Magnesium Price Spike: A Flash in the Pan?

April 2022

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Abstract

In September 2021, the town of Yulin in Northwest China's Shaanxi province substantially reduced its production of magnesium carbonate ($MgCO_3$), falling at least 70 percent from market expectations. Although production generally recovered within a few weeks, China is the world's largest magnesium producer, and this brief shutdown created substantial ripple effects throughout the downstream industries which incorporate magnesium into their products. Notably, the experience of the global automotive sector, which includes electric vehicle producers, highlights the effect that dwindling magnesium supplies can have on downstream production as magnesium is integral to strengthening and lightening of aluminum.

This working paper will provide a snapshot of the magnesium market at the end of 2021 and place the brief shutdown in China in context. It will begin with an introduction to the magnesium metal and a history of its production processes, and will explore the current market for magnesium. It will then provide an overview of major global magnesium producers and a closer look at U.S. production and the domestic magnesium market. The paper will then note contemporary supply chain challenges in the magnesium sector and conclude with a brief exploration of the potential future of the industry.

Office of Industries
Working Paper ID-083

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Office of Industries
U.S. International Trade Commission (USITC)
January 2022

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The authors would like to thank Heidi Colby-Oizumi and James Stamps for providing constructive comments and guidance, and Byron Barlow for his production support.

Introduction to Magnesium

Magnesium's name is derived from a district, Magnesia, located in Thessalia (northeastern Greece)—a region with known deposits of magnesium-containing minerals. Found in over 60 minerals, magnesium (Mg), comprises approximately 2 percent of the Earth's crust, is the 3rd-most plentiful element in seawater (concentration averages 0.13 percent), and the 8th-most abundant element in the universe.[1] However, despite magnesium's wide abundance, it is never found free in nature. As a result, although magnesium was formerly recognized as a separate element in 1755 by Scottish chemist Joseph Black, it wasn't until 1808 that English chemist Humphry Davy was able to isolate an impure form of the metal. Magnesium was finally isolated in its pure metal form in 1831 by Antoine-Alexandre Brutus Busy, a French pharmacist.[2]

Soon after the isolation of pure magnesium, English scientist Michael Faraday separated out magnesium through a process of electrolysis of fused anhydrous magnesium chloride ($MgCl_2$) in 1833, and in 1852 Robert Bunsen developed an electrolytic cell that optimized isolation of magnesium via the Faraday route.[3] Despite these advances in electrolysis and magnesium isolation, this method was not the first process utilized in industrial production of magnesium. Commercial-level production first began in 1863, using the reduction techniques pioneered by Henri Etienne Sainte-Claire Deville and H. Caron (the Deville-Caron method).[4] By 1886, a furthered modified version of Bunsen's electrolytic cell had been developed in a pilot plant in Germany and subsequently reached limited industrial production by 1909.[5] It was not until 1914 that the first magnesium production plant in the United States, helmed by General Electric Co., was established in Schenectady, NY.

Once established, magnesium production in the United States increased steadily. However, upon U.S. entry into World War II (WWII), magnesium production increased exponentially. Between 1940 and 1943, the U.S. government commissioned the construction of 13 domestic magnesium plants to support the war effort due to magnesium's use in the production of incendiary bombs. After the war, the U.S. magnesium facilities were largely sold to private industry or shuttered.[6] Although U.S. production of magnesium no longer occurs at the levels reached during WWII, there is still some domestic production. Today both seawater (including lake brines and bitterns) and several minerals (dolomite, magnesite, brucite carnallite, and olivine) are used to extract magnesium for commercial purposes at various sites around the world.[7]

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[1] Kramer, *Magnesium, Its Alloys and Compounds*, 2001, 3.

[2] Pure magnesium is a light, silvery-white metal that tarnishes slightly when exposed to air. National Center for Biotechnology Information, "PubChem Compound Summary for CID 5462224, Magnesium," accessed October 29, 2021.

[3] The electrolytic cells are large steel boxes with ceramic lining – wherein electrolyzed molten magnesium chloride separates to produce magnesium metal and chloride gas.

[4] Specifically, a reduction of a mixture of anhydrous magnesium chloride and calcium fluoride by sodium. Kramer, *Magnesium, Its Alloys and Compounds*, 2001, 3.

[5] Kramer, *Magnesium, Its Alloys and Compounds*, 2001, 3.

[6] Kramer, *Magnesium, Its Alloys and Compounds*, 2001, 3.

[7] Kramer, *Magnesium, Its Alloys and Compounds*, 2001, 3.

Magnesium Processing

As previously noted, commercial amounts of magnesium can be isolated from a variety of sources. One of the most common sources is the mineral dolomite, which has many accessible deposits globally.[8] Magnesium sourced from mineral deposits is generally retrieved via open pit methods and is the main source of magnesium extraction from China, the world's largest magnesium producer. Despite a variety of magnesium-containing mineral deposits throughout the United States, U.S. commercial magnesium is currently produced through isolation of magnesium from brine water—namely the Great Salt Lake in Utah.[9] As minerals (e.g., dolomite and magnesite) and/or brine serve as the two primary sources globally, magnesium is typically manufactured by one of two methods: (1) electrolytic reduction of magnesium chloride (from brine water) or (2) thermic reduction of dolomite.[10]

China, the largest producer of primary magnesium (i.e., not recycled), has used the Pidgeon process (silicothermic based) for over 40 years, and the majority of China's magnesium industry is based on this process.[11] The Pidgeon process can be broken down into 4 stages: calcination, pelleting, vacuum thermal reduction, and refining.[12] Broadly speaking, the Pidgeon process occurs through the reduction of magnesium oxide (produced during the calcination of dolomite) with ferrosilicon (fluorite is used as a catalyst), yielding magnesium vapor. The vapor is then cooled, and the solid magnesium product is collected.[13]

Anhydrous, electrolytic reduction is the method primarily utilized in the United States for commercial production of magnesium.[14] U.S. Magnesium, the largest magnesium producer in the United States, produces primary magnesium by treating (chlorinating) and dehydrating the brine water, to yield a solution containing magnesium chloride ($MgCl_2$). Magnesium chloride is then isolated as a purified

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[8] USITC, *Magnesium from Israel*, January 2020, I–15.

[9] In 2017, approximately 70 percent of the U.S. magnesium supply in the form of magnesium oxide came from seawater and natural brines. As of 2019 US Magnesium, the only major U.S. producer, primarily extracted its magnesium from the Great Salt Lake. USITC, *Magnesium from Israel*, January 2020, I–15; Kumar et al., "Metals Recovery from Seawater Desalination Brines," June 14, 2021, 7705.

[10] Kramer, *Magnesium, Its Alloys and Compounds*, 2001, 23.

[11] It is worth noting that the composition of dolomite is approximately 47 percent carbon dioxide (CO_2), which is yielded during calcination (thermal reduction)—this does not include CO_2 that is off-gassed during the heating of dolomite. Production of magnesium via the Magnetherm route ended in 2003 with the closure of the Marignac plant in France; the Pidgeon process has been used for 70 years. There are several other reductive thermal routes including the Silicothermic, Carbothermic, Aluminothermic, and Mintek. Silicothermic specifically refers to chemical reactions using silicon as the reducing agent at high temperature. Kramer, *Magnesium, Its Alloys and Compounds*, 2001, 23; Wulandari et al., "Magnesium: Current and Alternative Production Routes," Eng. Edge, 4; Sever and Ballain, "Evolution of the Magnetherm Magnesium Reduction Process," Magnes. Technol. 2013, 69–74; Wu, Han, and Liu, "Magnesium Smelting via the Pidgeon Process," Compr. Util. Magnes. Slag Pidgeon Process, 45.

[12] Wu, Han, and Liu, "Magnesium Smelting via the Pidgeon Process," Compr. Util. Magnes. Slag Pidgeon Process, 45.

[13] Most magnesium plants in China use coal as fuel, its estimated that 1 ton (t) of magnesium consumes eight to twelve tons of "high-quality" coal. Wu, Han, and Liu, "Magnesium Smelting via the Pidgeon Process," Compr. Util. Magnes. Slag Pidgeon Process, 47; Kramer, *Magnesium, Its Alloys and Compounds*, 2001, 23.

[14] The Dow Process involves that partial dehydration of brine, and does not produce marketable chlorine (Cl_2). Wulandari et al., "Magnesium: Current and Alternative Production Routes," Eng. Edge, 4–5. See United States Production and Market in Magnesium Market and Production for more information.

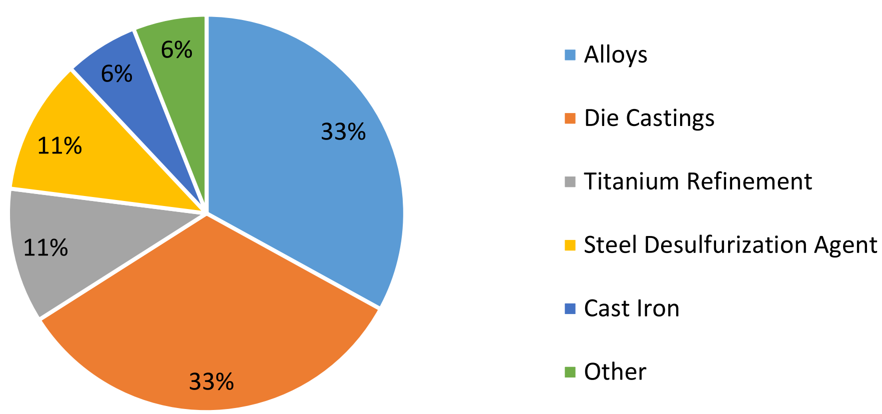
powder.[15] The $MgCl_2$ is then fed into an electrochemical cell—operating at approximately 700˚C— which yields chlorine gas and molten magnesium metal. The magnesium rises to the surface and is collected, and some electrochemical processes allows for high enough grade and quality chlorine gas (Cl_2) to be collected and marketed for sale.[16]

Magnesium Market and Production

Magnesium is principally used as an intermediate product in the metals industry, though in its pure form has been used in other sectors.[17] When magnesium is combined with other metals (i.e., magnesium alloys) the metals in which magnesium are incorporated can be made stronger, more durable, and lighter.[18] One 2012 study estimated than approximately one-third of global magnesium is used to alloy with aluminum to produce lighter aluminum for vehicles, both civil and military transport sectors, and the aerospace industry.[19]

In addition to magnesium's use in alloys, one-third of magnesium is used in die castings, titanium refining (11 percent), steel desulfurization (11 percent), and cast iron (6 percent, figure 1).[20] The widespread use of magnesium in alloys contributes to the large size of the industry; one 2020 study estimated that the global magnesium market had a value of \$3.3 billion, expected to more than double to \$6.8 billion by 2027.[21]

Figure 1 Share of different downstream uses for magnesium in 2020, global (percent)



[15] Purification includes removing various impurities that exist in brine like boron and various sulfates.

[16] USITC, *Magnesium from Israel*, January 2020, I-15–16; Wulandari et al., "Magnesium: Current and Alternative Production Routes," Eng. Edge, 4–5.

[17] Given its relatively low ignition temperature and its bright white light emitted when it is ignited, pure magnesium has been used in pyrotechnics, flares, and flashbulbs. However, this property makes pure magnesium a bad choice for building materials

[18] Loukil, "Alloying Elements of Magnesium Alloys," Magnes. Alloys Struct. Prop; Alliance Magnesium, "Magnesium: A Fast-Growing Market," 2021. See also Magnesium Market and Production.

[19] Loukil, "Alloying Elements of Magnesium Alloys," Magnes. Alloys Struct. Prop; Alliance Magnesium, "Magnesium: A Fast-Growing Market," 2021. See also Magnesium Market and Production.

[20] Alliance Magnesium, "Magnesium: A Fast-Growing Market," 2021.

[21] Grand View Research, "Metal Magnesium Market Size, Share & Trends Analysis Report," July 2020.

Source: Alliance Magnesium, "Magnesium: A Fast-Growing Market," 2021.

The share of magnesium used in downstream products varies by industry, and the broad consensus across industry is that the largest consumption of magnesium is in alloys—particularly in the auto sector. Its ability to lighten and strengthen aluminum makes magnesium useful in a variety of automotive parts, including instrument panels, seat pans, steering column parts, door inner panels, door handles, chassis parts, transmission cases, and engine blocks.[22] One industry representative noted that "there are no substitutes for magnesium in aluminum sheet and billet production," and that, "if magnesium supply stops, the entire auto industries will potentially be forced to stop."[23] The ability to lighten aluminum products helps to improve mileage and efficiency, a particularly important element for fuel-efficient vehicles and EVs.[24] From a country-level perspective, China is the largest consumer of magnesium and accounts for nearly 39 percent of consumption according to one estimate.[25] This is followed by the European (19 percent) and North American (19 percent) markets, and Japan (4 percent).[26] The largest importing markets are the United States, Canada, and Germany (nearly all of China's consumed magnesium is produced domestically).[27]

Although reserves of magnesium are extremely diffused and plentiful, production of primary magnesium is heavily concentrated among a handful of countries. In addition to being the largest consumer of magnesium, China is also the world's largest producer of primary magnesium and exporter. Supplying between 75 and 90 percent of global primary magnesium, more than 80 percent of primary magnesium exports in 2020, and with estimates ranging from 72 to 87 percent of annual global production, China represents by far the world's largest producer.[28] After China, reports indicate that the largest producers are the United States and Russia, each reportedly representing approximately 6.1 percent of global production.[29] The remainder of global production is divided among a variety of markets, mainly Brazil, Israel, Kazakhstan, Turkey, and Ukraine.[30] Secondary (recycled) magnesium represents a small, but growing, portion of global magnesium production.[31]

As noted above, magnesium constitutes approximately 2 percent of the Earth's surface, and is the third-most common element found in seawater.[32] As a result, magnesium is one of the few commercially sold metals that is produced from processes derived from both the land and the sea. As previously noted, in China the vast majority of magnesium is mined from dolomite, which is subsequently crushed, mixed with

[22] Grand View Research, "Metal Magnesium Market Size, Share & Trends Analysis Report," July 2020.
[23] Hume, "China's Magnesium Shortage Threatens Global Car Industry," October 19, 2021.
[24] Takano, "Magnesium Gains Luster," accessed January 19, 2022.
[25] Trading Economics, "Magnesium," December 2021.
[26] Trading Economics, "Magnesium," December 2021.
[27] Indexbox, "Approaching Magnesium Deficiency Threatens to Disrupt," October 27, 2021.
[28] China Nonferrous Network, "Global Magnesium Production and Demand," September 7, 2021; USGS, *Magnesium Metal*, January 2021.
[29] According to an estimate from the World Magnesium Conference of the International Magnesium Association, in 2020 1.1 million tons of magnesium were produced, of which 212,000 tons were produced out of China. Russia and the United States each accounted for 65,720 tons. China Nonferrous Network, "Global Magnesium Production and Demand," September 7, 2021.
[30] USGS, *Magnesium Metal*, January 2021.
[31] Light Metal Age Magazine, "Magnesium Market Outlook Is Solid," August 3, 2016.
[32] National Minerals Information Center, "Magnesium Statistics and Information," 2021.

ferrosilicon and placed in a furnace to subsequently condense into a recrystallized form, and then melted into ingot.[33] Production in the country is collocated with coal coking facilities, where waste gas from coking plants can be used to power these magnesium production processes.[34] Israel primarily uses lake brine, which is placed in evaporation ponds and subsequently flashed in a burner (similar to U.S production, see below). [35] Other countries such as Russia, Ukraine, and Kazakhstan, use magnesium salts mined from deep underground as their primary magnesium source material.[36]

Each of these production processes can be very labor- and capital-intensive (contributing to the concentration of magnesium production), as well as requiring substantial energy to produce at sufficient purity for commercial and industrial use. One 2020 study demonstrated the greenhouse gas emissions from magnesium production likely exceeds both aluminum or steel production on a per kilogram base, largely due to the substantial energy needs to produce magnesium.[37]

United States Production, Imports, and Uses

U.S. production of magnesium is limited and represents less than 10 percent of global primary magnesium production. The United States is likely the third-largest primary magnesium producer after China and Russia (however, the United States is the largest secondary magnesium producer; one report estimates the United States produces half of all global secondary magnesium production).[38] Despite the United States' comparatively small production as a share of global production, domestic primary magnesium production appears to represent an important share of U.S. consumption.[39] Magnesium in the United States is primarily used in castings (nearly half of reported U.S. consumption) particularly for the auto sector, followed by aluminum-based alloys for packaging and transportation (35 percent), and iron and steel desulfurization (16 percent).[40] For magnesium that has been processed from existing products through recycling (secondary magnesium), nearly 70 percent was used to produce aluminum alloys and the remainder for structural uses.[41]

In the United States, the predominant source of primary magnesium production is U.S. Magnesium's facility at the Great Salt Lake in Utah, which uses electrolysis to derive magnesium from the saltwater of the lake.[42] Although production figures are not available for U.S. Magnesium production, estimates range from a production capability of 42,000 to 65,000 tons annually, the majority of which is consumed domestically.[43] U.S. Magnesium's primary magnesium production temporarily reduced some of its

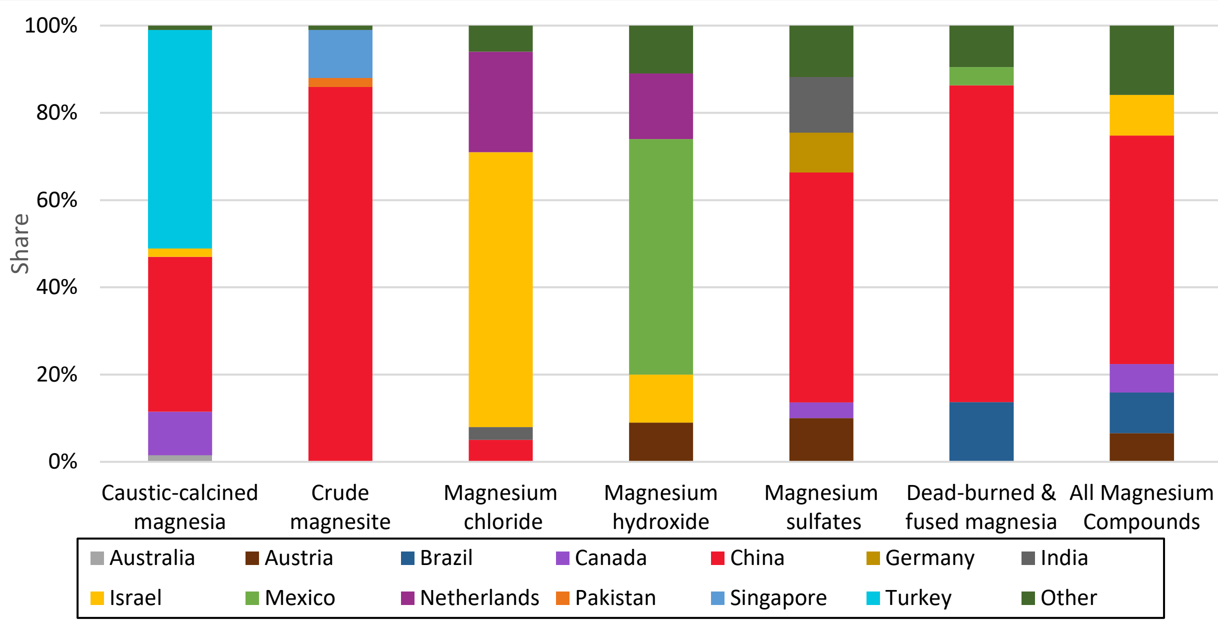
[33] Interview with government representative, November 18, 2021.
[34] Interview with government representative, November 18, 2021.
[35] Interview with government representative, November 18, 2021.
[36] Interview with government representative, November 18, 2021.
[37] Ehrenberger, *Carbon Footprint of Magnesium Production*, October 2020, 8.
[38] Light Metal Age Magazine, "Magnesium Market Outlook Is Solid," August 3, 2016.
[39] USGS, *Magnesium Metal*, January 2021.
[40] USGS, *Magnesium Metal*, January 2022.
[41] USGS, *Magnesium Metal*, January 2022.
[42] USGS, *Magnesium Metal*, January 2022.
[43] Interview with government representative, November 18, 2021.

capacity early in 2016 due to the shutdown of a neighboring titanium sponge plant.[44] Previous facilities in Oregon and Louisiana used seawater, a more diluted raw material, to isolate magnesium, but they were reportedly less competitive than the U.S. Magnesium production processes in the Great Salt Lake and shut down several decades ago.[45]

U.S. primary magnesium consumption not met by U.S. magnesium production is supplemented by imports from a variety of sources. During the period from 2017–20, Canada was the largest source of U.S. imports of magnesium (20 percent of imports on average), followed by Israel (15 percent), and Mexico (11 percent).[46] This mix of import sources contrasts with other markets, in some cases substantially. The European Union, for example, reportedly imports more than 90 percent of its primary magnesium from China, though the EU maintains domestic secondary magnesium production.[47]

With respect to magnesium compounds, U.S. production is also largely derived from seawater and saltwater brines, though production is more diverse over a variety of producers in several states. According to the United States Geological Survey (USGS), 2021 production of magnesium oxide and other compounds came from at least one company each in California, Delaware, Michigan, and Utah.[48] China appears to be the largest source overall for U.S. imports of magnesium compounds, though this can vary significantly based on the type of magnesium compound (figure 2).

Figure 2: U.S. magnesium compound imports by largest import sources, by type, 2016-19 (percent)



Source: USGS, Magnesium Compounds, January 2022.

[44] Titanium is extracted via the Kroll Process to produce magnesium sponge is a reaction that involves the reduction of magnesium. National Minerals Information Center, "Magnesium Statistics and Information," 2021.

[45] Interview with government representative, November 18, 2021.

[46] USGS, *Magnesium Metal*, January 2022.

[47] Global Times, "GT Voice: Magnesium Shortage Highlights Need for Global Coordination," October 25, 2021.

[48] USGS, *Magnesium Compounds*, January 2022.

Contemporary Supply Chain Challenges

At the onset of the COVID-19 pandemic, many commodities faced significant price fluctuations, due to a variety of factors such as labor constraints, factory shutdowns, and supply chain disruptions. Additionally, several other elements, such as expectations regarding existing capacities and anticipated demand for certain products, also played a role in commodity disruptions. Magnesium was no different; according to USGS, pricing for magnesium in 2020 fluctuated in both the United States and Europe due to an initial expectation that magnesium production would decline in China due to smelter shutdowns (which caused pricing to go up). However, the anticipated pricing increase was largely tempered due to an expectation that consumer demand for finished products using magnesium would decline in the short term (which caused prices to then go down).[49]

These slight price fluctuations were short-lived in both the United States and Europe in 2020, with prices stabilizing in both markets. However, in fall 2021, global prices for magnesium began to rise substantially, far exceeding any rise in 2020. Between July 1 and October 1, 2021, the spot price of magnesium in the Chinese market (both the largest consumer and producer of magnesium) rose by 90 percent from 19,850 yuan/ton ($3,097/T) to a peak of 71,250 yuan/ton ($6,439/T).[50] This rise is more remarkable when looking at the course of the entire year; from January to October 2021, the price of magnesium in the Chinese market rose nearly 160 percent, and at its peak in late September was more than 330 percent higher than when it began the year (figure 3).[51]

Figure 3. Spot price for magnesium in the Chinese market, 2018-21 (in Chinese Yuan)

Source: Trading Economics, "Magnesium," accessed January 3, 2022.

[49] USGS, *Magnesium Metal*, January 2021.
[50] Trading Economics, "Magnesium," December 2021.
[51] Trading Economics, "Magnesium," December 2021.

Given the concentration of primary magnesium production in China, many of the supply chain challenges which emerge in the magnesium sector derive from production challenges or developments in China.[52] The initial rise of magnesium prices in early 2021 was determined to be derived—in part—from the rising cost of ferrosilicon and coal in China.[53] According to one industry representative from a firm that supplies components to Chinese magnesium producers, between 2020 and 2021 the price of raw coal rose 3-fold, while the price of ferrosilicon rose slightly more than 3-fold in the same period.[54]

The price spike in magnesium during 2021, and subsequent concern from downstream users, appears to be directly related to energy policy enforcement developments in China, adding to ongoing challenges from the COVID-19 pandemic.[55] Magnesium production requires extensive energy—one estimate notes that it takes between 35 and 40 megawatt-hours to produce 1 ton of magnesium, equivalent to powering about ten to twelve thousand homes for an hour. To meet annual emissions targets, Northwest China's Shaanxi Province reportedly curtailed magnesium production in the later summer/early fall—a realization of the industry concerns voiced in 2020. According to one industry report, magnesium production in Yulin (which accounts for more than 60 percent of China's magnesium production) was reduced by 60 percent in September, while another industry producer notes his firm essentially stopped production for a 10-day period.[56] While production appeared to have resumed at conventional levels by October for some facilities, Chinese magnesium exports were expected to fall by up to 10 percent in 2021 due the production curtailments in the fall.[57]

When downstream consumers of magnesium, particularly the auto sector, realized that magnesium supplies could greatly decline during the later months of 2021, a substantial response from the industry followed. In early October, German auto manufacturer Volvo noted that a lack of magnesium supply would represent a "significant risk" to both production and profitability.[58] In mid-October, twelve business groups in European auto, metals, and packaging sectors noted an "imminent risk of Europe-wide production shutdowns" due to magnesium stocks that would only last until November (magnesium is difficult to stockpile because it begins to oxidize after 3 months).[59] Germany and the Czech Republic (two countries with significant auto and auto parts production), specifically Angela Merkel and Andrej Babis, both noted that magnesium disruptions could have a significant impact on the EU auto sector, particularly as Chinese production supplies more than 90 percent of European consumption.[60] Canadian metal

[52] It should be noted that on September 29, 2021, U.S. magnesium declared a force majeure due to equipment failures. Further details, including an expected restart date and the effect on capacity were not reported. This further compounded the tight magnesium metal supply occurring globally. USGS, *Magnesium Metal*, January 2022.
[53] China Nonferrous Network, "Global Magnesium Production and Demand," September 7, 2021.
[54] Xinhua News Agency, "China's 'Magnesium Capital' Strives to Ensure Global Supply," October 29, 2021.
[55] China Nonferrous Network, "Global Magnesium Production and Demand," September 7, 2021.
[56] Finally, another industry report noted "the local government ordered roughly 35 of its 50 magnesium smelters to close until the end of the year and told the rest to cut production by 50 per cent in order to hit energy consumption targets." Global Times, "GT Voice: Magnesium Shortage Highlights Need for Global Coordination," October 25, 2021; Hume, "China's Magnesium Shortage Threatens Global Car Industry," October 19, 2021.
[57] GT staff reporters, "Chinese Magnesium Exports Likely to Drop," October 24, 2021.
[58] Hume, "Volvo Cars Signals Alarm About Magnesium Shortage," October 25, 2021.
[59] Unlike some other metals like copper and steel, magnesium is often difficult to stockpile because it begins to oxidize after 3 months. Interview with government representative, November 18, 2021; Hume, "Volvo Cars Signals Alarm About Magnesium Shortage," October 25, 2021.
[60] Bounds and Khan, "EU Leaders Warn of Risk to Industry," October 22, 2021.

producer Matalco also told its clients that its magnesium supply had "dried up" and if disruptions continued it would have to curtail aluminum production.[61]

However, while the U.S. auto and other magnesium-incorporating industries expressed concerns similar to their European counterparts, their responses were muted compared to those of the EU industry. U.S. automakers Ford and General Motors noted that a magnesium shortage could potentially threaten auto production, though the threat of a magnesium shortage was presented in the context of a variety of other supply chain issues.[62] Additionally, while EU automakers and drink can manufacturers urged the European Commission to act by directly engaging with Chinese officials, similar efforts did not appear to occur publicly in the United States by U.S. firms.[63]

This divided response in the urgency from downstream consumers on magnesium supply chain issues from China may derive largely from the differing supply chains which supply primary magnesium to Europe and the United States. As the U.S. Production, Imports, and Uses section above noted, there are two distinct differences between the two markets: (1) the United States continues to maintain domestic manufacturing of primary magnesium (whereas the European Union does not); and (2) the United States sources its imports from a variety of countries, while Europe sources almost its entire supply from China. While secondary magnesium production in both markets creates a small domestic production capacity, this is likely not currently sufficient to meet the demands of auto or packaging manufacturers in either the European Union or the United States.

Future Outlook and Conclusion

Reserves for magnesium remain plentiful and exist in a variety of minerals (particularly dolomite and magnesite), saltwater sources (e.g., seas or lakes), and in naturally occurring magnesium salt deposits. However, isolation of magnesium from said sources into primary magnesium is energy-intensive and production is significantly concentrated among a handful of markets. Projects to expand production remain ongoing in the United States, Canada, Eastern Europe and Central Asia, though at the end of 2021 additional capacity has not yet been achieved in a globally significant way. One factor that may influence firm investment decisions in expanding primary magnesium production is potential future demand of magnesium. Both contemporary usage (primarily in aluminum alloys for autos, aerospace, and packaging) and new uses (such as batteries), could expand downstream demand and ultimately impact future investor interest in increasing production both in and outside of China.

For existing uses, there is evidence to suggest that demand for magnesium containing alloys (particularly titanium and aluminum) will continue to grow. One industry report noted that the rise of titanium alloyed with magnesium carbonate will contribute significantly to increased magnesium demand, with an estimated annual growth of at least 5 percent in this market segment through 2027.[64] With magnesium-aluminum alloys already contributing to existing large industries (reportedly 25 percent of global transport, 21 percent of construction, and 35 percent of the packing sectors incorporate aluminum alloyed with magnesium), several industry reports note the magnesium-based alloys likely will be a major

[61] Hume, "China's Magnesium Shortage Threatens Global Car Industry," October 19, 2021.
[62] GM Authority, "Magnesium Shortage Could Affect Auto Industry," October 21, 2021.
[63] Indexbox, "Approaching Magnesium Deficiency Threatens to Disrupt," October 27, 2021.
[64] Coherent Market Insights, "Magnesium Metal Market Size," 2021.

contributor to short term magnesium demand, following the dip in demand due to the COVID-19 pandemic.[65]

Beyond existing uses for magnesium, potential new downstream demand may emerge as technologies incorporating magnesium move from research and development to market introduction. Electric vehicle designs, for example, are expected to incorporate magnesium extensively in aluminum frames and other components due to its ability to lighten car weight and increase vehicle range, while there have been some expressions of industry interest in incorporating magnesium-alloyed aluminum into commercial aircraft designs.[66]

One potentially significant future market channel for magnesium is the development and commercial production of magnesium-based batteries.[67] An industry representative noted that the introduction of a magnesium-based battery, which would compete with lithium-based batteries in vehicles as well as other advanced technology and machinery, could substantially increase demand for magnesium.[68] Described by one industry publication as the "holy grail" of the battery industry, by one estimate a magnesium-based battery mass produced for downstream consumption could increase global magnesium demand by as much as ten-fold.[69]

The time horizon for some of magnesium's future and/or expanded uses is years long. In the short-term, both planned and unplanned shutdowns in China may lead to sustained price fluctuations for primary magnesium.[70] It is possible, if consumers become accustomed to a new reality (i.e., shutdowns to meet emissions targets) that downstream users of magnesium may be able to better plan for such moments; however, this type of planning (through short-term stockpiling, etc.) has yet to occur.

[65] Mordor Intelligence, "Metal Magnesium Market," accessed January 10, 2022.
[66] Mordor Intelligence, "Metal Magnesium Market," accessed January 10, 2022.
[67] Interview with government representative, November 18, 2021.
[68] Smith, "Magnesium Batteries," *Advanced Science News* (blog), November 5, 2019.
[69] Argonne National Laboratory, "'Holy Grail' for Batteries," 2017.
[70] See [Contemporary Supply Chain Challenges.]

Appendix A
Data for Figures

Table A.1 U.S. magnesium compound imports by largest import sources, by type, 2016-19 (percent)
Underlying data for figure 1.

Country	Caustic-calcined magnesia	Crude magnesite	Magnesium chloride	Magnesium hydroxide	Magnesium sulfates	Dead-burned & fused magnesia	All Magnesium Compounds
China	71	86	5	0	58	69	56
Canada	20	0	0	0	4	0	7
Australia	3	0	0	0	0	0	0
Israel	4	0	63	11	0	0	10
Singapore	0	11	0	0	0	0	0
Mexico	0	0	0	54	0	4	0
Netherlands	0	0	23	15	0	0	0
Austria	0	0	0	9	11	0	7
India	0	0	3	0	14	0	0
Germany	0	0	0	0	10	0	0
Turkey	0	0	0	0	0	5	0
Pakistan	0	2	0	0	0	0	0
Brazil	0	0	0	0	0	13	10
Other	2	1	6	11	13	9	17

Source: USGS, Magnesium Compounds, January 2022.

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