THE TECHNOCRACY
STUDENTS' TECHNICAL COMMITTEE, NIT RAIPUR

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PROBLEM STATEMENTS

MME01: <u>Dust-Repellent Thin-Film Coating for Solar Cells</u>

Solar cell efficiency can be significantly reduced by dust and dirt accumulation on their surface. Frequent cleaning can be expensive and impractical in remote locations. The goal is to create a surface coating for solar cells that repels dust and dirt particles, minimizing maintenance and maximizing energy output.

Current Challenges:

- Dust accumulation: Dust, sand and other airborne particles accumulate on solar cell surfaces, reducing light absorption and energy conversion efficiency.
- Maintenance costs: Manual cleaning of solar panels for large-scale installations can be expensive, labour-intensive and can damage delicate surfaces.
- Accessibility limitations: Cleaning solar panels in remote locations like deserts or rooftops can be difficult or even dangerous.

Problem Statement:

Design and fabricate a thin-film coating for solar cells that effectively repels dust and dirt particles, minimizing the need for cleaning and maximizing energy capture under real-world conditions.

The coating solution should -

▪ Allow for maximum light transmission to the solar cell for efficient energy conversion.

▪ Possess excellent dust and dirt repellency, with hydrophobic or self-cleaning properties.

▪ Be durable and withstand harsh environmental conditions (extreme temperatures, UV radiation, wind, rain).

▪ Be compatible with existing solar cell manufacturing processes for scalability.

▪ Be economically viable for large-scale adoption.

Potential Outcome:

▪ A self-cleaning solar cell coating can significantly reduce maintenance costs and improve the long-term performance of solar panels.

▪ Improve the durability and lifespan of solar cell installations.

▪ Beneficial for solar installations in dusty or remote locations, where cleaning is challenging.

▪ The coating will ensure solar cells maintain optimal performance by preventing the accumulation of dust and dirt, leading to higher energy capture and efficiency.

Expectations from the team:

▪ Research existing solutions and their limitations.

▪ Explore different coating materials and deposition techniques to achieve the desired properties.

▪ Develop a detailed design for the coating, specifying its material composition, thickness, and surface structure.

▪ Evaluate the coating's properties such as self-cleaning efficiency, light transmittance, durability, and adhesion to the solar cell surface.

▪ Demonstrate the effectiveness of the coating in repelling dust and dirt and compare the energy capture efficiency of coated vs. uncoated solar cells under simulated dust conditions.

MME02: Green Iron and Steel Production

The Steel industry is a significant contributor to global carbon emissions. Traditional methods of steel production rely heavily on coal as a reductant, which results in greenhouse gas emissions and environmental pollution. With increasing environmental regulations and the urgent need to combat climate change, there is a pressing need to develop more sustainable methods of iron and steel production.

Current Challenges:

- High Carbon Footprint: The blast furnace process, utilizes coal as a reducing agent. This process generates a substantial amount of carbon dioxide and other pollutants contributing to global warming.
- Limited Green Steel Options: Existing green steel production methods like hydrogen-based direct reduced iron (DRI) are energy-intensive and face challenges in terms of cost, scalability and efficiency.
- Sustainability and Efficiency: Replacing coal with renewable reductants can be challenging while maintaining high-quality steel production and efficient processes.
- Maintaining Material Properties: Green steel production methods must ensure the final product meets the same strength, ductility, and other crucial properties as conventionally produced steel.
- Integration with Existing Infrastructure: Adapting existing steel industries to incorporate green technologies requires innovative solutions to minimize disruption and costs.

Problem Statement:

Design an innovative and sustainable solution for green Iron and Steel production by substituting coal with renewable reductants, aiming to minimize carbon emissions and environmental impact while enhancing quality and process efficiency.
The solution should -

- Utilize renewable sources of energy to replace coal as the primary reducing agent.
- Explore alternatives or enhancements to existing green steel production methods.
- Significantly decrease greenhouse gas emissions compared to traditional steel production methods.
- Maintain or improve the overall efficiency of steel production, considering factors like energy consumption and production rate.
- Produce high-quality steel that meets industry standards for strength, ductility, and other relevant properties.
- Propose a solution that can be scaled for large-scale production and considers the environmental impact of the entire production process, including material sourcing and waste management.

Potential Outcome:

- Significantly reduce the carbon footprint of the steel industry.
- Promote the development and adoption of renewable energy sources for industrial processes.
- Enhance the sustainability of the steel supply chain while maintaining high-quality steel production.
- Contributing to a more sustainable future for steel production.

Expectations from the team:

- Conduct a comprehensive research analysis of existing green steel production methods and their limitations.
- Develop a detailed design of your proposed green steel production process, including the chosen renewable reductant, process design, technology considerations, process flow, potential benefits and future development considerations.
- Analyze the life cycle assessment of your proposed solution, focusing on its carbon footprint and environmental impact compared to traditional methods.
- Consider the economic feasibility and potential cost implications of your proposed solution.

MME03: E-Waste Metal Extraction

Electronic waste is one of the fastest-growing waste streams globally, driven by rapid technological advancements and high demand for electronic products. E-waste contains a variety of valuable metals such as gold, silver, copper, and rare earth elements, which can be recovered and recycled. However, existing extraction methods are often inefficient, environmentally hazardous, and expensive.

Current Challenges:

- Inefficient Recovery Methods**:** Conventional methods are not optimized for mixed e-waste streams, leading to low recovery rates and lost resources.
- Selectivity and Purity**:** Achieving high selectivity and purity of extracted metals from complex e-waste mixtures is a significant challenge.
- Environmental Impact**:** Existing extraction processes often generate significant amounts of hazardous byproducts and contribute to pollution, posing serious environmental and health risks.
- Economic Viability**:** The extraction of metals from e-waste using existing technologies can be prohibitively expensive, making recycling less favourable compared to raw material extraction.

Problem Statement:
Design a novel, sustainable, and scalable process for the selective extraction of valuable metals from mixed e-waste streams. Consider factors like efficiency, improved selectivity, environmental impact, cost-effectiveness and minimizing hazardous byproducts.

Your solution should -

- Effectively extract target metals with minimal contamination.
- Maximizes the recovery rate and purity of valuable metals from mixed e-waste streams.
- Ensure that the proposed solution minimizes environmental impact by focusing on reducing hazardous byproducts, overall ecological footprint, energy consumption, limited use of harmful chemicals, and proper waste management.
- Be scalable up to industrial levels without significant loss of efficiency and economically viable for industrial applications.

Potential Outcome:

- A significant improvement in the recovery rates and purity of valuable metals from e-waste.
- Increased profitability of e-waste recycling operations due to the cost-effectiveness and efficiency of the new process, encouraging wider adoption.
- Encouraging sustainable recycling practices to reduce electronic waste and preserve natural resources.

Expectations from the team:

- Design a detailed process flow.
- Analyze the efficiency and selectivity of your method.
- Evaluate the environmental impact and cost-effectiveness of your solution.
- Present a clear plan for potential scalability in an industrial setting.
- Propose methods for minimizing hazardous waste generation and its safe disposal.

MME04: Advanced Battery System Design for High-Performance EVs

Electric vehicles (EVs) are playing a crucial role in the transition towards sustainable transportation. However, battery technology remains a key challenge, limiting factors like range, charging speed, and overall cost. There is a need to develop a next-generation battery system that addresses the limitations of current EV batteries.

Current Challenges:

- Energy Density**:** Existing battery technologies struggle to achieve high energy densities required for extended driving ranges without sacrificing other performance metrics.
- Charging Speed**:** Long charging times remain a major barrier to EV adoption, hindering convenience and usability for consumers.
- Compactness and Lightweight**:** Current battery systems are often bulky, limiting their integration into vehicles, and impacting overall weight and design flexibility.
- Durability and Safety: Battery systems must withstand harsh operating conditions, including temperature variations, mechanical stress, and potential impact accidents, without compromising safety.
- Lifespan**:** Battery degradation over time reduces overall vehicle efficiency and increases maintenance costs, necessitating longer-lasting solutions.
- Degradation and Thermal Stability**:** Managing degradation mechanisms and ensuring thermal stability under various operating conditions are critical for extending battery lifespan and enhancing safety.

Problem Statement:

Develop a battery or supercapacitor system for electric vehicles that address the following limitations:
high energy density, fast charging, compactness (compact and lightweight), scalability, durability, safety, prolonged battery lifespan, affordability, and sustainability, while minimizing degradation and ensuring thermal stability.

Potential outcome:

- Enabling EVs with longer range, faster charging times, and improved efficiency. ▪ Improved battery durability and safety, promoting a more sustainable and reliable transportation future.
- Development of more compact and lightweight battery systems, enhancing vehicle design and performance.
- Making EVs more affordable and accessible to a wider consumer base.
- Promoting sustainable practices in the EV battery supply chain.

Expectations from the team:

- Conduct comprehensive research on existing battery technologies and future trends in EV battery development.
- Develop a detailed design of your proposed battery system, including material considerations and cell design.
- Analyze the performance of your system, focusing on energy density, charging speed, durability, safety and thermal behaviour.
- Evaluate the technical feasibility and safety aspects of your solution, as well as its economic feasibility and environmental impact, considering material costs, manufacturing processes, real-world implementation in EVs and potential for recycling.
- Prepare a compelling presentation outlining your research, proposed solution, and its potential benefits on the future of EV battery technology.

MME05: Recover Aluminium from Dross

Aluminium dross, a by-product of aluminium smelting and casting processes, poses significant environmental and economic challenges. It consists of a mixture of aluminium metal and oxides, along with other impurities such as aluminium nitride, aluminium carbide, and aluminium oxide. The efficient recovery of aluminium from dross is essential to minimize waste generation, promote resource sustainability, and alleviate environmental concerns associated with its disposal.

Current Challenges:

- Complex Composition: Aluminium dross is a complex mixture containing various aluminium compounds and impurities, making its recovery challenging and requiring sophisticated separation techniques.
- Environmental Impact: Traditional methods of aluminium recovery from dross, such as landfilling or dumping, result in environmental pollution and resource wastage, highlighting the need for environmentally friendly solutions.
- Economic Viability: Existing recovery methods may not be economically viable due to high energy consumption, resource requirements, and low yields of pure aluminium, posing barriers to widespread adoption in industrial settings.

Problem Statement:

Develop a novel, efficient method to recover aluminium from aluminium dross. This method should be environmentally friendly, and economical and achieve a high yield of pure aluminium. This will minimize waste, and promote resource sustainability.

Potential Outcome:

- The development of an environmentally friendly aluminium recovery method will minimize the environmental impact associated with aluminium dross disposal, reducing pollution and promoting sustainable resource management.
- By efficiently recovering aluminium from dross, the proposed solution will conserve valuable resources and reduce the reliance on primary aluminium production, contributing to the conservation of natural resources.
- The economic viability of the recovery method will lead to cost savings for aluminium producers, reducing operational expenses associated with waste management and raw material procurement.

Expectations from the team:

- Design and implement innovative separation techniques capable of effectively separating aluminum metal from dross, while minimizing the generation of hazardous by-products.

- Ensure that the proposed method is environmentally friendly, with minimal emissions of pollutants and greenhouse gases throughout the recovery process.
- Develop a cost-effective recovery process that utilizes readily available materials and resources, minimizes energy consumption, and maximizes the yield of pure aluminium.
- Achieve a high yield of pure aluminium from dross, minimizing the loss of valuable metal and maximizing the overall recovery efficiency.
- Design the method to be scalable and adaptable to different production scales and variations in dross composition, allowing for its implementation in various industrial settings.

MME06: Innovative Waste Management System for Iron and Steel Production

The iron and steel industry is fundamental to modern infrastructure and manufacturing, providing essential materials for construction, transportation, and various industrial applications. However, this industry is also a major producer of waste, generating substantial amounts of solid, liquid, and gaseous byproducts. Efficient and sustainable waste management is crucial to mitigate the environmental impact, comply with regulatory standards, and enhance the overall efficiency of production processes. Innovations in waste management can significantly contribute to the sustainability and economic viability of the iron and steel industry.

Current Challenges:

- Solid Waste Management**:** The production of iron and steel generates significant solid wastes, such as slag, dust, and sludge. These materials often require complex processing and recycling methods to prevent environmental contamination.
- Liquid Waste Treatment**:** Effluents from iron and steel production contain contaminants like heavy metals, oils, and other chemicals. Effective treatment and reuse of these liquid wastes are essential to prevent pollution and conserve water resources.
- Gaseous Emissions**:** Emissions such as carbon dioxide, sulfur dioxide, and other pollutants contribute to air pollution and climate change. Developing methods to manage and reduce these emissions is critical for environmental protection.
- Resource Utilization: Maximizing the use of byproducts and converting waste into valuable resources can improve the sustainability of the production process. However, finding cost-effective and efficient ways to do this remains a challenge.
- Regulatory Compliance**:** The industry faces stringent environmental regulations that require the adoption of sustainable waste management practices. Compliance can be costly and technically demanding.
- Economic Viability**:** Implementing advanced waste management solutions must be economically feasible to encourage widespread adoption within the industry.

Problem Statement:

Develop an innovative waste management system for Iron and Steel production, addressing solid, liquid, and gas waste byproducts, that efficiently utilizes or recycles waste streams, ensuring sustainability and reducing environmental impact while enhancing the overall efficiency of the production process.

Potential Outcome:

- Significant reduction in the environmental footprint through effective waste management practices.
- Improved resource utilization and recycling, contributing to the sustainability of the iron and steel industry.
- Lower waste disposal costs and potential revenue from recycled materials, improving the economic viability of the production process.

Expectations from the team:

- Address the management of solid, liquid, and gaseous wastes with integrated solutions that consider the entire production process.
- Propose novel technologies or methods that significantly improve upon existing waste management practices.
- Design processes that maximize the recycling and reuse of waste materials, reducing the overall waste footprint.
- Minimize the environmental impact of waste byproducts through effective treatment, recycling, and emissions reduction strategies.
- Ensure the proposed solutions are economically viable, considering implementation and operational costs.
- Develop solutions that can be scaled up to industrial levels without significant loss of efficiency or increase in costs.

MME07: Advanced Biocompatible Material for Enhanced Biofluid Diagnostics

Accurate detection and analysis of biomarkers in biofluids such as blood, saliva, and cerebrospinal fluid (CSF) are essential for early disease diagnosis and effective monitoring. However, these biomarkers often face degradation and interference within biofluids, leading to unreliable diagnostic results. There is an urgent need for innovative materials that can protect these biomarkers from degradation, selectively capture them, and possess antimicrobial properties. Such materials would significantly enhance diagnostic precision and efficiency across a range of biofluids, paving the way for improved healthcare outcomes.

Current Challenges:

- Analyte Degradation**:** Biofluids contain numerous enzymes and other reactive substances that can degrade target analytes, compromising the integrity and reliability of diagnostic tests.
- Non-Specific Binding**:** Current materials often lack the selectivity needed to bind specific biomarkers, leading to non-specific interactions and false-positive or false-negative results.
- Material Degradation**:** Materials used in biofluid applications must resist degradation to maintain their functionality over time, particularly in harsh biological environments.
- Antimicrobial Properties**:** Biofluids can be prone to microbial contamination, which can interfere with the capture and analysis of target analytes.
- Integration with Diagnostic Systems**:** New materials must be compatible with existing diagnostic technologies and workflows to facilitate seamless integration and application.

Problem Statement:

Design a biocompatible material capable of protecting target analytes in biofluids (bodily fluids like blood, saliva, CSF, etc.) against degradation and interference, while selectively capturing them. This material should selectively bind to specific biomarkers, resist degradation, and possess antimicrobial properties. This material should facilitate strong analyte protection, high capture efficiency, and adaptability for application across diverse biofluids, for more precise and efficient diagnoses. The goal is to enhance capture efficiency, ensure accurate analysis, and improve diagnostic capabilities across various biofluids.

Potential Outcome:

- Improved protection and selective capture of target analytes will lead to more accurate and reliable diagnostic results.
- High capture efficiency and reduced degradation will enhance the overall efficiency of diagnostic processes.
- Antimicrobial properties will minimize the risk of microbial contamination, ensuring cleaner and more accurate sample analysis.

Expectations from the team:

- Develop a material that can selectively bind to specific biomarkers in various biofluids, minimizing non-specific interactions.
- Ensure the material resists degradation in harsh biological environments to maintain its functionality over extended periods.
- Incorporate antimicrobial features to prevent microbial contamination and ensure the integrity of captured analytes.

- Design the material to be adaptable for use across different biofluids, ensuring consistent performance and reliability.
- Optimize the material for high capture efficiency of target analytes, improving diagnostic accuracy.
- Ensure the material is biocompatible, avoiding any adverse reactions when in contact with biofluids.

MME08: AI-Powered Refractory Monitoring and Optimization

The efficient operation of high-temperature industrial furnaces is crucial for various manufacturing processes across multiple industries, including steel, cement, glass, and ceramics. Central to the functionality of these furnaces is the integrity of their refractory linings, which protect the furnace walls from extreme temperatures, chemical corrosion, and mechanical stress. However, the maintenance and management of refractory linings present significant challenges due to the harsh operating conditions and the complex nature of degradation mechanisms.

Current Challenges:

- Conventional refractory inspections are manual, time-consuming and lack real-time insights into lining conditions, leading to overlooked early indications of degradation and necessitating reactive maintenance.
- Inadequate consideration of dynamic process variations and material properties in furnace settings results in uneven wear and a diminished lifespan of refractory materials.
- Inefficient furnace operation due to lack of real-time feedback on refractory health can lead to premature wear and energy wastage.
- Furnace operations are often suboptimal due to a lack of precise control over refractory conditions, impacting energy efficiency and operational costs.
- Variations in temperature, pressure, feedstock composition, and operational modes affect refractory lifespan in intricate ways. Existing models struggle to capture these complexities and provide actionable insights.
- Refractory replacements are expensive, and frequent repairs significantly impact operational costs. Optimizing furnace conditions and maximizing refractory lifespan would lead to substantial cost savings.

Problem Statement:

Develop an AI-powered monitoring and optimization system for real-time assessment of refractory linings in high-temperature industrial furnaces. Utilize AI-enabled sensors to continuously evaluate refractory health, predict remaining life, recommend adjustments, and optimize furnace operations for extended refractory lifespan and enhanced energy efficiency.

Potential outcome:

- The implementation of an AI-powered refractory monitoring system is expected to significantly reduce operational costs by enabling predictive maintenance and optimizing furnace operations.
- The system can proactively identify potential issues, allowing for timely maintenance interventions, potentially extending the lifespan for refractory linings, and reducing the frequency and costs associated with replacements.

Expectations from the team:

- Design a network of advanced sensors (including thermal, acoustic, vibration, and image analysis) and placement strategies for accurate real-time data collection and continuous monitoring of critical parameters such as temperature and stress within the refractory lining.
- Develop AI algorithms to facilitate real-time monitoring, failure prediction, and dynamic optimization.
- Design a decision support system that uses AI predictions to recommend optimal furnace operating parameters for maximizing refractory lifespan and minimizing energy consumption.
- Evaluate the potential for the system's integration with existing industrial setups and scalability to different furnace types.