Global Magnesium Mining and Processing

Environmental and Social Impacts



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History of Magnesium (Mg)

- **Magnesium is one of the elements essential to all cellular life**, including being an important element in chlorophyll and in about 300 enzymes in the human body[2]
- Human discovered magnesium compounds as early as the seventeenth century[3]
- While some scientists later suspected that some of these compounds contained a new element[4] what would later be called magnesium could not be extracted with the technology available at that time because of the strong bond between it and other atoms like oxygen[3]
- **Magnesium was first isolated as a pure element in 1808**[5] and named after Magnesia, a district of Thessaly (Greece) where the mineral magnesia alba was first found

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Uses

- **Magnesium is produced in the form of magnesium compounds as well as by itself (what is referred to by the United States Geological Survey (USGS) as "magnesium metal")**
- The major uses of magnesium metal are: aluminium alloys, die casting and steel desulphurisation[6]
- Magnesium metal has the advantages of[3]
  - light weight
  - high specific strength
  - good ductility
  - good damping and machinability
  - a strong electro-magnetic shielding effect
  - good shock absorption
  - good thermal conductivity and thermal fatigue performance, and
  - is easy to recycle
- **Magnesium alloys are used in small and portable electronic applications such as camera, cell phone and laptop for its lightness combined to strength and durability**, e.g. to replace plastics[7]
- Many electronics require parts or casings with complex shapes which are possible with magnesium[7]

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Abundance

- Magnesium is easy to find; it's estimated to be the ninth most common element in the universe[2]
- **It is also the eighth most abundant element and constitutes about 2 percent of the Earth's crust**[5] and 13% of the planet's mass[8]

Table 1.1 Distribution of chemical elements in the earth's crust

Element	Mass content/%	Element	Mass content/%
Oxygen	48.06	Calcium	3.45
Silicon	26.30	Sodium	2.74
Aluminum	7.73	Potassium	2.47
Iron	4.75	Magnesium	2.00
Hydrogen	0.76	Other	0.76

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- In addition, magnesium is present in seawater[3].
- Although seawater is only approximately 0.13% magnesium, given the volumes of oceans, salt lakes, etc., **magnesium resources are virtually unlimited**[1]

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Deposits and Reserves

- **Magnesium resources (both ores and seawater) are are globally widespread**[1]
- Magnesium is highly reactive element and can only exist in nature in the form of compounds because of its high chemical activity[3]
- There are over 80 minerals that have more than 20% Mg within their crystal structure[9]
- **Dolomite is the raw material for the majority of the magnesium plants in China**; it is also used in Turkey and Brazil[7]
- Magnesite mineral (MgCO3) deposits are fairly widespread but high-purity deposits of adequate size are uncommon[7]

Some commonly-mined magnesium-containing ores to create magnesium metal are magnesite and dolomite:[8]

Table 1. Main sources of magnesium minerals.

Type of Mg source	Wt.%, Mg (theoretical Mg content)	Formula
Carnallite	8.7	$KMgCl_3 \cdot 6H_2O$
Magnesite	47.6	$MgCO_3$
Dolomite	22.0	$CaCO_3 \cdot MgCO_3$
Brucite	69.0	$Mg(OH)_2$
Olivine	19.0	$Mg_2Fe_2SiO_4$
Bischofite	11.9	$MgCl_2 \cdot 6H_2O$

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Criticality

- China is one of the countries with the most abundant magnesium resources in the world, with total reserves accounting for 22.5% of the world's total[3]
- In addition, **China produces around 87 per cent of the world's magnesium**[11]
- In fact, Fugu County in Shaanxi province is China's "Magnesium Capital". This county produced more than 40% of the global magnesium production[12]
- **So despite widespread and unlimited Mg sources, magnesium was designated a critical material by the EU Commission in 2017 due to the absence of primary production in Europe**[8]
- Norway, for example, stopped producing the mineral because they were unable to compete with lower costs of Chinese producers[8]
- Overall, five regions in the world, including European Union, the United States, Japan, and South Korea, have listed magnesium as one of the critical resources[12]

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Supply Risk Issues

- The Chinese government has been trying to curb domestic power consumption and regulate soaring electricity prices. **In 2021, many magnesium plants were either shut down or halved their production capacities due to the power cuts**[11]
- This action is in part in support of China's attempt to hit peak coal usage by 2025, on its road to carbon neutrality by 2060[13]
- It was also due to drought in hydro-rich Yunnan province and high coal prices[13]
- In addition to the magnesium production itself, the producers of ferrosilicon from the coal process—which is used in the Chinese magnesium production process—was also targeted for limited production[13]
- Clearly, **China's magnesium production can significantly influence the global magnesium supply**[12]
- The price of Mg, which in recent years oscillated around $2,000 per tonne, raised to more than $11,000 during the 2021 shutdown[8]

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Supply Risk Issues (cont.)

- **Stockpiling isn't an option. Magnesium starts to oxidize after three months if simply put in storage requiring ongoing production to meet needs**[8]
- Production was also reduced at the only U.S. primary magnesium smelter. In September 2021, the only U.S. primary magnesium smelter producer declared force majeure on supply contracts, citing equipment failures[1]

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Mining and Processing

World Primary Production and Reserves:

	Smelter production	
	2021	**2022[e]**
United States	W	W
Brazil	20	20
China	[e]930	900
Israel	18	20
Kazakhstan	16	15
Russia	[e]58	50
Turkey	13	13
Ukraine	10	2
World total (rounded)[7]	1,070	1,000

- **Both dolomite and magnesite are mined and concentrated by conventional methods.** Magnesium-bearing ores are worked by open pit methods, although narrow and deep deposits may be worked by underground drifts and stopes[7]
- **In China, 11.6 kg of ore is used to produce 1 kg of Mg[14]**
- Magnesium is produced and processed in relatively small quantities throughout the world, compared to aluminum. Annual magnesium production has been around 500–700,000 metric tons per year, whereas aluminum is produced annually up to 35 million metric tons[15]
- **Magnesium production is a capital-intensive business and the ability of proposed projects to get off the ground will depend at least in part on the price of magnesium**. Given the availability of substitutes, the demand for magnesium is also price sensitive[6]

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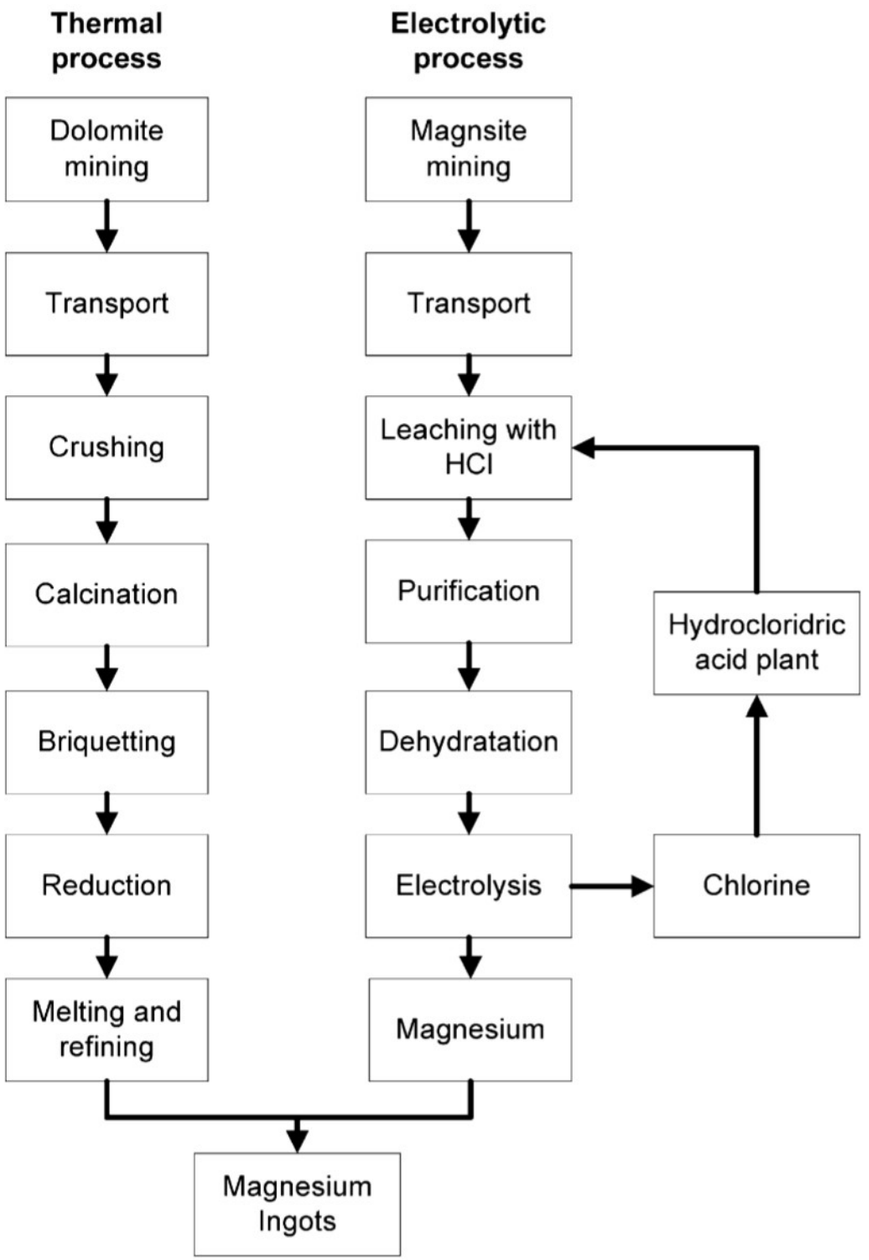


Fig. 1. Simplified process chart of primary magnesium production via thermal and electrolytic process.

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Production Process

- **The Pidgeon process (thermal) and the electrolysis processes are still the two main magnesium metal production methods, which depend on the type of ore being used**[3]
- Electrolysis once accounted for approximately 75 percent of world magnesium production but as China became the top global magnesium producer, the low cost of labour and energy there allowed the Pidgeon process to be economically viable despite being less efficient than electrolysis
- **At present, magnesium metallurgy via the Pidgeon process accounts for nearly 95% of the total magnesium production in China**[16]
- The Pidgeon process makes use of resources such as dolomite, coal, and ferrosilicon in the central and western regions of China[3]
- In recent years, Shannxi Province has developed a circular industrial chain of using the exhaust gas of a coal production facility to produce ferrosilicon and then using ferrosilicon to reduce metal magnesium, achieving great cost savings[3]
- **Typical usage of ferrosilicon material is 1.08–1.2 tons of ferrosilicon per ton of magnesium**[17]
- Primary magnesium metal contains a minimum of 99.8 percent magnesium, which is of sufficient purity for most applications. Higher purity can be obtained by distillation[5]

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Magnesium Slag and Dust

- **However, for every tonne of metallic magnesium that was produced via smelting, approximately 6.5–7 tonnes of magnesium slag are produced**[3]
- Magnesium slag is a gray alkaline block or powder that is produced in the process of preparing magnesium[3]
- Its small particle size makes it difficult to manage and disperses easily into the air[18]
- **Soil covered with magnesium slag is easy to harden. The land and surrounding areas on which magnesium slag has accumulated can no longer be used for agricultural cultivation**[3]
- When magnesium slag enters rivers and groundwater systems with rainwater leaching and infiltration; this can change the pH of a water body and seriously affect the ecological security of water resources[3]
- In addition, **magnesium slag easily causes dust pollution. They are easily inhaled into the respiratory tract and can cause respiratory diseases.** In addition, the dry and windy climate of the northern region of China exacerbates the severity of damage[3]

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Emissions

- Most magnesium plants in China use coal as fuel. **The production of every 1 t of magnesium consumes 8–12 t of high-quality coal (including the production of ferrosilicon[19], releasing 37 kg of CO2 gas**[20]
- **In addition to the coal-combusting pollution and dust, the main pollutants that are generated during the process include CO2, SO2, HF. Every tonne of magnesium that produced produces 24–34 kg of HF and 85–110 kg of particulate matter**[16]
- In China, the detected fluorine content in the magnesium slag leaching was more than 10 times the national standard[16]
- The current practice of using sulphur in casting operations in China, despite alleviating greenhouse gas emissions, has other drawbacks. Owing to the high temperature of the molten metal, the dispersed sulphur over molten metal surface oxidises to form SO2 and SO3 gases[14]
- **In the US, a settlement was made between EPA, DOJ and a magnesium metal producer in Utah in 2021 to ensure it treats its waste streams to remove dioxins, furans, hexachlorobenzene and PCBs to reduce environmental impacts from its operations**[21]

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Previously, Sulfur Hexaflouride Emissions

- **The use of sulfur hexafluoride (SF6)** - which has about 23,800 times the global warming potential of CO2 over a 100 year time horizon[22] - as a cover gas for molten magnesium to prevent oxidation **has apparently been stopped in magnesium production in China as of 2010**[23]
- **Unfortunately, with a long atmospheric residence time of 3200 years, almost all the SF6 released so far will have accumulated in the atmosphere and will continue to do so**[23]

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Energy Use

- The current, state-of-the-art Pidgeon process is known for consuming a massive amount of energy per production batch[24]
- **Scientists estimated the global warming impact of producing magnesium metal in China to be ~60% higher than producing aluminum**[24]
- The main reason for this is the low reduction rate of MgO during the reduction process, which is about 80% and has not been greatly improved upon to date[19]
- **Having said that, magnesium energy use does vary by country**:[8]
- Note some comparison estimates of metals still place aluminum at having more GWP than magnesium[25]

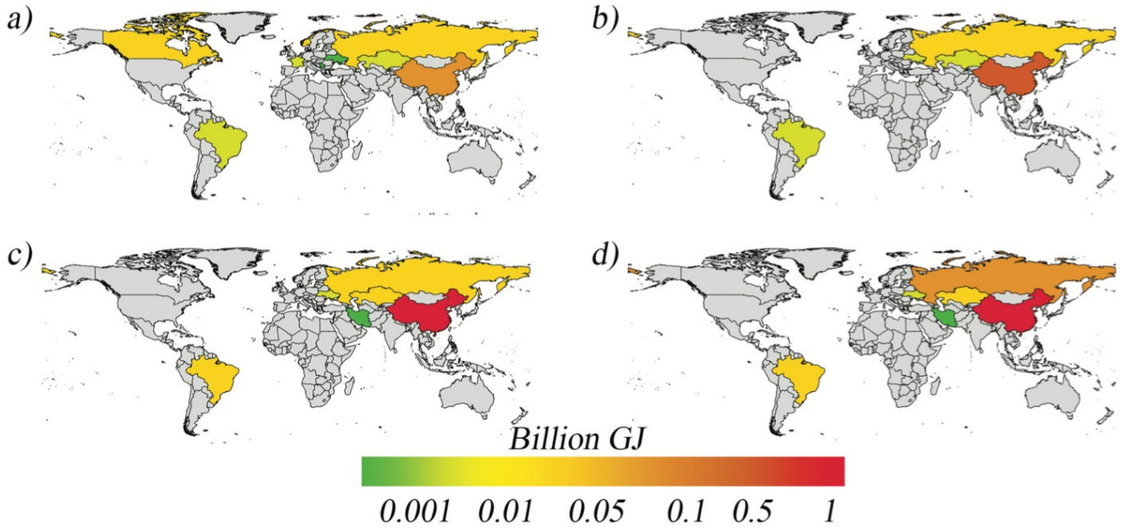


Figure 4. Global energy consumption of primary production of magnesium in mining stage in (a) 2000 (b) 2010 (c) 2020, and (d) 2050.

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Water Use

- **Primary production of magnesium uses a considerable amount of water in different processes such as mineral processing, dust suppression, etc.**[8]
- In most mining operations, water comes from groundwater sources, streams, rivers, lakes, or commercial water service suppliers[8]
- **Considering the water material intensities, the Pidgeon, Magnetherm and in part AM processes have high water factors; this means that they should be performed in areas where water supplies are easily accessible and abundant**[6]
- A US magnesium producer in Utah applied for a permit in 2023 to extend Great Salt Lake intake into deeper water, but the permit was denied by State regulators. The producer stated that the declining water level after several years of drought threatened to disrupt production[1]
- **Most industrial fresh water in Mg production is used for cooling the equipment and can be recycled or used for other purposes after purification**[8]

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Environmental Impacts

- When the stratum containing the dolomite is older, the content of MgO in the ore is higher. **Dolomite rocks that are hard can therefore withstand weathering better than many other rocks. So, they are usually found at high positions, and mining usually begins with large-scale blasting**[3]
- **Soils in northern China near (dolomite) magnesium processing sites are covered with a hard-white crust from magnesium slag dust**, which affects ecological functions of soil particularly by reducing the water penetration rate[26]
- **In Slovakia**, scientists recorded significant differences in species richness and the species pools in all organism groups along the gradient in magnesite processing areas, including a **decrease in overall species diversity**[27]
- **Unfortunately, switching to seawater isn't a great option either.**
- **Brine disposal has negative environmental impacts**, as it contains up to twice as much salt as seawater, in addition to chemicals added in the pretreatment and membrane cleaning processes which might be toxic to marine organisms[28]
- Also, because of the higher density compared to seawater, the brine slides towards the seabed, exposing marine organisms from the discharge point to the bottom of the seabed[28]

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Recycling

- Most uses of magnesium compounds [i.e. the non-metal magnesium uses] are dissipative, so the material cannot be recovered[5]
- Recycled magnesium (metal) retains the same chemical, physical, and mechanical characteristics before it was recycled. Additionally, it has been calculated that **recycling magnesium only consumes 5% of the energy needed to produce it**[24]
- **The recycled content of magnesium was estimated to be 33% in 2004, similar to that of aluminum**[10]
- When aluminum beverage cans are recycled, this conserves both the aluminum and magnesium content of the alloys as well as the energy required to produce them[22]
- **A significant amount of recycled magnesium comes from post-industrial recycling, not post-consumer recycling**[8]

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Summary

- Magnesium (Mg) is produced in the form of magnesium compounds as well as by itself as magnesium metal. The metal has multiple useful qualities including being lightweight
- Magnesium resources are virtually limitless given its presence in seawater, although currently the metal is usually produced from ore
- Despite its abundance, Mg is a critical mineral for multiple countries due to China producing around 87% of the world's magnesium
- This supply risk became clear in 2021 when China shut down many processing plants to hit annual carbon emission targets
- All Mg production processes create magnesium slag, a dust which is hard to control and lands on the ground, forming a crust which is detrimental to plant life
- In addition, China's use of coal creates various emissions problems; and some scientists estimated the global warming impact of magnesium metal in China to be ~60% higher than aluminum
- Recycling could provide benefits (e.g. only 5% of energy), but good systems for post-consumer magnesium recycling don't exist. Most Mg is recycled when aluminum beverage cans are recycled, as it is included there as an alloy, or from pre-consumer industrial scrap.

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Thank you

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References (1 of 3)

[1] USGS. (2023). Magnesium (Metal)—Commodity Summary. https://pubs.usgs.gov/periodicals/mcs2023/mcs2023-magnesium-metal.pdf

[2] Bamberger, L. A. D., George E. Totten, Menachem. (2019). The Importance of Magnesium and Its Alloys in Modern Technology and Methods of Shaping Their Structure and Properties. In Magnesium and Its Alloys. CRC Press. https://doi.org/10.1201/9781351045476-1

[3] Wu, L., Han, F., & Liu, G. (2021). Overview of Magnesium Metallurgy. In L. Wu, F. Han, & G. Liu (Eds.), Comprehensive Utilization of Magnesium Slag by Pidgeon Process (pp. 1–44). Springer. https://doi.org/10.1007/978-981-16-2171-0_1

[4] Friedrich, H. E., & Mordike, B. L. (Eds.). (2006). History. In Magnesium Technology: Metallurgy, Design Data, Applications (pp. 1–28). Springer. https://doi.org/10.1007/3-540-30812-1_1

[5] Kramer, D. A. (2001). Magnesium, its alloys and compounds. US Geological Survey Open-File Report, 1, 341. https://doi.org/10.3133/ofr01341

[6] Cherubini, F., Raugei, M., & Ulgiati, S. (2008). LCA of magnesium production: Technological overview and worldwide estimation of environmental burdens. Resources, Conservation and Recycling, 52(8), 1093–1100. https://doi.org/10.1016/j.resconrec.2008.05.001

[7] European Commission. (2017). Study on the review of the list of critical raw materials: Critical raw materials factsheets. Publications Office of the European Union. https://data.europa.eu/doi/10.2873/398823

[8] Rahimpour Golroudbary, S., Makarava, I., & Kraslawski, A. (2022). Environmental Assessment of Global Magnesium Production. Mineral Processing and Extractive Metallurgy Review, 0(0), 1–18. https://doi.org/10.1080/08827508.2022.2084734

[9] Simandl, G. J., Schultes, H., Simandl, J., & Paradis, S. (2007). Magnesium-raw materials, metal extraction and economics-global picture. 827–831. https://cmscontent.nrs.gov.bc.ca/geoscience/PublicationCatalogue/External/EXT096.pdf

[10] UNEP. (2017). Recycling Rates of Metals. https://www.resourcepanel.org/reports/recycling-rates-metals

[11] Yang. (2021, October 26). Millions of jobs are under threat because China has slashed its magnesium output. ABC News. https://www.abc.net.au/news/2021-10-27/magnesium-shortage-in-europe-and-us-china-slows-down-supply/100570048

[12] Guo, T., Geng, Y., Song, X., Rui, X., & Ge, Z. (2023). Tracing magnesium flows in China: A dynamic material flow analysis. Resources Policy, 83, 103627. https://doi.org/10.1016/j.resourpol.2023.103627

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References (2 of 3)

[13] Home, A. (2021, October 27). Europe's magnesium crunch poses another carbon conundrum. Reuters. https://www.reuters.com/business/energy/europes-magnesium-crunch-poses-another-carbon-conundrum-andy-home-2021-10-26/

[14] Koltun, P. (2004). Global Warming Impact of the Magnesium Produced in China Using the Pidgeon Process. Resources, Conservation and Recycling, 42, 49–64. https://doi.org/10.1016/j.resconrec.2004.02.003

[15] Brown, R. E. (2016). Environmental Challenges for the Magnesium Industry. In W. H. Sillekens, S. R. Agnew, N. R. Neelameggham, & S. N. Mathaudhu (Eds.), Magnesium Technology 2011 (pp. 7–11). Springer International Publishing. https://doi.org/10.1007/978-3-319-48223-1_3

[16] Wu, L., Han, F., & Liu, G. (2021). Comprehensive Utilization of Magnesium Slag by Pidgeon Process. Springer Nature. https://doi.org/10.1007/978-981-16-2171-0

[17] Gao, F., Nie, Z., Wang, Z., Gong, X., & Zuo, T. (2009). Life cycle assessment of primary magnesium production using the Pidgeon process in China. The International Journal of Life Cycle Assessment, 14(5), 480–489. https://doi.org/10.1007/s11367-009-0101-9

[18] Aşkın, A., Tatar, İ., Kılınç, Ş., & Tezel, Ö. (2017). The Utilization of Waste Magnesite in the Production of the Cordierite Ceramic. Energy Procedia, 107, 137–143. https://doi.org/10.1016/j.egypro.2016.12.151

[19] Wu, L., Han, F., & Liu, G. (2021). Magnesium Smelting via the Pidgeon Process. In L. Wu, F. Han, & G. Liu (Eds.), Comprehensive Utilization of Magnesium Slag by Pidgeon Process (pp. 45–68). Springer. https://doi.org/10.1007/978-981-16-2171-0_2

[20] Wada, Y., Fujii, S., Suzuki, E., Maitani, M. M., Tsubaki, S., Chonan, S., Fukui, M., & Inazu, N. (2017). Smelting Magnesium Metal using a Microwave Pidgeon Method. Scientific Reports, 7(1), Article 1. https://doi.org/10.1038/srep46512

[21] US EPA, O. (2021, January 19). U.S. settles with U.S. Magnesium, the largest producer of magnesium metal in the Northern Hemisphere, for alleged illegal disposal of hazardous waste at Rowley, Utah facility (Utah) [News Release]. https://www.epa.gov/newsreleases/us-settles-us-magnesium-largest-producer-magnesium-metal-northern-hemisphere-alleged

[22] USGS. (2001). Magnesium recycling in the United States in 1998 [Circular]. https://pubs.usgs.gov/of/2001/of01-166/of01-166.pdf

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References (3 of 3)

[23] Simmonds, P. G., Rigby, M., Manning, A. J., Park, S., Stanley, K. M., McCulloch, A., Henne, S., Graziosi, F., Maione, M., Arduini, J., Reimann, S., Vollmer, M. K., Mühle, J., O'Doherty, S., Young, D., Krummel, P. B., Fraser, P. J., Weiss, R. F., Salameh, P. K., … Prinn, R. G. (2020). The increasing atmospheric burden of the greenhouse gas sulfur hexafluoride (SF6). Atmospheric Chemistry and Physics, 20(12), 7271–7290. https://doi.org/10.5194/acp-20-7271-2020

[24] Tan, J., & Ramakrishna, S. (2021). Applications of Magnesium and Its Alloys: A Review. Applied Sciences, 11(15), Article 15. https://doi.org/10.3390/app11156861

[25] Nuss, P., & Eckelman, M. J. (2014). Life Cycle Assessment of Metals: A Scientific Synthesis. PLOS ONE, 9(7), e101298. https://doi.org/10.1371/journal.pone.0101298

[26] Jia, C., Allinson, G., Dai, S., & Tai, P. (2022). Formation process and thermodynamic mechanism of the crust in magnesite mining areas. Arabian Journal of Geosciences, 15(7), 580. https://doi.org/10.1007/s12517-022-09849-y

[27] Blanár, D., Guttová, A., Mihál, I., Plášek, V., Hauer, T., Palice, Z., & Ujházy, K. (2019). Effect of magnesite dust pollution on biodiversity and species composition of oak-hornbeam woodlands in the Western Carpathians. Biologia, 74(12), 1591–1611. https://doi.org/10.2478/s11756-019-00344-6

[28] Fontana, D., Forte, F., Pietrantonio, M., Pucciarmati, S., & Marcoaldi, C. (2022). Magnesium recovery from seawater desalination brines: A technical review. Environment, Development and Sustainability. https://doi.org/10.1007/s10668-022-02663-2

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