# Indian Institute of Technology Kanpur

**Proposal for a New Course**

1. **Course No**: SEE6XX
2. **Course Title**: Recycling Energy Materials
3. **Per Week Lectures**: 3( L), Tutorial: 0 (T), Laboratory: 0 ( P), Additional Hours[0-2]: 0(A) Credits (3*L+2*T+P+A): 3-0-0-9, or 9 credits. **Course Duration**: Full semester
4. **Proposing Department**/IDP : SEE, Other Dept may be interested in proposing this course: MSE, CHEM, Earth Sciences, Chemistry, Other faculty members interested in teaching this course: Srinivas Kartik Yadavalli
5. **Proposing Instructor**: Vivek Verma
6. **Course Description and details:**

## A. Course Objectives

This course will address the importance of recycling energy materials, especially for extracting critical minerals. Basic metallurgical concepts will help us understand the core of recycling technology better. The course will delve into details of few selected devices including lithium batteries, solar cells, magnets, and catalysts. Finally, we will also highlight environmental economic and social aspects of recycling and various efforts India has been taking in improving recycling.

## Expected learning outcomes from this course.

By the end of the course, the students will be able to:

- Understand the importance of recycling energy materials.
- Corelate critical minerals resources with recycling energy materials
- Grasp basic metallurgical concepts needed to understand recycling.
- Understand the overall recycling process for few of the crucial components of energy materials.
- Correlate environmental, social and economic aspects pertaining to recycling these materials.

## B. Course Content (next page)

| No | Broad title | Topics | Lectures (50min) |
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| 1 | Introduction to energy materials and devices | Batteries, solar cells, catalysis, autocatalytic converter in IC vehicles, magnets in EV and wind energy | 2 |
| 2 | Recycling of energy materials | Importance of recycling energy materials, need for critical materials, materials and their volumes, resource constraints | 2 |
| 3 | Critical minerals aspects | Critical mineral definition, Indian critical minerals list, critical minerals requirement, resource constraints, geopolitical constraints | 4 |
| 4 | Recycling techniques for metals/minerals | pyrometallurgy, hydrometallurgy, electrometallurgy | 7 |
| 5 | Purification and refining techniques | electrorefining, precipitation, crystallization, solvent extraction | 1 |
| 6 | Material characterization techniques used in metal/mineral recycling | Inductive Coupled Plasma (ICP-MS/OES) Spectroscopy, Wavelength and Energy Dispersive Spectroscopy | 2 |
| 7 | Li-ion battery recycling | Li-ion battery construction, discharging and shredding, black mass preparation, transition metal recovery, Li recovery, emerging technology like direct recycling | 6 |
| 8 | Solar cell recycling | solar cell construction, mechanical dismantling, delamination, metal recovery using hydrometallurgical methods | 4 |
| 9 | Catalyst recycling | Metals applied in industrial catalysts, End of life Heterogeneous catalysis, autocatalytic converters, hydrometallurgical and pyrometallurgical methods for PGMs recovery | 3 |
| 10 | Permanent Magnets recycling | Preprocessing, hydrogen decrepitation, alloy processing, hydrometallurgical and pyrometallurgical routes | 3 |
| 11 | Environmental and social impact of recycling | Life Cycle Assessment (LCA), Life Cycle Cost Analysis, Social LCA | 3 |
| 12 | Efforts taken by India | National critical mineral mission, EPR, battery waste management rules. Conclusion | 2 |
| | | Total | **39** |

## C. Pre-Requisites

No mandatory course requirement. However, general understanding of basic Materials Science will be beneficial.

## D. Short Summary for including in the Courses of Study Booklet

This course highlights the urgent need for India to source various critical minerals via recycling needed to make various clean energy technologies possible. Only when India is mature enough in recycling the critical materials, we can reduce our material import dependency on other countries and become truly Atma-Nirbhar. This course forms one of the seven key pillars, recycling, of the recently announced National Critical Mineral Mission by Govt of India in early 2025.

## 7. Recommended Books/Textbooks


- Ghosh, Ahindra, and Hem Shanker Ray. *Principles of extractive metallurgy*. New Age International, 1991.
- National Critical Minerals document, 2025, Ministry of mines.
- Nassar, N.T., Graedel, T.E., Harper, E.M., 2015. By-product metals are technologically essential but have problematic supply. Science Advances 1, e1400180. https://doi.org/10.1126/sciadv.1400180
- Binnemans, K., Jones, P. T., Blanpain, B., Van Gerven, T., Yang, Y., Walton, A., & Buchert, M. (2013). Recycling of rare earths: A critical review. *Journal of Cleaner Production*, *51*, 1–22. https://doi.org/10.1016/j.jclepro.2012.12.037
- Sim, Ying, Ankit, Yeow Boon Tay, Dwarakanath Ravikumar, and Nripan Mathews. "Open challenges and opportunities in photovoltaic recycling." *Nature Reviews Electrical Engineering* 2, no. 2 (2025): 96-109.


## Suggested readings


- A. P. Paiva, F. V. Piedras, P. G. Rodrigues, and C. A. Nogueira, "Hydrometallurgical recovery of platinum-group metals from spent auto-catalysts – Focus on leaching and solvent extraction," *Separation and Purification Technology*, vol. 286, p. 120474, Apr. 2022, doi: 10.1016/j.seppur.2022.120474.
- Z. Peng *et al.*, "Pyrometallurgical Recovery of Platinum Group Metals from Spent Catalysts," *JOM*, vol. 69, no. 9, pp. 1553–1562, Sep. 2017, doi: 10.1007/s11837-017-2450-3.
- H. Dong, J. Zhao, J. Chen, Y. Wu, and B. Li, "Recovery of platinum group metals from spent catalysts: A review," *International Journal of Mineral Processing*, vol. 145, pp. 108–113, Dec. 2015, doi: 10.1016/j.minpro.2015.06.009.
- Tunsu, C., Petranikova, M., Gergorić, M., Ekberg, C., & Retegan, T. (2015). Reclaiming rare earth elements from end-of-life products: A review of the perspectives for urban mining using hydrometallurgical unit operations. *Hydrometallurgy*, *156*, 239–258. https://doi.org/10.1016/j.hydromet.2015.06.007
- Lange, Jean-Paul. "Managing plastic waste—sorting, recycling, disposal, and product redesign." *ACS Sustainable Chemistry & Engineering* 9, no. 47 (2021): 15722-15738.
- Chowdhury, M.S., Rahman, K.S., Chowdhury, T., Nuthammachot, N., Techato, K., Akhtaruzzaman, M., Tiong, S.K., Sopian, K. and Amin, N., 2020. An overview of solar photovoltaic panels' end-of-life material recycling. *Energy Strategy Reviews*, *27*, p.100431.
- Verma, V., Joseph, J.R., Chaudhary, R. and Srinivasan, M., 2023. Upcycling spent cathode materials from Li-ion batteries to precursors: Challenges and opportunities. *Journal of Environmental Chemical Engineering*, *11*(4), p.110216.
- Whittle D, Yellishetty M, Walsh S, Mudd D, Weng Z. Critical Minerals Assessment. Monash University, Melbourne, Australia,[Online] availa ble at https://www. monash. edu/data/assets/pdf_file/0006/2246298/CMC-Critical-Minerals-Assessment-29-June-2020. pdf (Accessed 20 October 2023). ОТРАСЛЕВАЯ И РЕГИОНАЛЬНАЯ ЭКОНОМИКА BRANCH AND REGIONAL ECONOMY. 2020.
- Various other review papers on specific topics

8. Any Other Remarks: nil

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| Date: 17-OCT-2025 | Proposer: Vivek Verma |
| Dated: 4 Dec 2025 | DUGC/DPGC convener:  |

This course is approved.

Chairman, SUGC/SPGC
Dated: