td>
<td>1430</td>
<td>677</td>
<td>2107</td>
<td>0.995</td>
<td>18.45</td>
<td>8.2</td>
</tr>
<tr>
<td>GTR M</td>
<td>80,000</td>
<td>$0.62</td>
<td>$421M</td>
<td>5262</td>
<td>1364</td>
<td>603</td>
<td>1967</td>
<td>0.898</td>
<td>22.88</td>
<td>11.47</td>
</tr>
<tr>
<td>Congo</td>
<td>60,000</td>
<td>$0.55</td>
<td>$514</td>
<td>5666</td>
<td>1210</td>
<td>648</td>
<td>1858</td>
<td>0.843</td>
<td>23.19</td>
<td>12.60</td>
</tr>
<tr>
<td>Magnola</td>
<td>63,000</td>
<td>$0.66</td>
<td>$492M</td>
<td>7800</td>
<td>1452</td>
<td>900</td>
<td>2352</td>
<td>1.067</td>
<td>11.09</td>
<td>3.4</td>
</tr>
<tr>
<td>GTRW</td>
<td>80,000</td>
<td>$0.57</td>
<td>$423M</td>
<td>5287</td>
<td>1254</td>
<td>604</td>
<td>1858</td>
<td>0.843</td>
<td>24.8</td>
<td>13.5</td>
</tr>
<tr>
<td>Hazelw</td>
<td>34,000</td>
<td>$0.55</td>
<td>$178M</td>
<td>5235</td>
<td>1210</td>
<td>600</td>
<td>1810</td>
<td>0.82</td>
<td>25.9</td>
<td>14.5</td>
</tr>
<tr>
<td>Batchelor</td>
<td>10,000</td>
<td>$0.70</td>
<td>$134M</td>
<td>1540</td>
<td>1540</td>
<td>176</td>
<td>1716</td>
<td>0.778</td>
<td>93.7</td>
<td>54.8</td>
</tr>
<tr>
<td>PMMA</td>
<td>50,000</td>
<td>N/a</td>
<td>N/a</td>
<td>N/a</td>
<td>N/a</td>
<td>N/a</td>
<td>N/a</td>
<td>N/a</td>
<td>N/a</td>
<td>N/a</td>
</tr>
<tr>
<td>Anaconda</td>
<td>90,000</td>
<td>N/a</td>
<td>N/a</td>
<td>N/a</td>
<td>N/a</td>
<td>N/a</td>
<td>N/a</td>
<td>N/a</td>
<td>N/a</td>
<td>N/a</td>
</tr>
</tbody>
</table>

*Annual cost for a 15 year loan at 8% interest, basis $/ton installed capacity

ROI = 100x2000x [sales price/lb – total cost/lb] / Installed capital cost/ton