Sustainable Waste Management in the Fertilizer Industries in Paradeep: A Circular Economy Approach

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Abstract

As industrialization accelerates, effective waste management within the fertilizer industry has become a critical concern, especially in regions like Paradeep, Odisha, home to some of India's leading fertilizer production facilities. This study focuses on sustainable waste management in fertilizer industries in Paradeep through the lens of a circular economy approach. The research aims to evaluate current waste management practices, assess their environmental impact, and propose strategies for optimizing resource utilization while minimizing waste.

The study employs a comprehensive analysis of secondary data, case studies, and insights from key stakeholders to explore how circular economy principles can transform waste into valuable resources. This includes reducing waste generation, recovering essential materials, and mitigating environmental harm. By adopting these principles, Paradeep's fertilizer industries can achieve enhanced economic viability, resource efficiency, and reduced environmental degradation.

The research is divided into five chapters, addressing the critical aspects of waste characterization, environmental impact assessment, and the application of sustainable practices in the fertilizer industry. The outcomes are expected to contribute to sustainable development in Paradeep, offering a model for waste management that balances industrial growth with environmental stewardship.

Keywords: Sustainable Waste Management, Circular Economy, Phospho-gypsum Management, Zero Liquid Discharge (ZLD), Effluent Treatment Plant (ETP), Resource Recovery, Environmental Impact Assessment, Hazardous Waste Management, Waste Valorization, Hydrofluorosilicic Acid Recovery, Green Technology Initiatives, Community-Based Waste Management

1. Introduction

Industrial development has significantly contributed to India's economy, with the fertilizer industry alone accounting for about 25% of the national GDP. Paradeep, located in Odisha, has emerged as a critical industrial hub, home to major fertilizer industries such as Paradeep Phosphates Limited (PPL) and the Indian Farmers Fertilizer Cooperative Limited (IFFCO)[1]. While the fertilizer sector supports agricultural productivity, it also generates substantial amounts of solid, liquid, and gaseous wastes that, if mismanaged, can severely impact the environment by polluting air, water, and soil. Given the limitations of the traditional linear economy model—characterized by the "take-make-dispose" approach—there is a pressing need for adopting a circular economy framework [2,3]. This model focuses on waste minimization, resource recovery, and the transformation of waste into valuable secondary products, ensuring economic viability and environmental sustainability.

This study aims to develop a sustainable waste management framework for Paradeep's fertilizer industries through the application of circular economy principles. The objectives include assessing the current waste generation and its environmental impacts, analyzing existing waste management practices through primary and secondary surveys, and proposing strategies to enhance resource efficiency and minimize waste. The scope is specifically limited to Paradeep's fertilizer industries, focusing on production units and their environmental management practices. It covers critical aspects such as waste characterization, environmental impact assessment, resource recovery strategies, and feasible implementation models for sustainable waste management. However, the study faces certain limitations, such as the restricted availability of comprehensive industrial data and the rapidly evolving nature of industrial technologies, which may require periodic updates to the proposed framework.

The expected outcomes of this research include the identification and quantification of waste streams, evaluation of existing waste management practices, development of sustainable strategies aligned with circular economy principles, and an analysis of environmental and economic benefits. Policy recommendations based on the findings will help strengthen regulatory compliance and promote sustainable industrial development. By adopting the proposed strategies, Paradeep's fertilizer industries can set a benchmark for integrating circular economy principles into industrial waste management, achieving a balance between industrial growth and environmental protection, and contributing significantly toward sustainable development goals.

2. Methodology

2.1 Identification of the Problem

Understanding the existing scenario and analyzing the future aspects.

2.2 Aim of the Study

Strengthening a circular economy framework for fertilizer industries in Paradeep, optimize resource utilization, minimize waste, and mitigate environmental impact.

2.3 Objectives of the Study

1. To assess current waste generation and its environmental impact.
2. To develop a sustainable waste management framework using a circular economy approach.
3. To analyze the fertilizer industries' waste through primary and secondary surveys.
4. To evaluate the feasibility and propose implementation strategies for the developed framework.

2.3.1 To Assess Current Waste Generation and Its Environmental Impact

Studied and reviewed SPCB guidelines, Studied different types of waste generated from fertilizer industries, Analyzed the environmental impact of different wastes.

2.3.2 To Develop a Sustainable Waste Management Framework Using a Circular Economy Approach

Studied key concepts about Sustainable Waste Management and Circular Economy principles and benefits, Studied the current conditions of fertilizer industries in India and Odisha, and types of wastes generated.

2.3.3 To Analyze the Fertilizer Industries' Waste through Primary and Secondary Surveys

- Prepared a questionnaire for the field survey.
- Visited two fertilizer industries in Paradeep and collected primary data.
- Collected qualitative and quantitative data based on parameters like waste quantity, waste management techniques, and disposal methods.
- Prepared flowcharts showing how waste is circulated in the circular economy model.

2.4 Literature Study

- Studied journals like:
  - "Organic Desorption and Chemical Regeneration of spent carbon developed from fertilizer waste slurry" by S. K. Srivastava and Renu Tyagi, 1995.

- "Process development for the removal of substituted phenol by carbonaceous adsorbent" by S. K. Srivastava, Renu Tyagi, Naresh Pal, and Dinesh Mohan, 1997.
- "Nitrogenous Wastewater Treatment by activated algae" by S. K. Gupta, 1985.
- "Waste Management Strategy of a Fertilizer Plant" by R. Bhutiani, D.R. Khanna, and P.P. Sarkar, 2003.
- "Industrial hazardous waste management studies" by R.P. Prajapati, Anand Sharma, and D.R. Tiwari, 2009.

- Studied case studies:
  - **International Case Study** – Floodplain Lakes as an Indicator of Increasing Industrial Pollution (Fertilizer Factory, Poland).
  - **National Case Study** – Waste Management Strategy of Fertilizer Plant, IFFCO, Aonla, Uttar Pradesh.
  - **Case Study on Circular Economy Model and SDGs** (Latin America and the Caribbean Foundations).

2.5 Data Collection and Analysis

Major wastes generated from fertilizer industry. Phospho-Gypsum Management and Resource Circulation. Gypsum Management. SPCB Guidelines for development of basic infrastructure of gypsum handling and storage. Initiatives for Phospho-Gypsum Management and Resource Circulation. Fluorine Management and Valorization. Disposal of sludge from ETP. Disposal of sulphur muck. Existing scenarios of fertilizer industries of Paradeep (SPCB data).

2.5.1 Major Wastes Generated from Fertilizer Industries

Name of the Solid Waste	Source	Category
Phospho-Gypsum	Phosphoric Acid Plant	Non-Hazardous
Sulphur Muck	Sulphuric Acid	Hazardous
Sludge from ETP	ETP	Hazardous
Fluorine	Phosphoric Acid Plant	Hazardous

Table no 1: Major Wastes Generated from Fertilizer Industries

2.5.2 Phospho-Gypsum Management & Resource Circulation

Paradeep Phosphates Limited (incorporated in 1981) is a premier fertilizer company engaged in manufacturing of complex phosphatic fertilizers. Phosphogypsum (PG) is a waste material, generated about 5 units from the production of 1 unit of phosphoric acid (P2O5) in PAP by reacting rock phosphate ores (Imported) and Sulphuric acid. PG generated in PAP is dumped in slurry form at designated gypsum pond. After settlement of solid inside the gypsum pond, water containing 1-2% P2O5 from the pond is further utilized in the phosphoric acid production process. Major portion of the solid gypsum after excavation & natural drying are sold to domestic and international customers and part used for internal use in different application. Gypsum sold are majorly used in cement industry in the cement manufacturing process as retarding agent of cement which is mainly used for regulating the setting time of cement and is an indispensable component.

Paradeep Phosphates Limited (incorporated in 1981) is a leading fertilizer company engaged in the manufacturing of complex phosphatic fertilizers.

- Products:
    - DAP (Diammonium Ammonium Phosphate)
    - NPK (Nitrogen Phosphorous Potassium)
- Production Capacity:
    - 4 identical trains, 1.9 million MT/year
- Raw Materials:
    - Phosphoric Acid
    - Sulphuric Acid
    - Ammonia

- Phospho Gypsum Generation
  Phospho-gypsum is generated during phosphoric acid (P_2O_5) production at the Phosphoric Acid Plant (PAP).
  Approximately 5 units of Phospho-gypsum are produced for every 1 unit of phosphoric acid (P_2O_5).
- Production Process
  The production of phosphoric acid involves reacting imported rock phosphate ores with sulfuric acid.
- Phospho Gypsum Disposal
  After production, the Phospho-gypsum is dumped in slurry form at a designated gypsum pond.
- Water Utilization
  Once the solids settle in the gypsum pond, the water (containing 1–2% P_2O_5) is extracted and reused in the phosphoric acid production process.
- Gypsum Sales
  A significant portion of the solid gypsum is excavated, naturally dried, and sold to both domestic and international customers.
- Internal Use of Gypsum
  Part of the gypsum is retained for internal applications within various processes inside the plant.

Gypsum sold are majorly used in cement industry in the cement manufacturing process as retarding agent of cement which is mainly used for regulating the setting time of cement and is an indispensable component. Phospho-gypsum is mixed with water to create a slurry, which is then transported to the storage center. This process results in significant water wastage and contamination.

2.5.3 Gypsum Management

- Sale to domestic & International Market
  - Cement industry
  - Building construction material
- Use of Gypsum in road and infrastructure development
- Manufacturing of Zypmite (A value added product as water soluble fertilizer)

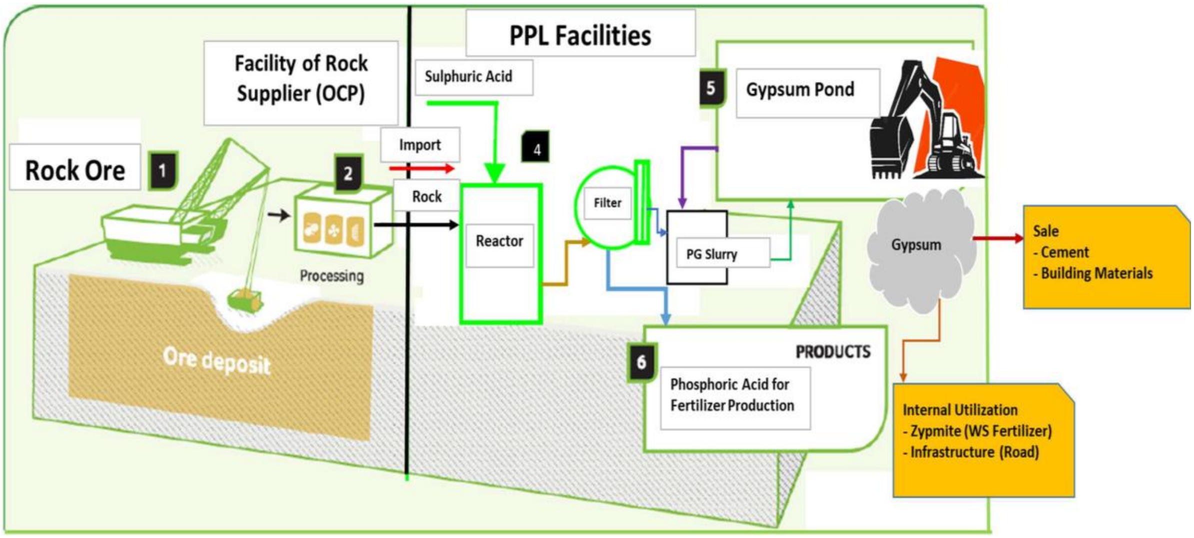


Figure no 1: Resource circulation: Rock deposit >>> Phosphoric Acid in Fertilizer manufacturing & Waste product (Phospho-gypsum) Utilization

Construction of Road using Neutralized Phospho Gypsum

Based on the sample road at PPL Site "Indian Road Congress" (IRC) approved that NPG can be used for the construction of road such as embankment, subgrade and granular sub base layers. PPL proposed to use NPG in the upcoming new approach road to Plant & Township from our Zero Point (Paradeep Port Authority's Flyover drop point) to the road leading to Plant near Shymakoti Bridge.

2.5.4 Fluorine Management and Valorization

Environmental & Production Upgrade: PPL Paradeep is enhancing its production by adding a fifth evaporator and equipping all units with Fluorine Recovery Units (FRUs) to improve phosphoric acid concentration, reduce fluorine emissions, and strengthen environmental sustainability in its manufacturing process.

Sustainability and Compliance: The upgrade ensures adherence to emission standards, minimizing environmental impact while promoting responsible production. By integrating FRUs into all evaporators, PPL Paradeep reinforces its commitment to sustainable operations, regulatory compliance, and enhanced environmental protection in phosphoric acid processing.

Vapour from concentration section of Phosphoric Acid Plant (PAP) containing hydrofluosilicic acid is recovered in the absorption column as 18-22% FSA.

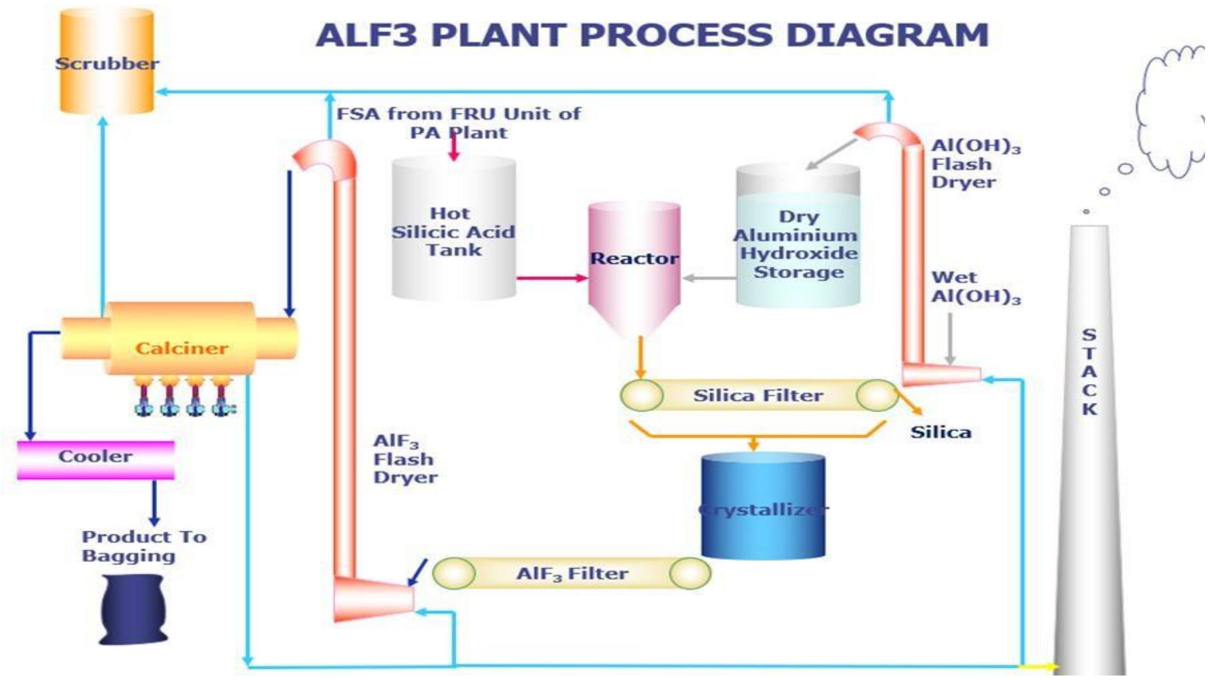
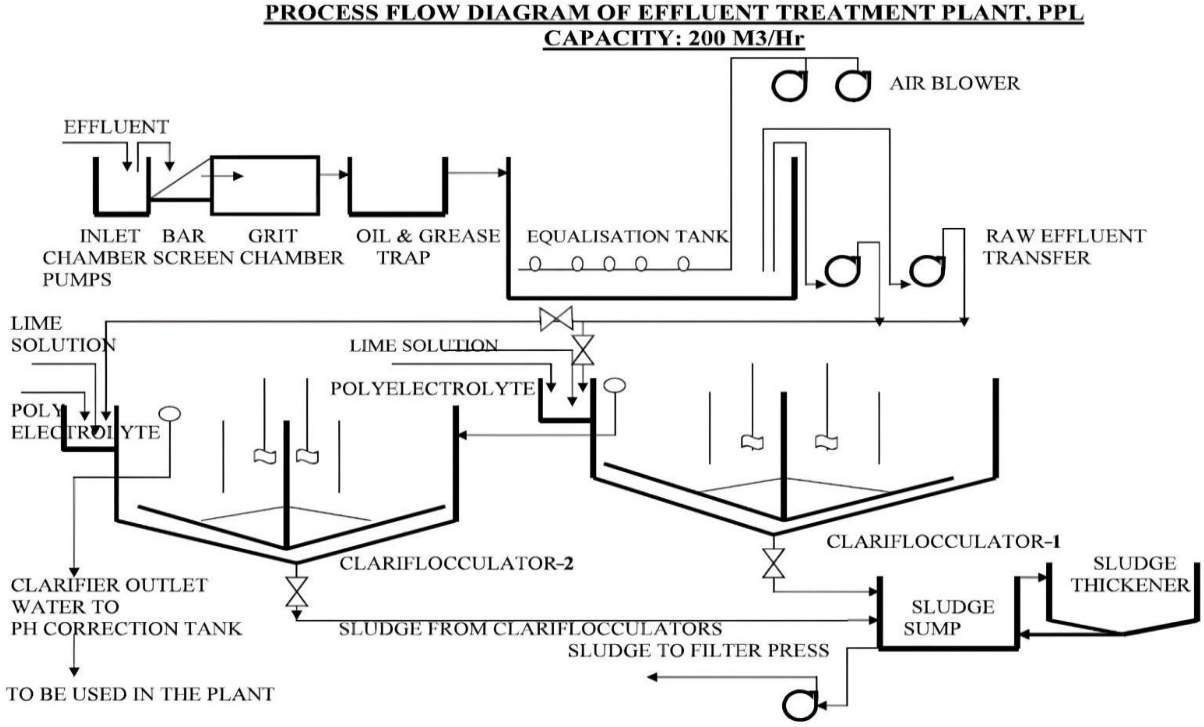


Figure no 2: ALF3 Plant Process Diagram

2.5.5 Disposal of Sludge from Effluent Treatment Plant



2.5.6 Disposal of Sulphur Muck

Sulphur Muck is generated during production of sulphuric acid in sulphuric acid plant. Solid raw sulphur before being fed to the melting tanks is mixed with lime to neutralize the free acidity in sulphur. After melting, liquid sulphur is filtered and fed to the sulphur burners. Sulphur muck containing about 60% sulphur is generated during filtration. Sulphur muck shall be used as filler in DAP plant which increases the sulphur content in DAP fertilizer.

2.5.7 Pollution Control Measures Adopted by Fertilizer Industries

Sl.No	Name & Address of the Industry	Product	Capacity	APC Measures
1.	IFFCO Ltd., Paradeep	Phosphatic Fertilizer	1.92 MTPA	Alkali Scrubber, Ventury Scrubber, ESP
		Electric Energy	64 MW	Alkali Scrubber, Ventury Scrubber, ESP
2.	PPL, Paradeep	Phosphatic Fertilizer	1.5 MTPA	Alkali Scrubber, Three Stage Fume Scrubber, Ventury Scrubber, Cyclone

		Electric Energy	55 MW	Alkali Scrubber, Three Stage Fume Scrubber, Ventury Scrubber, Cyclone
		Zynmite	240 TPD	Alkali Scrubber, Three Stage Fume Scrubber, Ventury Scrubber, Cyclone

Table no 2: Pollution Control Measures Adopted by Fertilizer Industries

2.6 Inferences and Conclusions

- Issue 1: Transportation of Gypsum to Storage Sites via Pipes in Slurry form Leading to High Water Contamination and Wastage
  - Large amount of water is required to create and transport the gypsum slurry.
  - Additional energy and resource are needed for water treatment and recycling.
  - Spills or leaks from pipelines can contaminate surrounding soil and water bodies.

- Issue 2: Use of Large Number of Plastic Bags for Packaging of Fertilizers Causing Environmental Pollution
  - Fertilizer bags, made from non-biodegradable plastics like polypropylene or polyethylene, accumulate in landfills and the environment, leading to long-term pollution and microplastic contamination in soil and water.
  - Leftover fertilizer in discarded plastic bags can leach into soil and water bodies, causing nutrient pollution, eutrophication, and harm to aquatic ecosystems.
  - In many areas, plastic fertilizer bags are burned for disposal, releasing toxic fumes and greenhouse gases that contribute to air pollution and climate change.

- Issue 3: Accumulation of Leftover Phosphogypsum creates a Waste Management Challenge
  - After the massive sale of gypsum, the fertilizer industry still have large amounts of leftover waste gypsum as a byproduct of phosphate-based fertilizer production.
  - Unused gypsum often accumulates in landfills, contributing to environmental issues like soil contamination, water pollution and land degradation.
  - If not properly managed, gypsum waste can disrupt ecosystems and create long term sustainability challenges.

2.7 Proposals and Recommendations

1. Pneumatic Transport (Dry Gypsum) : Instead of using water, gypsum can be transported in a dry, powdered form using compressed air through pipelines.

Advantages:

- Eliminates Water Usage: No need for water treatment or drying.
- Reduces Pipeline Wear: No abrasive slurry, lowering maintenance costs.
- Faster Transport: High-speed airflow ensures quick gypsum transfer.
- Compact Storage: Dry gypsum takes up less space than wet slurry.

2. Belt Conveyor Systems (Dry Bulk Gypsum) : Instead of pipelines, covered conveyor belts can transport gypsum in a solid or granulated form.

Advantages:

- No Water Required: Completely dry transport system.
- Lower Maintenance Costs: No pipe corrosion or clogging issues.
- High Capacity: Can handle large volumes of gypsum at once.
- Energy Efficient : Uses less energy compared to slurry pumping.

3. Instead of using plastic for fertilizer packaging, the industry can switch to biodegradable packaging made from mushrooms (mycelium).

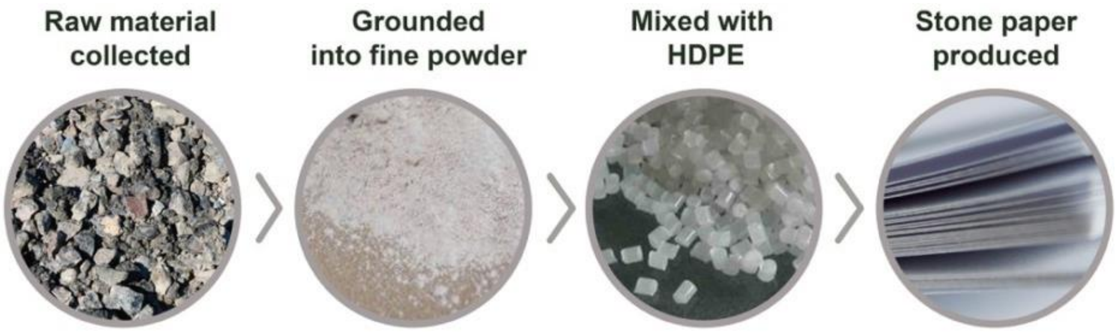
- Mycelium, the root-like structure of fungi, can be grown into durable, lightweight, and compostable materials that replace plastic.

Advantages:

- Replaces Plastic Waste: No more plastic pollution from fertilizer bags
- 100% Biodegradable: Decomposes naturally, leaving no toxins.
- Enhances Soil Health: Mycelium improves soil structure when broken down.
- Sustainable & Cost-Effective: Uses agricultural waste as raw material, reducing costs.

4. Circular Economy in Paper Industry: Fertilizer industry by-products, including mineral residues, and bio-based compounds, can be repurposed to create sustainable textiles, and biodegradable paper alternatives. This promotes a circular economy, where waste from one industry becomes valuable raw material for another.

- Phospho-gypsum and calcium-rich residues can be processed into stone paper, an eco-friendly, tree-free alternative to traditional paper. Stone paper is water-resistant, durable, and recyclable making it ideal for packaging, printing, and notebooks.



Conclusion

In conclusion, this thesis has thoroughly examined sustainable waste management practices within the fertilizer industries in Paradeep, employing a circular economy approach. As industrial activities expand in this critical region of Odisha, the necessity for effective waste management strategies becomes ever more vital. This study has identified the extensive range of waste generated by the fertilizer production processes, including solid, liquid, and gaseous emissions, and highlighted the environmental impacts accompanying these discharges.

The adoption of circular economy principles offers a transformative pathway for the fertilizer sector, allowing for the minimization of waste generation, maximization of resource recovery, and significant reduction of environmental harm. By focusing on waste as a potential resource rather than a liability, the industry can not only enhance its economic viability but also contribute positively to environmental sustainability.

Key recommendations made in this research include optimizing current waste management frameworks, implementing advanced waste treatment technologies, and promoting the repurposing of by-products into valuable materials. Through collaboration between stakeholders—including policymakers, industry leaders, and local communities—a more sustainable future can be achieved.

Ultimately, this thesis provides a comprehensive framework that not only addresses the immediate waste management challenges faced by the fertilizer industries in Paradeep but also offers a scalable model for other regions confronting similar environmental issues. By embracing sustainable practices and circular economic principles, the fertilizer industry can play a pivotal role in fostering a resilient and sustainable ecosystem for agriculture and the environment alike.

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