Rare Earth Metals Recycling using a Novel Low-cost Distillation Technology

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Abstract

Recycling has been proposed as a promising potential source of supply to meet some of the US rare-earth demand for use in permanent magnets. The high growth rates of products that make use of rare-earth magnets, particularly wind turbines and electric and hybrid vehicles, show that their stock in use is on the rise and in the near term will become available as scrap feed for recycling. This study presents an overview of magnet recycling technologies and focuses on the technoeconomic analysis of liquid metal leaching and distillation, including the effect of a new continuous gravity-driven multiple effect thermal system (G-METS) metal distillation technology on energy use and overall cost. The G-METS system can potentially reduce the energy consumption of the overall process to 64 kWh/kg, which is about 30% less than metal production from ore and 61–67% less than the process using conventional distillation.

Background

- There are multiple processes for producing new REPMs from old ones.
- In this graph, one can group recycling processes in terms of how many "steps back" they take in the value chain to recover rare earths.

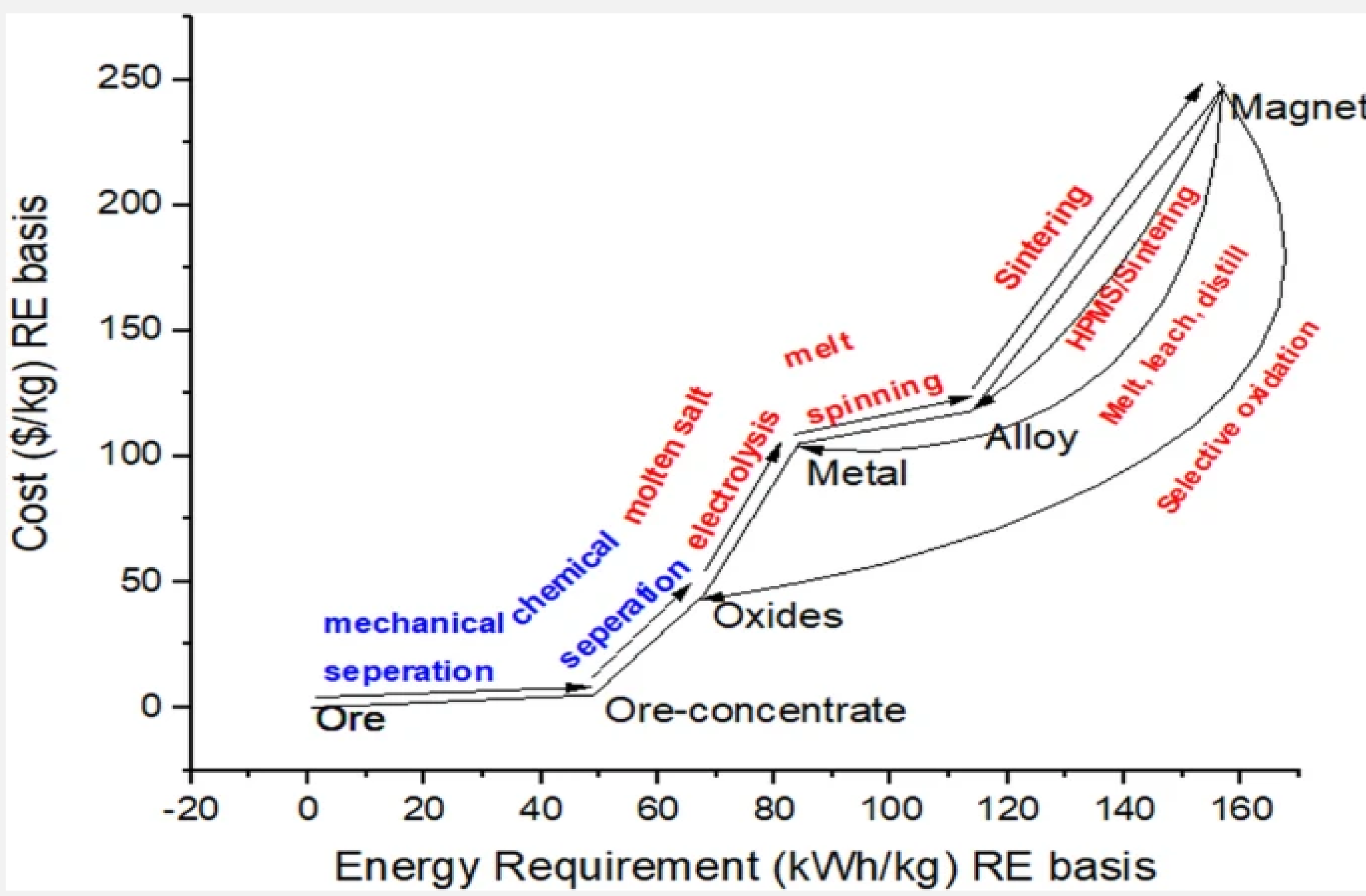

Figure 1: Cumulative energy and cost[19,20,21,22] of various stages of NdFeB magnet production, with alloy production energy use roughly estimated; "RE basis" indicates per kilogram of contained rare-earth metal.

- An essential aspect for understanding the recycling potential of rare-earth elements (REEs) from EoL products is evaluating the quantities of these elements in secondary sources.
- Studies show that a maximum recycling rate of 20% can be reached in at least 10 years with perfect recovery and a continuous growth trend.[3]

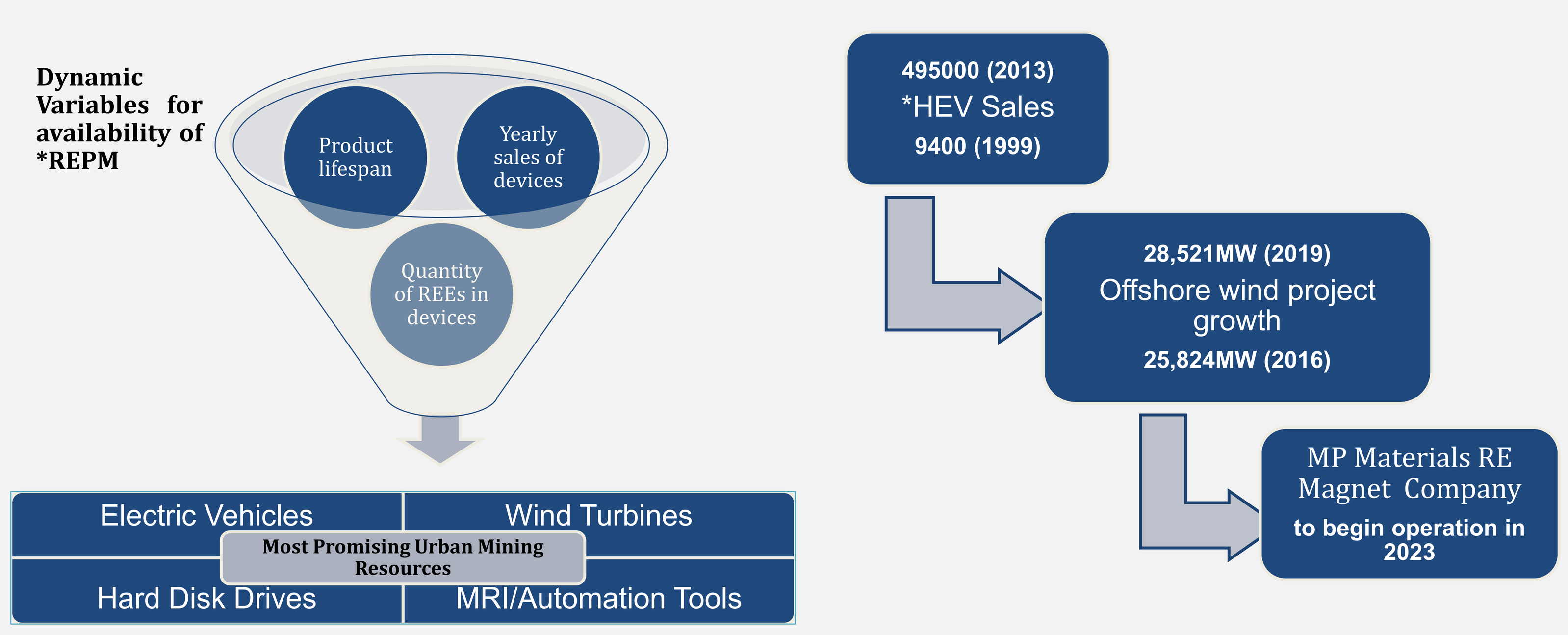

Figure 2: Availability of rare earth permanent magnet scraps for recycling.
*REPM – Rare Earth Permanent Magnet , HEV – Hybrid Electric Vehicles

Methodology

- Techno-economic analysis(TEA) of integrating a novel low-cost distillation technology (*GMETS) into a liquid metal leaching and distillation recycling process was carried out using the ARPA-E Metals tool spreadsheet.
- A process flow diagram was developed to estimate the economic feasibility of the leaching process.
- Mg and Bi were the proposed leaching agents.
- Various adjustable parameters such as the Mg/scrap feed ratio, Bi/leaching vessel waste ratio, and Mg and Bi losses to waste streams were modeled to determine their effects on the overall target recovery and energy use.
- Material requirement, energy requirement and cost analysis were carried out.

*GMETS – Gravity Multiple Effect Thermal System

Model Results

- Figure 3 shows the proportions of each material flow compared with the product flow.
- For a plant with a target of 205 metric tons of RE alloy per year and an additional 11 tons of Dy metal,
  - about 745 metric tons of scrap feed, ~ 149 metric tons of Mg, and 104 tons of bismuth will be required. Magnesium and bismuth are recycled after distillation.

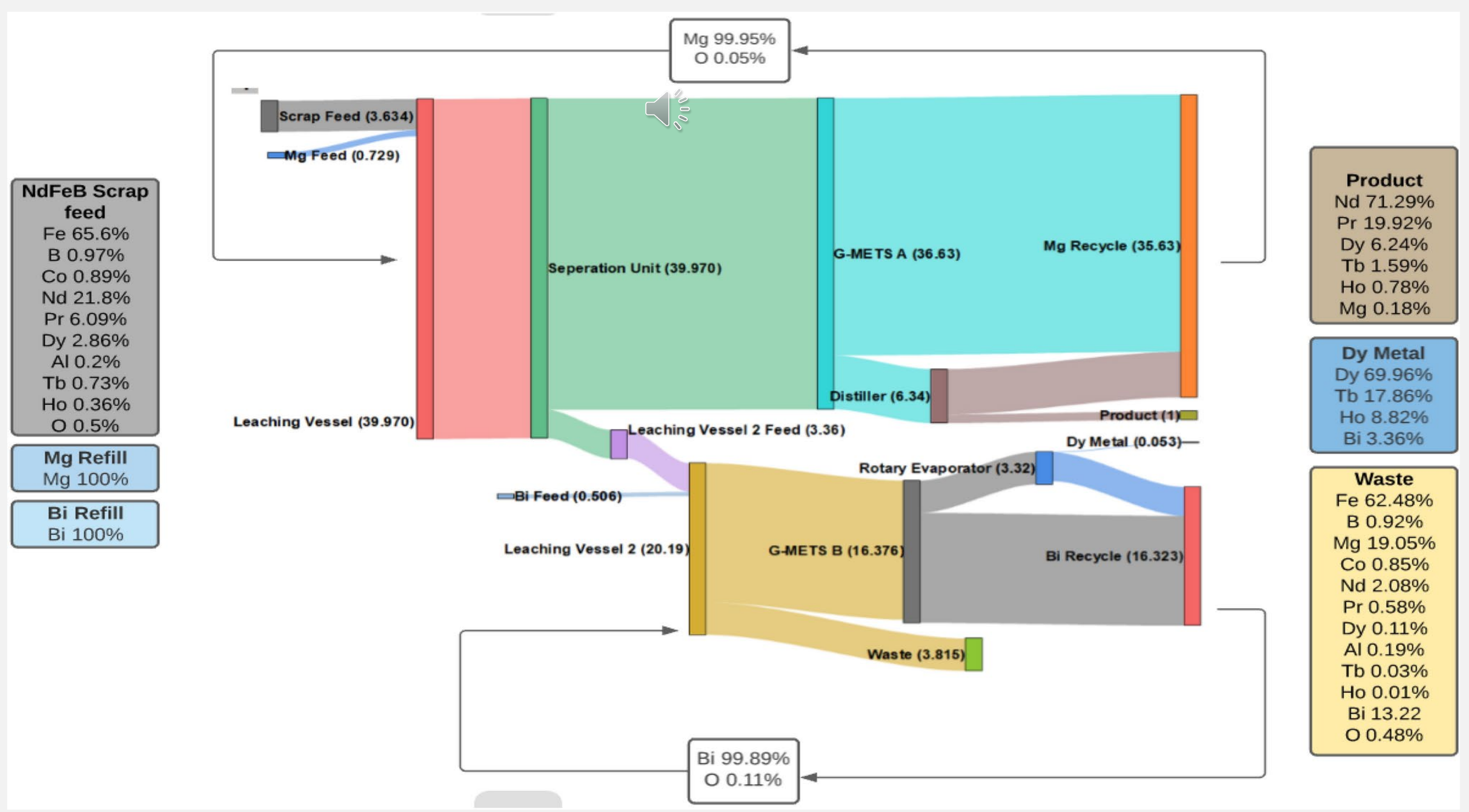

Figure 3: Material balance flow ratios for Mg/Bi leaching and distillation process; mass flow rates in parentheses are ratios to the main product output stream.

- The energy requirement can be seen in figure 4 with a total energy usage of 64.28 kWh/kg of RE (mixed rare-earth metals obtained)
- This increases to 248.1 kWh/kg without G-METS.
- Figure 5 shows the annual operating cost with and without GMETS; this decreases with the integration of the GMETS distillation technology.

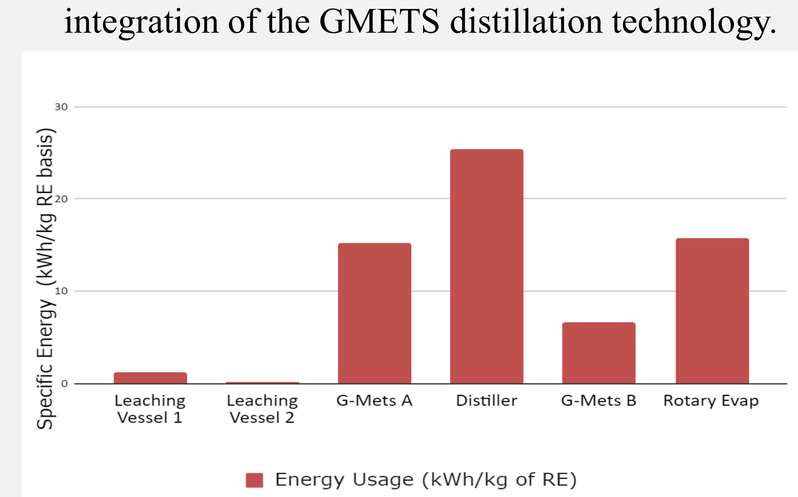

Figure 4: Cumulative energy and cost[19,20,21,22] of various stages of NdFeB magnet production, with alloy production energy use roughly estimated; "RE basis" indicates per kilogram of contained rare-earth metal.

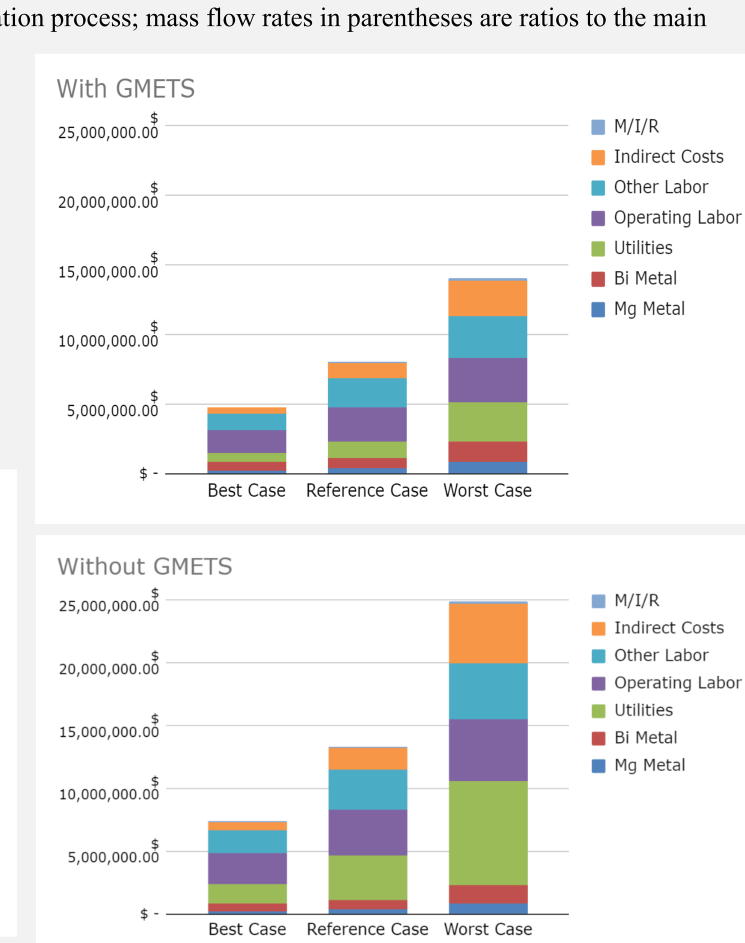

Figure 5: Three annual operating cost stack scenarios for a 205 t/year RE alloy recovery and further 11 t/year of Dy (using bismuth) with and without GMETS as well as conventional distillation. *M/I/R, maintenance/insurance/royalties.

Discussion/ SDGs

- The introduction of the G-METS system has the potential to reduce the energy required and thus the cost of utilities for the process by 67% (for the reference case).
- This thereby reduces the total annual cost and production cost by 40% compared with traditional distillation.
- Rare earth magnet misch metal recovered using our technology will be used in devices for clean energy applications (SDGs 7 and 13).
- We are working to scale-up this recycling process, supporting SDGs 9 and 12.

Conclusion

- TEA of recovery of REEs from NdFeB scrap using a novel G-METS distillation system was performed for a magnesium and bismuth leaching process.
- The G-METS system can potentially reduce the energy consumption of the overall process to 64 kWh/kg, which is about 30% less than metal production from ore and 61–67% less than the process using conventional distillation.
- The processing cost is lowered from $34/kg to $115/kg for the best-case and worst-case scenarios without G-METS distillation, to $22/kg to $65/kg with it.
- The largest operating cost factor is labor, whose cost per kilogram of product would likely decline with increasing scale. These costs compare with today's NdPr metal prices of $100–$120/kg, which would make operating margins much larger with G-METS than without it.
- The G-METS distillation process can therefore be considered a potential enabling technology for liquid metal leaching and distillation.

References

1. T. Akahori, Y. Miyamoto, T. Saeki, M. Okamoto, and T. Okabe, *Magnesium Technol.* 2014, 35. https://doi.org/10.1007/978-3-319-48231-6_10 (2014).
2. G. Gaustad, E. Williams, and A. Leader, *Resour. Conserv. Recycl.* 167, 105213. https://doi.org/10.1016/j.resconrec.2020.105213 (2021).
3. A.C. Powell, *REWAS 2019*, ed. G. Gaustad, C. Fleuriault, M. Gökelma, J. A. Howarter, R. Kirchain, K. Ma, C. Meskers, N. R. Neelameghan, E. Olivetti, A. C. Powell, F. Tesfaye, D. Verhulst, and M. Zhang, (Springer, 2019), p. 9. https://doi.org/10.1007/978-3-030-10386-6_2
4. T. W. Ellis and F. A. Schmidt, Recycling of Rare Earth Metals from Rare Earth-Transition Metal Alloy Scrap by Liquid Metal Extraction, (U.S. Patents, 5,437,709, 1995) https://patents.google.com/patent/US5437709A/en. Accessed May 17 2021.
5. R. T. Ott and R. W. McCallum, Recovering rare earth metals from magnet scrap, (U.S. Patent 10,323,299, Jun. 18, 2019. https://patents.google.com/patent/US10323299B2/en. Accessed May 17 2021
6. A.E. Telgerafchi, G. Espinosa, M. Rutherford, A. Powell, and D. Dussault, *Magnesium* 2021, 145. https://doi.org/10.1007/978-3-030-65528-0_22 (2021).
7. K. Binnemans, P.T. Jones, B. Blanpain, T. Van Gerven, and Y. Pontikes, *J. Clean. Prod.* 99, 17. https://doi.org/10.1016/j.jclepro.2015.02.089 (2015).
8. B. Fernandes, A. Abadias Llamas and M. A. Reuter, *JOM* 72(7), 2754. https://doi.org/10.1007/s11837-020-04185-6 (2020).

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