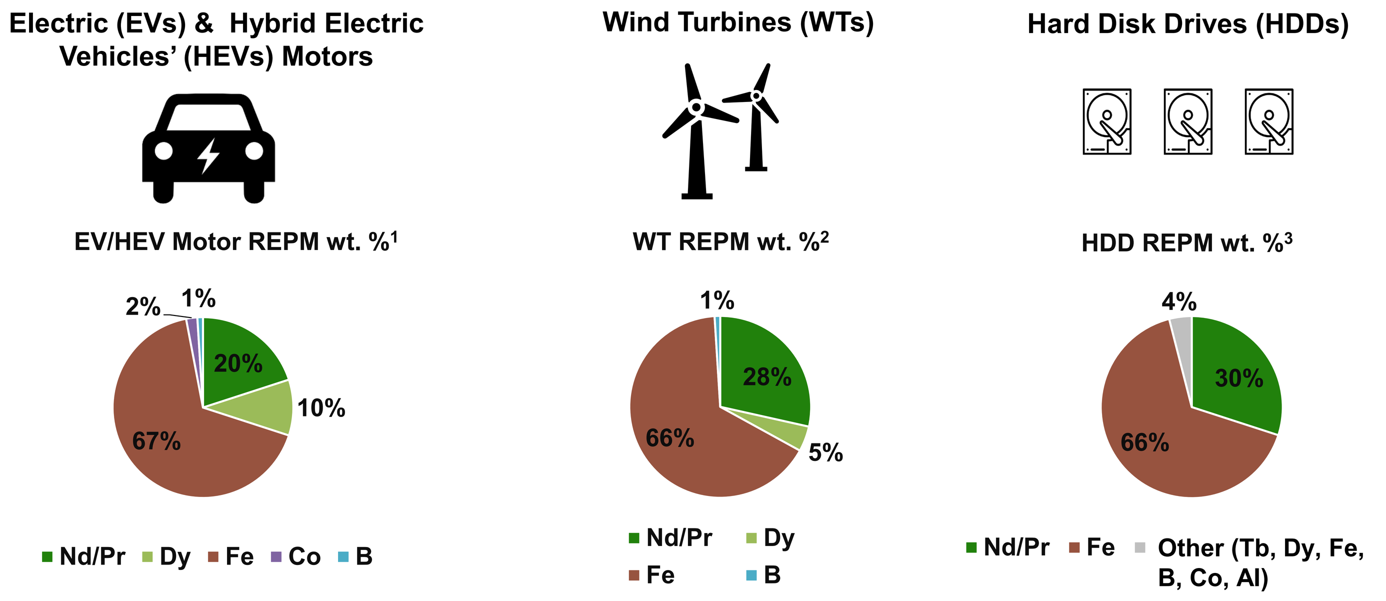
Design and Optimization of Processes for Recovering Rare Earth Elements from End-of-Life Hard Disk Drives

Chris Laliwala and Ana I. Torres

Department of Chemical Engineering, Carnegie Mellon University

Motivation

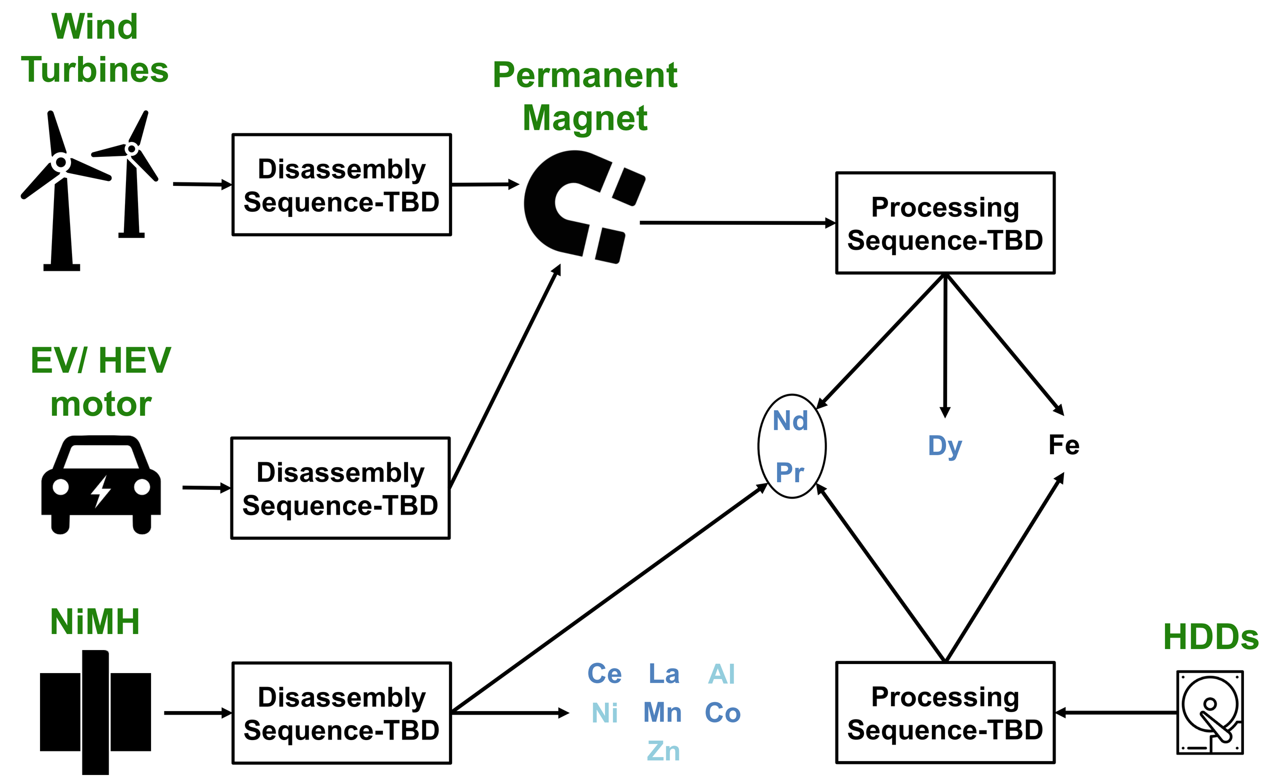
Rare Earth Elements (REEs) are essential to rare earth permanent magnets (REPM)



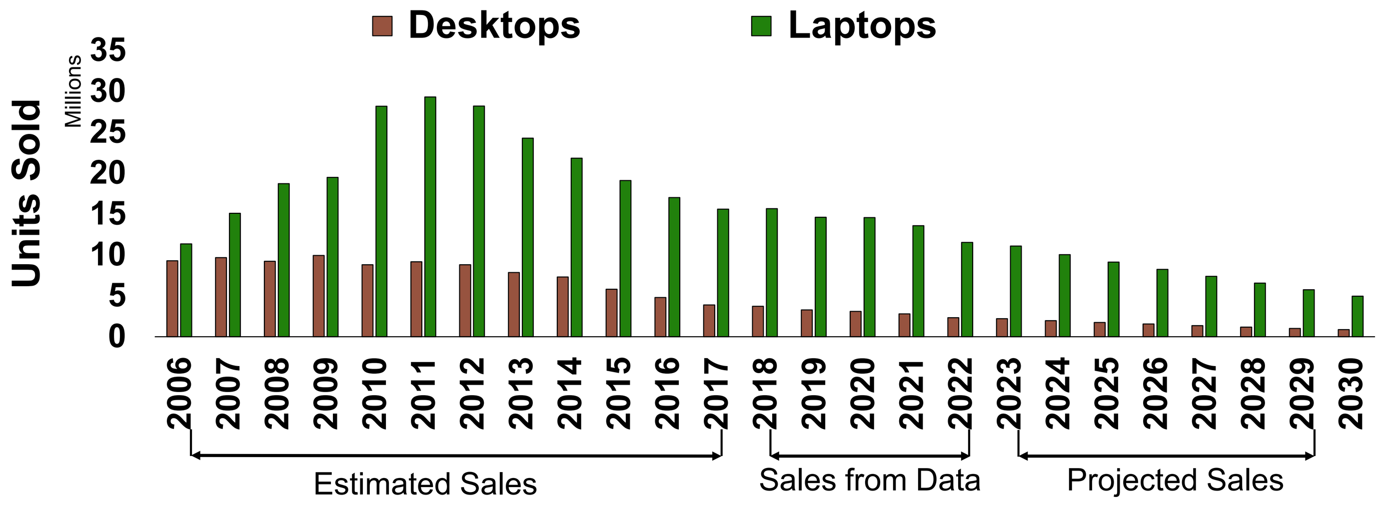
Hard Disk Drives (HDDs) are a Potential Source of REEs

- HDDs, which were used in all laptops and desktops until 2013, are receiving increasing attention in the U.S. as a potential source of REEs as evidenced by the work of agencies and national laboratories such as:
  - The National Renewable Energy Laboratory (NREL)[4].
  - The Environmental Protection Agency (EPA)[5].
  - The Critical Minerals Institute (CMI)[6].

Long term goal: design a feedstock agnostic process to recover rare earth oxides (REOs) from EOL products.

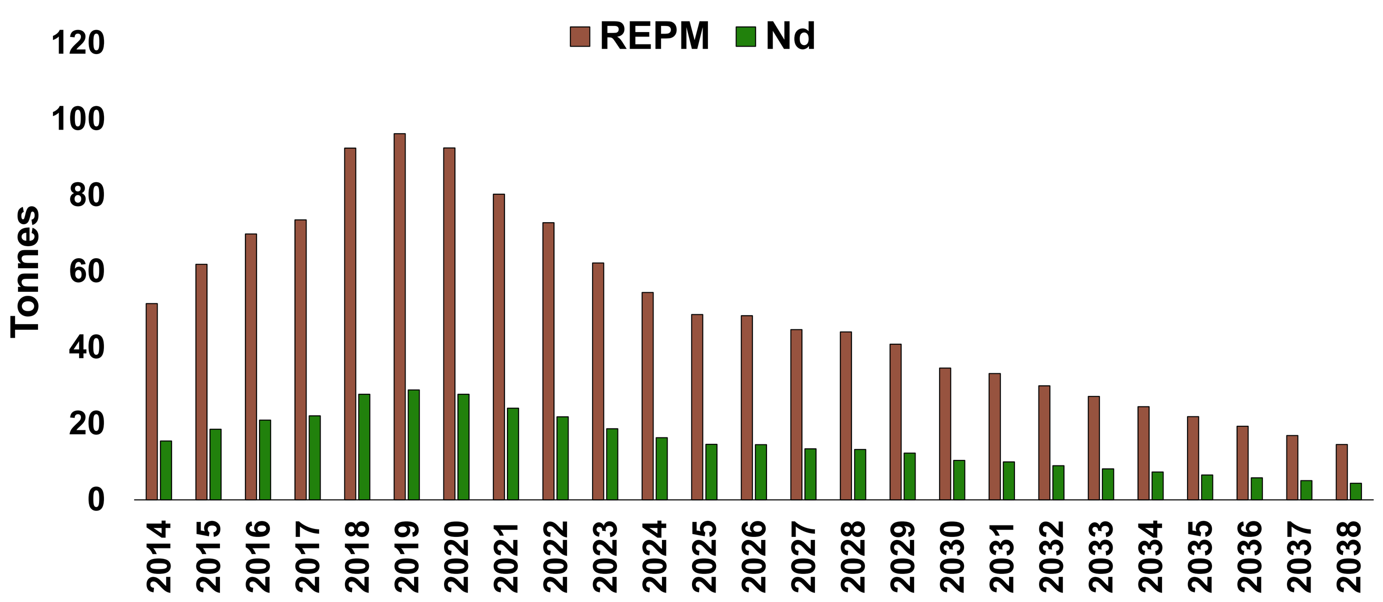


Quantification of Feedstock[7,8]

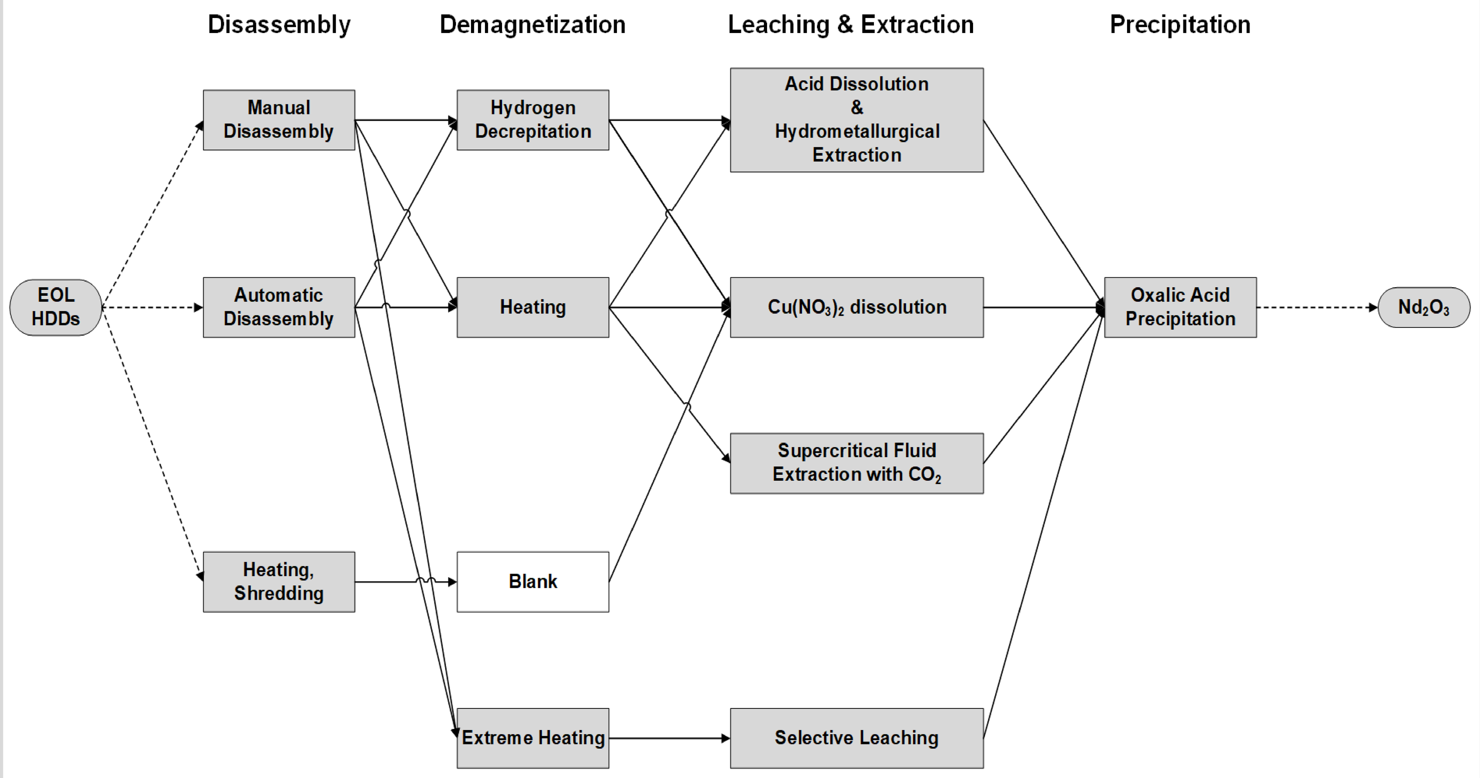


- Consumer laptops and desktops assumed to have an 8-year lifespan.
- Laptops assumed to have 2.5" HDDs which contain 2.5g of REPM[3].
- Desktops assumed to have 3.5" HDDs, REPM linearly correlated to when HDD was produced[3]:

$$17.87 - 0.35t \; (t = 0 \; @ \; 1990)$$

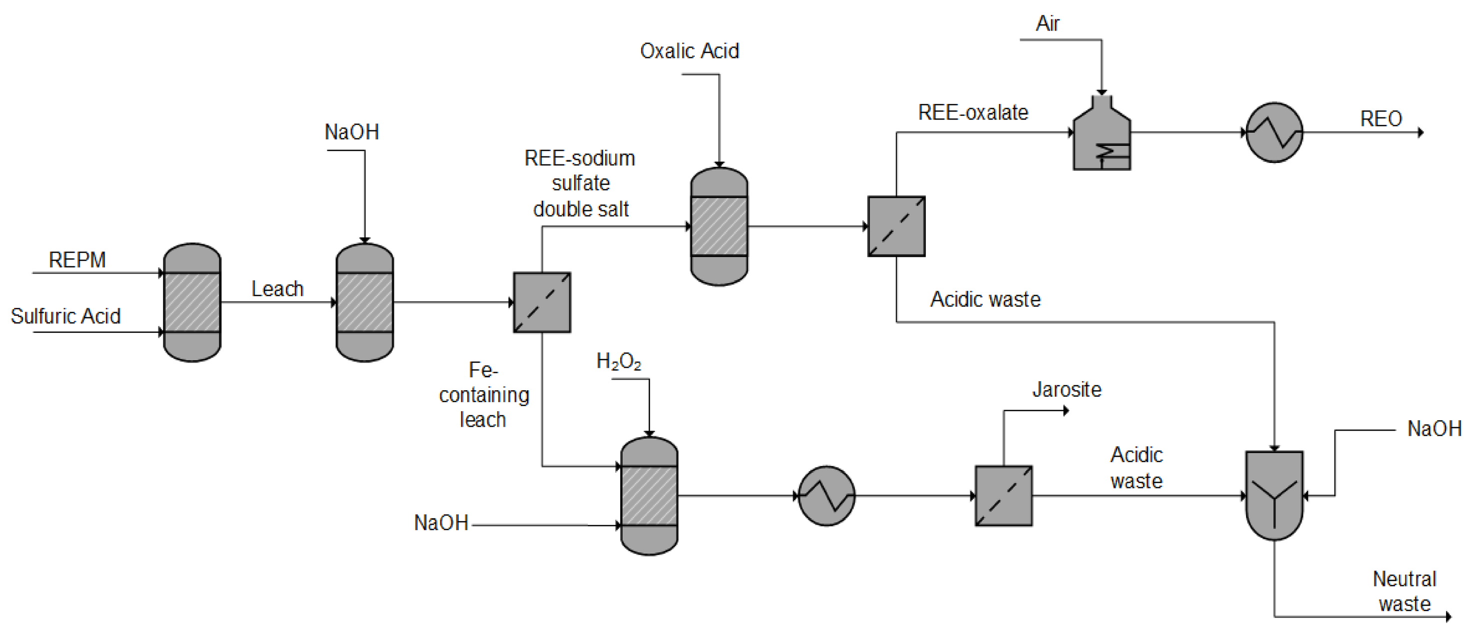


Superstructure and Assumptions



Simplified scheme of the superstructure[9-15].

Aspen Modeling

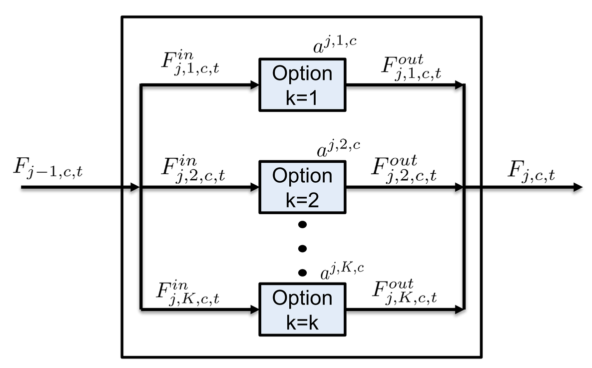


Aspen Plus model for the hydrometallurgical extraction process node[12].

Optimization Problem

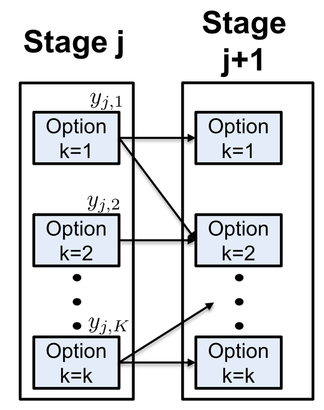
max z = Net Present Value (NPV)

s.t. **Mass Balance Constraints**



- Linear relations from literature or Aspen Plus simulations

Logical Constraints



- Only one technology selected per stage
- If/then constraints to set available options

Costing Constraints

- Disassembly stage: CAPEX and OPEX calculated using discrete units

$$Units^{j,k} = \left\lceil \sum_{c} \varphi^{EVs,t_{max}} * \frac{1}{rate^{j,k}} \right\rceil$$

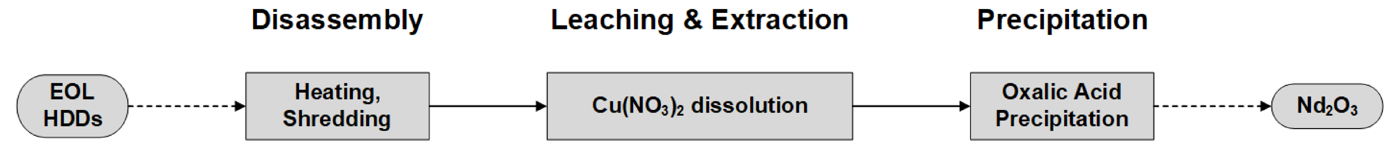
$$CAPEX_{j=dis.\,stage,k} = \sum_{k} Units^{j,k} * CU^{j,k} * y_{j,k}$$

$$OPEX_{j=dis.\,stage,k} = \sum_{k} Units^{j,k} * YCU^{j,k} * y_{j,k}$$

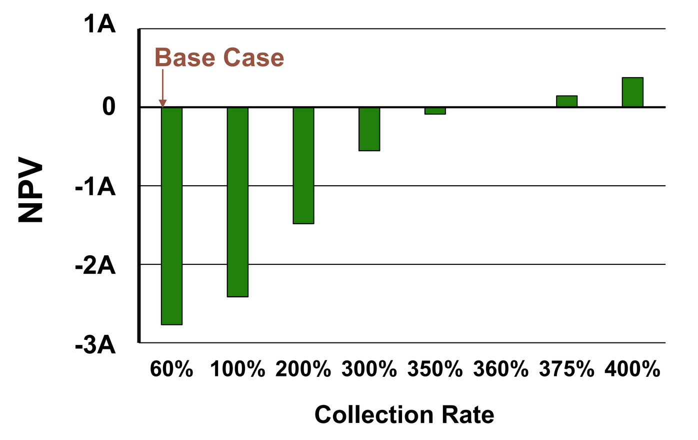
- Rest of the stages:
  - OPEX assumed to vary linearly with inlet flow
  - CAPEX: piecewise linear
  - Data from literature or Aspen Process Economic Analyzer

- Plant installed in 2024, operation runs from 2025 through 2038.
- REO prices were taken from literature[16].

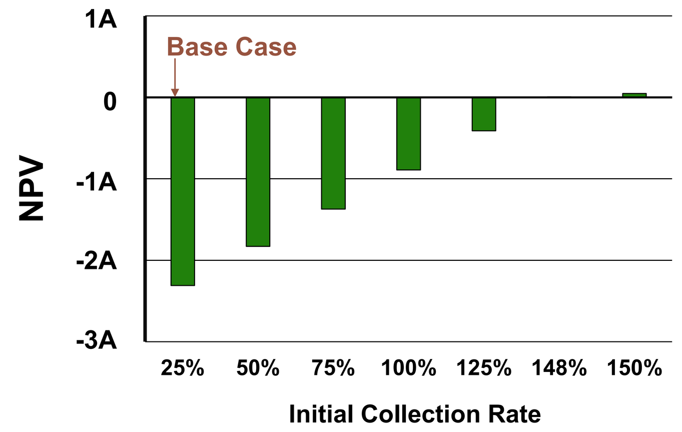
Optimal pathway for REE recovery from EOL HDDs[13,15]



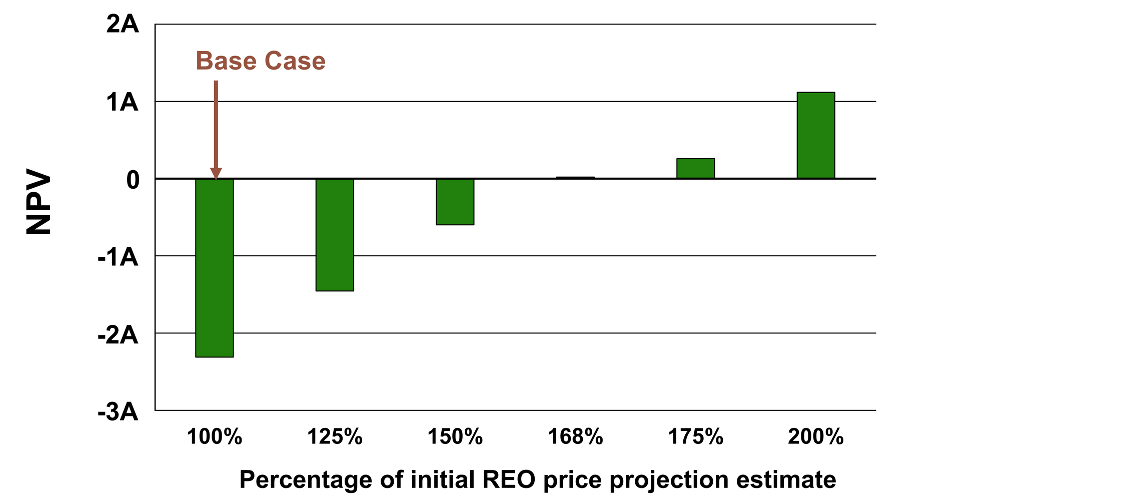
Sensitivity Analysis



- The NPV break-even point occurred at ~360%, suggesting that insufficient EOL HDDs are generated during production for the process to be profitable.



- The NPV break-even point occurred at ~148%, suggesting that not enough EOL HDDs were generated before the start of production for the process to be profitable.



- The NPV break-even point was found to occur at ~168%, suggesting that the REO projected price would have to be significantly higher than the base case for the process to be profitable.

Conclusion

- The optimal pathway was found to consist of shredding, copper nitrate dissolution, and oxalic acid precipitation. It never changed during any of the sensitivity analyses.
- Results show that the venture considering HDDs from PCs is likely not profitable as there is not enough REPM available for recycling from EOL HDDs at the given projected REO prices.
- Expanding the plant to process multiple feedstocks or introducing multiple agents to handle different processing steps may make the venture profitable.

Future Work

- Further optimize the acid-free dissolution extraction process.
- Utilize the Life Cycle Assessment (LCA) framework to consider environmental impacts in the objective function.

Acknowledgment & Contact

Contact: Ana I. Torres, aitorres@cmu.edu

Acknowledgment: This effort was funded by the U.S. Department of Energy's Process Optimization and Modeling for Minerals Sustainability (PrOMMiS) Initiative, supported by the Office of Fossil Energy and Carbon Management's Office of Resource Sustainability.

Disclaimer

References

[1] Blast U, Blank R, Buchert M, Elwert T, Finsterwalder F, Hornig G, Klier T, Langkau S, Marscheider-Weidemann F, Muller JO, Thurigen CH, Treffer F, Walter T. Recycling von komponenten und strategischen metallen aus elektrischen fahrantrieben: kennwort: MORE (Motor Recycling) (2015)
[2] Dias PA, Bobba S, Carrara S, Plazzotta B. The role of rare earth elements in wind energy and electric mobility: an analysis of future supply/demand balances (2020)
[3] Sprecher B, Kleijn R, Kramer GJ. The case of computer hard disk drives. *Environ Sci Technol* 48, 16:9506-9513 (2014)
[4] NREL. https://www.nrel.gov/news/program/2021/in-a-circular-economy-hard-drives-could-have-multiple-lives-in-the-future.html
[5] EPA. https://www.epa.gov/vcs/using-standards-promote-reuse-rare-earth-materials
[6] CMI. https://www.ameslab.gov/news/it-s-all-part-of-the-grind-cmi-s-new-hard-drive-shredder-serves-up-plenty-of-material-for#:~:text=The%20Critical%20Materials%20Institute%20specializes,motors%2C%20and%20wind%20turbine%20generators
[7] Statista. https://www.statista.com/statistics/273495/global-shipments-of-personal-computers-since-2006/
[8] Statista. https://www.statista.com/outlook/cmo/consumer-electronics/computing/desktop-pcs/united-states?currency=USD&locale=en#revenue
[9] Peeters JR, Bracqguene E, Nelen D, Ueberschaar M, Van Acker K, Duflou JR. Forecasting the recycling potential based on waste analysis: a case study for recycling Nd-Fe-B magnets from hard disk drives. *J of Clean Prod* 175:96-108 (2018)
[10] Peiró LT, Girón AC, Durany XG. Examining the feasibility of the urban mining of hard disk drives. *J Clean Prod* 248:119-216 (2020)
[11] Walton A, Yi H, Rowson NA, Speight JD, Mann VSJ, Sheridan RS, Bradshaw A, Harris IR, Williams AJ. The use of hydrogen to separate and recycle neodymium-iron-boron-type magnets from electronic waste. *J Clean Prod* 104: 236-241 (2015)
[12] Lyman JW, Palmer GR. Recycling of rare earth and iron from NdFeB magnet scrap. High Temp Mater and Process 11: 175-187 (1993)
[13] Nawab A, Yang X, Honaker R. Parametric study and speciation analysis of rare earth precipitation using oxalic acid in a chloride solution system. *Miner Eng* 176: 107352 (2022)
[14] Azimi G, Sauber ME, Zhang J. Technoeconomic analysis of supercritical fluid extraction processes for recycling rare earth elements from neodymium iron boron magnets and fluorescent lamp phosphors. J Clean Prod 422: 138526 (2023)
[15] Chowdhury NA, Deng S, Jin H, Prodius D, Sutherland JW, Nlebedim IC. Sustainable recycling of rare-earth elements from NdFeB magnet swarf: techno-economic and environmental perspectives. ACS Sustain Chem Eng 0: 15915-15924 (2021)
[16] Hykawy J, Chudnovsky T. https://www.stormcrow.ca/wp-content/uploads/2021/03/20210308-Stormcrow-UCore-Initiation-Final.pdf