DI03000101: Electrical Power Transmission & Distribution

GTU Course Presentation

July 25, 2026

Course Contents I

Composition of Power Cables & The Need for Recycling I

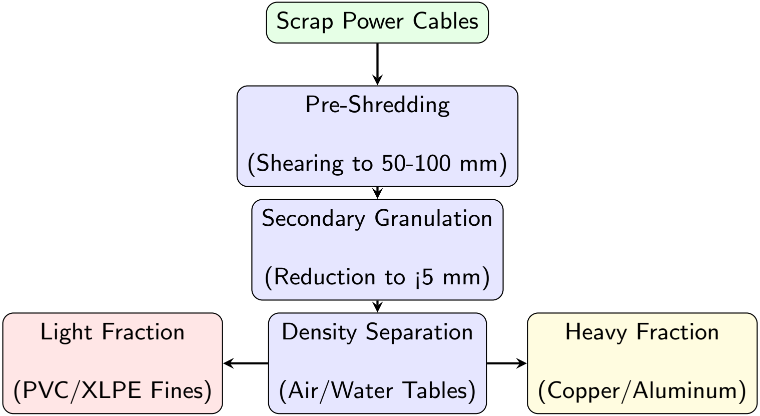
High-voltage and medium-voltage power cables contain valuable metals and complex polymeric insulation that cannot simply be landfilled due to environmental hazards and economic loss.

Composition of Power Cables & The Need for Recycling II

Key Points

- Conductive Core: Typically contains high-purity copper (99.9%) or electrical-grade aluminum (99.5%), which have high scrap value.
- Insulation Layers: Formulated using Cross-linked Polyethylene (XLPE), Polyvinyl Chloride (PVC), Paper Insulated Lead Covered (PILC), or Ethylene Propylene Rubber (EPR).
- Shielding and Armoring: Consists of lead sheaths, steel tape/wire armoring, and copper wire screens for mechanical and electromagnetic protection.
- Sustainability Imperative: Prevents heavy metal pollution (e.g., lead from PILC cables) and significantly reduces greenhouse gas emissions compared to primary smelting (~85% savings for Cu).

Mechanical Shredding & Separation Flowsheet I



Mechanical Shredding & Separation Flowsheet II

Key Points

- Step 1 (Pre-shredding): Rotary cutters shear heavy armored cables into manageable segments.
- Step 2 (Granulation): High-speed granulators reduce materials to fine particle sizes to liberate metals from insulation.
- Step 3 (Air Classification): Gravity separators use fluidizing air and vibration to separate dense metals from lighter plastics.
- Recovery Efficiency: Mechanical processing yields up to $98-99\%$ metal purity if the feedstock is properly classified.

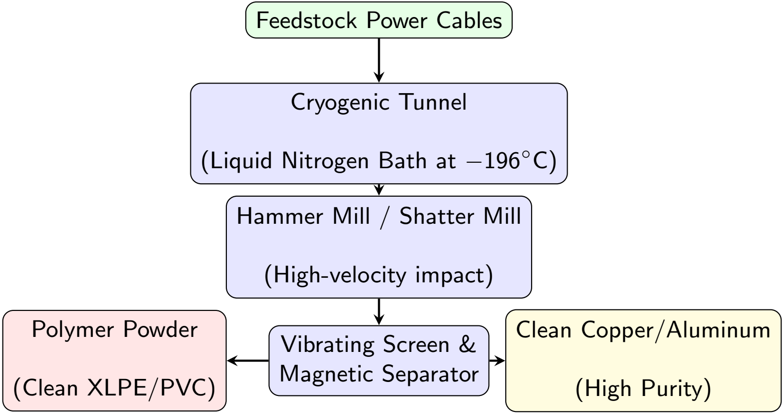
Pyrolysis is a thermochemical process that decomposes the organic polymer matrix of cable insulation under an inert atmosphere (absence of oxygen) to recover metals without oxidation.

Pyrolysis & Thermal Degradation of Insulation II

Key Points

- Reaction Atmosphere: Conducted in nitrogen or vacuum at temperatures ranging from 400°C to 700°C.
- Chemical Equation: Polymer (XLPE/PVC) $\xrightarrow{\Delta,\ \text{No } O_2}$ Pyrolytic Gas + Pyrolytic Oil + Char + Metals.
- Metal Quality Preservation: Unlike open burning, pyrolysis prevents the oxidation of copper to CuO or Cu_2O, preserving its high conductivity and market value.
- Byproduct Utilization: The volatile organic gases produced can be condensed into pyrolytic oil or combusted to supply the process heat, enhancing thermal efficiency.

Cryogenic Cable Recycling System I



Cryogenic Cable Recycling System II

Key Points

- Glass Transition Principle: Polymer insulation is cooled below its glass transition temperature ($T_g \approx -40^\circ$C to -110°C), rendering it extremely brittle.
- Ductility Retention: Metals (Copper and Aluminum) remain ductile at these low temperatures, preventing metal dusting or loss.
- Delamination: Upon impact in the hammer mill, the frozen, brittle polymer shell shatters instantly and cleanly detaches from the metallic core.
- Purity: Produces extremely clean copper fractions ($> 99.9\%$) with zero thermal degradation or gas emissions.

Recycling of Lead-Sheathed & Paper-Insulated Cables I

Paper-Insulated Lead-Covered (PILC) cables were widely used in old distribution networks. Recycling them requires specialized containment and processing to handle hazardous lead and oil-impregnated paper.

Recycling of Lead-Sheathed & Paper-Insulated Cables II

Key Points

- Lead Sheath Recovery: Lead ($T_m \approx 327.5°$C) is stripped mechanically or melted at low temperatures, ensuring zero lead volatilization (which occurs at $> 600°$C).
- Oil-Impregnated Paper: The paper insulation contains hydrocarbon-based insulating oils, requiring solvent extraction or controlled thermal treatment to prevent soil/water contamination.
- Hydrometallurgical Refining: Recovered lead undergoes electrorefining or pyrometallurgical refining to remove copper and antimony impurities, restoring it to battery-grade purity ($> 99.97\%$, ASTM B29).
- Environmental Protection: Strict ventilation and

Environmental Regulations & Halogenated Plastics I

Recycling plastic cable insulation, especially Polyvinyl Chloride (PVC), presents significant environmental challenges due to the release of toxic halogens and plasticizers during thermal treatment.

Key Points

- Dehydrochlorination of PVC: When PVC is heated above 250°C, it undergoes thermal degradation releasing corrosive hydrochloric acid gas: -(CH_2-CHCl)-$_n$ $\xrightarrow{\Delta}$ -(CH=CH)-$_n$ + nHCl.
- Dioxin and Furan Formation: Incomplete combustion of chlorinated polymers leads to the emission of highly carcinogenic polychlorinated dibenzo-p-dioxins (PCDD) and dibenzofurans (PCDF).
- Acid Gas Scrubbing: Wet scrubbers using alkaline solutions (e.g., sodium hydroxide NaOH or calcium hydroxide $Ca(OH)_2$) are required to neutralize acid gases: $HCl + NaOH \rightarrow NaCl + H_2O$.
- XLPE Recycling Bottlenecks: Cross-linked Polyethylene (XLPE) cannot be remelted like thermoplastic PE because of its 3D thermoset network, requiring

Circular Economy & Economic Feasibility I

The economics of cable recycling are driven by the high commodity prices of copper and aluminum, balanced against the operational costs of sorting, shredding, and environmental compliance.

Circular Economy & Economic Feasibility II

Key Points

- Resource Efficiency Index: Recycling copper consumes only about 15% of the energy required for primary copper mining and refining ($E_{\text{primary}} \approx 30 - 85$ MJ/kg vs. $E_{\text{recycling}} \approx 10$ MJ/kg).
- Cost-Benefit Analysis: ROI is heavily dependent on throughput volume and the purity of recovered metals. High-purity scrap copper commands up to 95% of the London Metal Exchange (LME) spot price.
- Design for Recycling (DfR): Modern cable manufacturing trends focus on using halogen-free flame-retardant (HFFR) compounds and thermoplastic elastomers (TPE) that are easier to recycle than XLPE and PVC.
- Extended Producer Responsibility (EPR): Regulatory frameworks enforce that utilities and manufacturers