Clean, Low-Energy Method for Primary Magnesium Metal Production

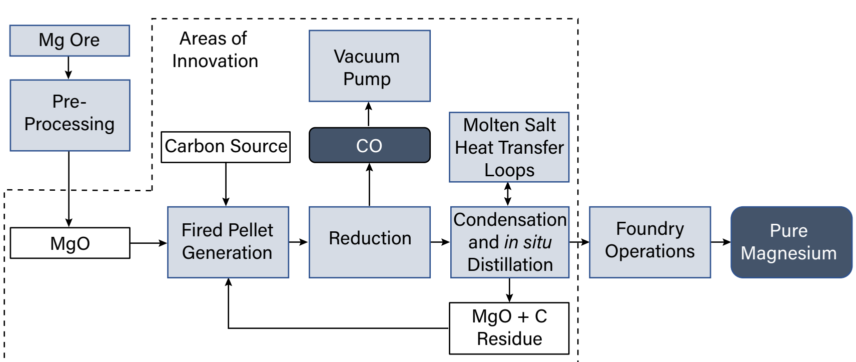
Magnesium metal is a critical infrastructure material commonly associated with structural lightweighting in automotive, aircraft, and portable electronic segments. Currently, China uses the silicothermic Pidgeon process to produce 85% of global Mg metal. This crude process, which emits on average 28 kg CO_{2eq}/kg Mg, is inefficient and polluting, but its low labor and energy costs translate to the lowest metal price. "Although it supported the survival and development of the global magnesium industry, the Pidgeon process has no future due to its carbon footprint," says Alexandru Rosu, the business development lead for private equity investment firm Amerocap LLC's Romanian magnesium project.

Another way to produce Mg metal relies on electrolytic technologies. However, this method has high capital costs and produces toxic dioxins and chlorine compounds, and thus is not a major contributor to world production.

To reduce the cost, emissions, and waste associated with primary production of Mg metal, Colorado-based Big Blue Technologies (BBT), with funding from the National Science Foundation (NSF), is developing a new carbothermal reduction (CTR) method. CTR is a thermochemical approach in which MgO reacts with carbon, liberating Mg gas along with byproduct carbon monoxide. This method is analogous to the silicothermic Pidgeon process where silicon, produced by reducing silicon dioxide with carbon, is then used to reduce MgO to Mg. CTR, in comparison, is a direct production route with fewer steps that consumes about half the energy. Using renewable electricity resources and select raw materials, BBT's process can be nearly net-zero in emissions from ore-to-ingot (0.5–15 kg CO_{2eq}/kg Mg).

Previous attempts to commercialize CTR failed due to difficulties with material handling, refining, and the re-oxidation of metal product during condensation, a problem known as reversion. BBT's process overcomes these hurdles and prioritizes safety.

BBT's process technology relies on metal deposition in a high-temperature condenser with subsequent *in situ* vacuum distillation. In the first step, crude Mg deposits onto the sidewalls of the condenser. Subsequently, the temperature of the condenser is increased (700–750°C) to vaporize the Mg and collect a 99.9% pure metal product. The product magnesium does not require further refining and can be directly alloyed and/or cast into ingots. During this process, fines are captured and oxidized immediately, eliminating the significant safety hazards posed by conveyance of pyrophoric materials.



▲ Big Blue Technologies' carbothermic process for magnesium production relies on a high-temperature condenser in which molten chloride salt is used as the cooling fluid (>350°C).

Process design was driven by three key considerations from prior work at Univ. of Colorado at Boulder: condense at low, but economic, vacuum conditions; condense at relatively high temperatures to facilitate large crystal growth and mitigate pyrophoric fines; and incur relatively short exposure times of the condensate to the CO atmosphere. While the condenser is critical, engineering an integrated system to exploit these principles has been the focus of all prototyping over the past six years.

Today, BBT operates a 50-kW custom-built vacuum arc furnace at 1 kg-Mg/hr and continues to increase production rates. BBT has built out MgO-to-ingot processing capabilities, and is launching a cyclic batch process to demonstrate continuous operation. Using BBT's process data as input, a techno-economic analysis suggests that a commercial system would produce Mg at a cost of <\$2/kg Mg with energy consumption of <15 kWh/kg, which far exceeds current commercial capabilities. In addition, MgO can be sourced from various primary ores as well as industrial waste products.

Mac McCreless, CEO of Garrison Minerals, says, "BBT's process has major implications for reducing emissions in transportation sectors. We've seen the successes of this team and the technology and believe in the capacity to scale this process to meet current market needs in North America, filling a major supply gap." CEP

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