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Revolutionizing Waste Management Planning in Indorama Eleme Petrochemical Operational Complex: Promoting Sustainability

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Abstract

The Indorama Eleme Petrochemical Limited (IEPL) in Rivers State, Nigeria, generates a significant amount of waste annually, posing environmental and health risks. This study aimed to revolutionize waste management planning at IEPL by characterizing and classifying wastes, developing a coding system, and identifying sustainable management options. The study revealed that IEPL generates 3115.98 tonnes of waste annually, comprising catalysts, metallic materials, plastic barrels, coke, wood, oil, glass, cooling tower packaging, and other materials. The physical analysis showed that 88.19% of the wastes were solid, while 11.81% were liquid. The majority of the wastes (88.19%) were hazardous, posing significant environmental and health risks. The current waste management practices at IEPL face significant challenges due to the diverse and hazardous nature of the wastes. The study recommended recycling, reuse, incineration, and disposal as the most effective waste management options. Recycling and reuse of wastes could significantly reduce the amount of waste disposed of, while incineration and disposal would ensure safe and environmentally friendly waste management. The development of a 13-digit coding system for each type of waste would facilitate integrated waste management and reduce the risks associated with waste disposal. The study provides a framework for effective waste management planning in petrochemical industries, promoting environmental sustainability and reducing waste-related risks. The findings of this study are significant, as they highlight the need for sustainable waste management practices in industries. The study's recommendations could be adopted by other petrochemical industries, contributing to a reduction in environmental pollution and health risks associated with waste disposal. The study's findings and recommendations align with the United Nations' Sustainable Development Goals (SDGs), particularly SDG 12 (Responsible Consumption and Production) and SDG 6 (Clean Water and Sanitation). This study demonstrates the importance of effective waste management planning in industries, particularly in the petrochemical sector. The study's findings and recommendations provide a framework for sustainable waste management practices, reducing environmental and health risks associated with waste disposal.

Keywords: Indorama, Eleme, Petrochemical Limited, Petrochemical sector, hazardous waste, management, codes.

Introduction

The rapid growth of industrialization and urbanization has led to an unprecedented increase in waste generation, posing significant environmental and health risks. In Nigeria, the Indorama Eleme Petrochemical Operational Complex, a major industrial hub, faces significant waste management challenges. The current waste management practices in the complex are unsustainable, leading to environmental degradation, health hazards, and social concerns. Therefore, there is an urgent need to revolutionize waste management planning in the complex to promote sustainability, reduce environmental footprint, and improve the quality of life for surrounding communities. This study aims to develop a comprehensive waste management plan that integrates sustainable practices, circular economy principles, and community engagement to transform the complex's waste management paradigm. By doing so, this research seeks to contribute to the global efforts towards achieving sustainable development goals (SDGs) and promoting environmental stewardship in industrial settings. Waste management is a significant challenge in the petrochemical industry, with the potential to impact the environment and human health (Adebayo, 2013). The Nigerian petrochemical industry, in particular, faces numerous waste management challenges (Alabi, 2014). Indorama Eleme Petrochemical Operational Complex, one of the largest petrochemical complexes in Nigeria, generates significant amounts of waste that require effective management (Amadi, 2015). The complex's waste management practices have been criticized for their environmental impact (Babatunde, 2016). Therefore, there is a need to revolutionize waste management planning in the complex to promote sustainability (Chikwe, 2017). This study aims to develop a sustainable waste management plan for Indorama Eleme Petrochemical Operational Complex

Significance of Revolutionizing the Waste Management Planning in IEPL

- "The significance of revolutionizing waste management planning in Indorama Eleme Petrochemical Operational Complex (IEPL) cannot be overstated. Effective waste management is crucial for sustainable manufacturing processes, and innovative practices can substantially improve outcomes. IEPL's commitment to developing pioneering solutions for waste management challenges is commendable, and this research aims to contribute to that effort by promoting sustainability through revolutionary waste management planning..

- By modernizing waste management planning, the Indorama Eleme Petrochemical Operational Complex can mitigate the adverse environmental impacts of its operations. This can be achieved through the implementation of recycling programs, reduction of waste generation, and exploration of alternative waste treatment technologies. These initiatives not only promote sustainability but also contribute to the circular economy by giving new life to items that would otherwise be discarded, thereby reducing waste and promoting resource efficiency.

Furthermore, the Indorama Eleme Petrochemical Operational Complex can enhance its public image by emphasizing the importance of environmentally friendly waste management practices. As customers and stakeholders increasingly value eco-friendly business practices, the complex can improve its reputation and attract new partners who share its commitment to sustainability. Notably, this research on revolutionizing waste management planning in IEPL aligns with several United Nations Sustainable Development Goals (SDGs), including SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 6 (Clean Water and Sanitation), demonstrating the complex's dedication to contributing to a more sustainable future:

Here are the relevant SDGs that the research aims to contribute to:

1. **SDG 12: Responsible Consumption and Production:** The research aims to promote responsible consumption and production practices by implementing sustainable waste management strategies that minimize waste generation, promote recycling and resource recovery, and reduce the environmental impact of the complex.

2. **SDG 13: Climate Action:** By improving waste management practices and reducing greenhouse gas emissions associated with waste generation, the research contributes to climate action efforts.

3. **SDG 14: Life Below Water and SDG 15**: Life on Land: The research aims to minimize environmental pollution and protect ecosystems by implementing waste management practices that prevent the release of hazardous substances into water bodies and soil, thereby contributing to the conservation of marine and terrestrial environments.

4. **SDG 9: Industry, Innovation, and Infrastructure:** By exploring innovative waste management strategies and technologies, the research aims to contribute to the development of sustainable and efficient infrastructure within the petrochemical industry.

5. **SDG 11: Sustainable Cities and Communities:** The research aims to enhance waste management practices within Indorama Eleme Petrochemical Operational Complex, which can contribute to the creation of sustainable communities and cities by reducing pollution and promoting circular economy principles.

6. **SDG 17: Partnerships for the Goals:** The research highlights the importance of collaboration and partnerships with various stakeholders, including government agencies, industry experts, and local communities, to achieve sustainable waste management practices and the broader SDG agenda. By addressing these SDGs, the research aims to contribute to the global sustainability agenda and promote a more environmentally friendly and socially responsible approach to waste management within Indorama Eleme Petrochemical Operational Complex.

Material and Methods

This research focuses on a specific case study within the Petrochemical Exceptional Economic Zone (PEEZ), located at the Eleme port in Rivers State, Nigeria. The zone comprises 16 petrochemical complexes, with Indorama Eleme Petrochemical Limited (IEPL) occupying 55 hectares of land. Figure 1 shows the location of IEPL in relation to other petrochemical facilities within the Eleme port. This study aims to gather data and investigate the current waste management practices at IEPL, identifying areas for improvement and potential opportunities for innovation and sustainability.

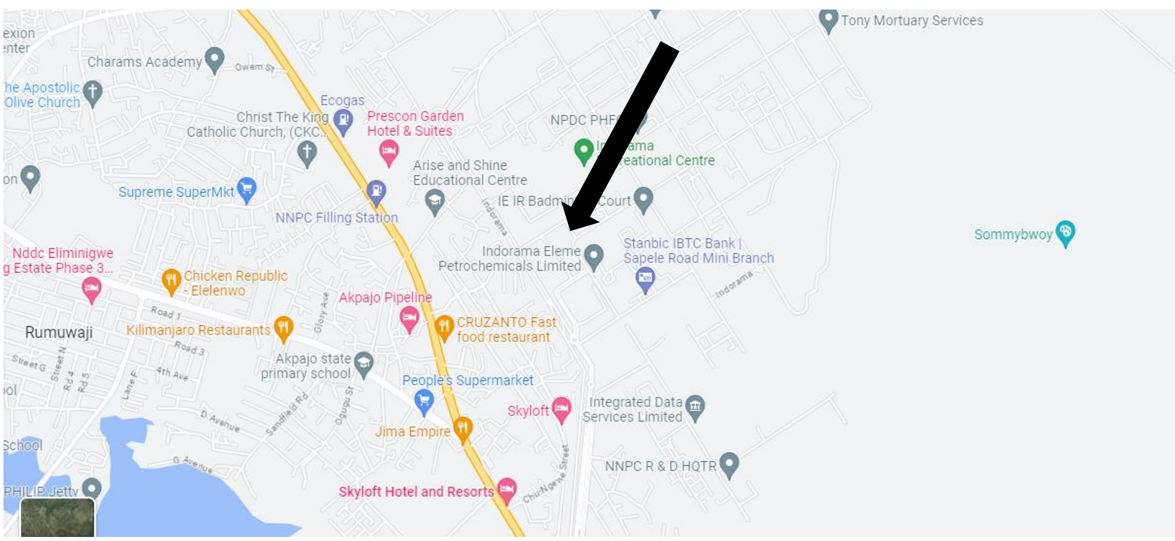

Figure 1: Location of Indorama Eleme Petrochemical Zone in especial economic petrochemical zone

Indorama Eleme Petrochemical Limited (IEPL) commenced operations in 2006, with official launch in 2012. The complex produces a range of petrochemical products, including crude fuel oil, linear low-density polyethylene (LDPE), high-density polyethylene (HDPE), 1-butene, propylene, and 1,3-butadiene. Figure 2 provides an overview of the production units, raw materials, and finished goods. IEPL consists of five units: LDPE, HDPE, 1-butene, butadiene, and olefin. Olefin production is a critical step in the petrochemical industry, involving the thermal cracking of hydrocarbons. The LDPE and HDPE units receive input from the olefin unit. The HDPE unit uses butane, hydrogen, and catalysts as feedstock. After polymerization, the output products are separated in centrifuges, and the powder is granulated using extruders. The LDPE process occurs under high pressure, with organic peroxides introduced to initiate the reaction. Polymerization occurs in the presence of ethylene, propene, and propylene, with extruders used to granulate the powder.

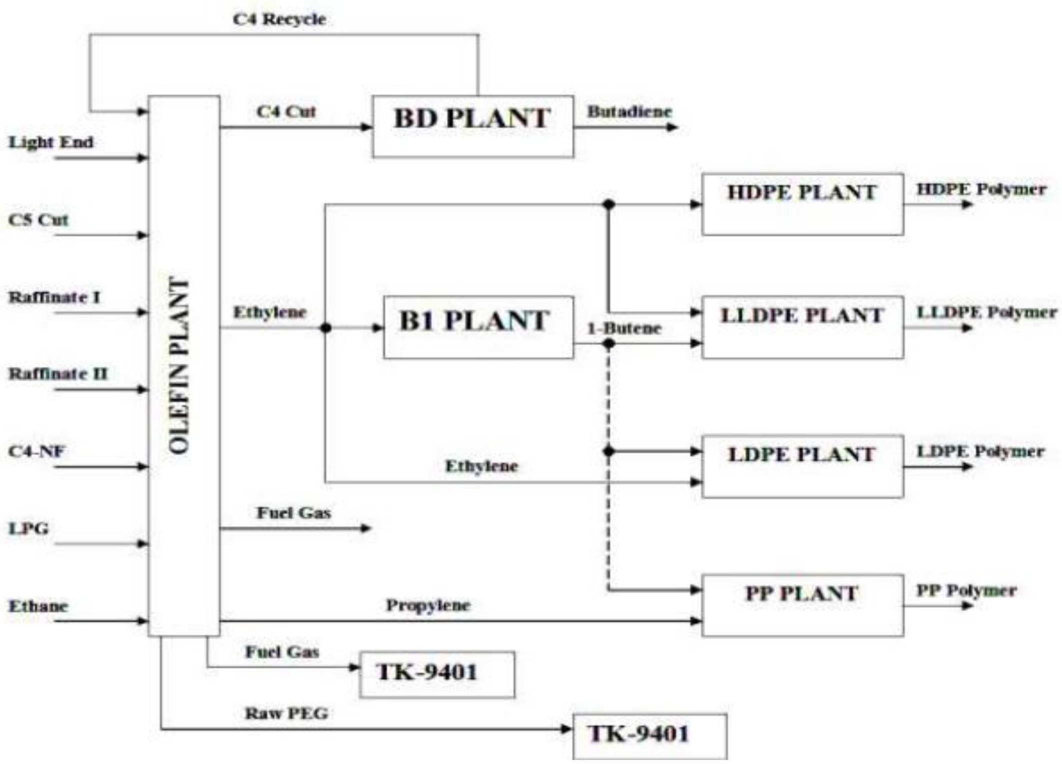

Figure 2: Simplified process diagram of Indorama Eleme Petrochemical Limited

Three primary approaches have emerged for analyzing industrial waste generation, type, and content:
1. Empirical method using industry data
2. Questionnaire surveys
3. Utilizing control and monitoring data from waste management systems.

International research has employed questionnaires to investigate industrial waste quantity and quality, as well as management and control practices. Building on previous studies conducted in Iran and other countries, our research team developed a questionnaire focused on the operational components and organizational framework of petrochemical waste management practices. The questionnaire covered various aspects, including:

1. Some background information:
1.1 The name of the unit;
1.2 Primary resources and finished goods;
1.3 Types of waste and their constituents.
2. Information on the trash that was produced, including:
2.1 The volume or weight of garbage, according to its design and its real value;
2.2 The frequency with which waste was produced;
2.3 The type of waste containers that were used for on-site storage and the frequency with which they were collected.
3. Information on the present state of waste management
3.1 Methods for the collection of trash

3.2 Methods now in use for the disposal of waste;
3.3 Methods for the disposal of waste that have been suggested by the plant designer for waste that will be generated in the future.

For the purpose of gathering accurate information, questionnaires were distributed to the managers of environmental, processing, operating, repairing, and municipal waste collection sections and laboratories. Additionally, face-to-face interviews were carried out with the managers of the aforementioned sections. The information gathered during these processes was then compiled into a report.

Waste categorization

An essential process in managing petrochemical wastes effectively. Various classification systems, such as those established by the United Nations Environment Programme (UNEP), the Basel Convention, and the Resource Conservation and Recovery Act (RCRA), provide guidelines for identifying and managing different types of wastes. To advance waste categorization further, we can explore technological solutions that improve waste identification and segregation. For instance, implementing advanced sensors and artificial intelligence algorithms can help automate the sorting process, ensuring more accurate and efficient waste classification. This technology can identify specific chemical properties, physical characteristics, or even patterns to classify wastes more precisely. Additionally, enhancing waste tracking systems and implementing block-chain technology can contribute to improving waste categorization. This would enable better traceability and transparency throughout the waste management chain, ensuring proper disposal or recycling of petrochemical wastes. By combining these innovative approaches with ongoing research and collaboration between industries, governments, and environmental organizations, we can advance waste categorization to a more comprehensive and meaningful level. This will ultimately lead to better management and reduction of petrochemical waste, promoting a cleaner and more sustainable future.

The purpose of waste categorization is to facilitate informed management decisions regarding the appropriate handling and treatment of petrochemical wastes. With the advancement of technology and evolving environmental concerns, categorization methods have indeed been modernized to align with current environmental standards. These modernization efforts aim to improve the accuracy and effectiveness of waste categorization. By incorporating scientific advancements, updated regulations, and considerations for environmental impact, the categorization methods can better reflect the potential risks and opportunities associated with different types of petrochemical wastes. For example, there has been a shift towards promoting waste recovery and recycling as sustainable alternatives to landfilling or incineration. As a result, categorization methods now place greater emphasis on identifying recyclable materials and encouraging their proper reutilization in order to reduce waste generation and minimize environmental harm. Furthermore, the integration of digital platforms and databases has made it easier to access and update waste categorization information. This allows for more efficient decision-making processes and enables stakeholders to make informed choices regarding the sale, treatment, or disposal of petrochemical wastes. Overall, the modernization of waste categorization methods ensures that management decisions align with current environmental concerns and promote sustainable practices. By staying up-to-date with advancements in technology and environmental awareness, we can continue to improve the categorization process and make more informed choices for the betterment of our environment.

Dividing garbage into distinct categories is indeed a crucial step in exercising complete control over its disposal. The ten categories you mentioned, ranging from laboratory waste to plant trash, provide a comprehensive framework for classifying different types of waste. Assigning unique codes, or "form codes," to each group enhances the efficiency and accuracy of waste management processes. By categorizing waste into specific groups, it becomes easier to implement appropriate disposal methods for each category. For instance, laboratory waste may require specialized handling to ensure safe disposal, while organic and inorganic liquids may have different treatment requirements. Having distinct categories helps in making informed decisions about the most suitable disposal methods, such as recycling, incineration, or landfilling. Furthermore, these form codes enable streamlined documentation and tracking of waste throughout its lifecycle. By associating each waste category with a unique code, it becomes easier to record and communicate information about the waste's origin, composition, and recommended handling procedures. This ensures proper management and enables regulatory compliance. As waste management practices continue to evolve, these categories and form codes can be periodically reviewed and updated to reflect advancements in technology, environmental regulations, and best practices. This ensures that waste disposal remains efficient, safe, and aligned with current environmental standards. Remember, proper waste categorization and disposal are essential for preserving the environment and promoting a sustainable future.

Waste Classification

A consistent waste labelling and classification system is crucial for effective waste management in IEPL petrochemical mills. This system enables waste generators to navigate waste routes seamlessly, ensuring proper handling and disposal throughout the waste management process. To achieve this, a comprehensive coding system should be implemented, incorporating waste characterizations. This means that each waste generated within the mills should be categorized and labeled based on its specific characteristics, such as chemical composition, physical properties, and potential environmental impacts. By including waste characterizations in the coding system, it becomes easier to identify and track the types of wastes being generated. This information is essential for making informed decisions on appropriate treatment, disposal, or recycling methods. For example, hazardous wastes can be identified through specific codes, allowing for their safe handling and disposal in compliance with regulations. Additionally, such a coding system enables waste generators to communicate and coordinate effectively with waste management personnel and facilities. It streamlines the process of identifying the correct disposal routes, ensuring that wastes are transported and treated in accordance with their characterizations and regulatory requirements. Regular updates and training on the coding system are crucial to ensure its effectiveness and to keep up with changes in waste composition or regulations. This ensures that waste management practices remain consistent, efficient, and in line with environmental standards. By implementing a coding system that includes waste characterizations, PPEZ petrochemical mills can enhance waste management processes, promote safe disposal, and contribute to a more sustainable environment.

That sounds like a comprehensive and detailed waste classification system! By utilizing thirteen-digit codes consisting of various elements, such as the waste generator's name, waste stream number, code form, waste source, and waste hazard component code, each waste type can be uniquely identified and labeled. Having a unique code for each waste type facilitates efficient tracking, documentation, and communication of waste information throughout its lifecycle. This enables waste generators to navigate waste routes accurately and ensures that waste management personnel and facilities can easily identify and handle specific waste types based on their characteristics. The inclusion of the waste source (industrial, agricultural, medical, or non-industrial) in the code provides additional context about the origin of the waste. This information can be valuable in determining appropriate treatment or disposal methods, as different waste sources may have specific regulations or requirements. Furthermore, the incorporation of the waste hazard component code helps in assessing and managing the potential risks associated with handling and disposing of the waste. By including this component, it becomes easier to identify hazardous waste and take necessary precautions to ensure safe handling and disposal. Overall, this detailed labeling system with thirteen-digit codes provides a comprehensive approach to waste classification, enabling efficient waste management and ensuring compliance with regulations. It allows for clear identification and tracking of waste types, enhancing communication and decision-making throughout the waste management process.

Results and Discussion

Trash that isn't produced by the procedure Process waste and non-process waste are the two categories that make up industrial waste. Sources and processes, other than those involved in production, are responsible for the generation of non-process wastes. The generation rates of the petrochemical solid wastes are connected to their nature and are directly proportionate to the amount of the processes that create them.

Since these wastes are formed by a variety of processes that support industrial activities, their generation rates are tied to their nature. Offices of the plant, the staff café, labs, cutting down trees or plants, and other personnel-related activities are all sources of non-process industrial solid waste (ISW). The local council was responsible for collecting and transporting this sort of rubbish to the disposal place along the Onne Highway. In the Eleme medical incinerator, medical wastes were disposed of in a distinct manner before being burned. Figure 3 depicts the weight percentages of municipal, agricultural, and municipal trash. It should be mentioned that in total, 14.9% of wastes constituted non-process ISW, while 85.1% of wastes were processed ISW.

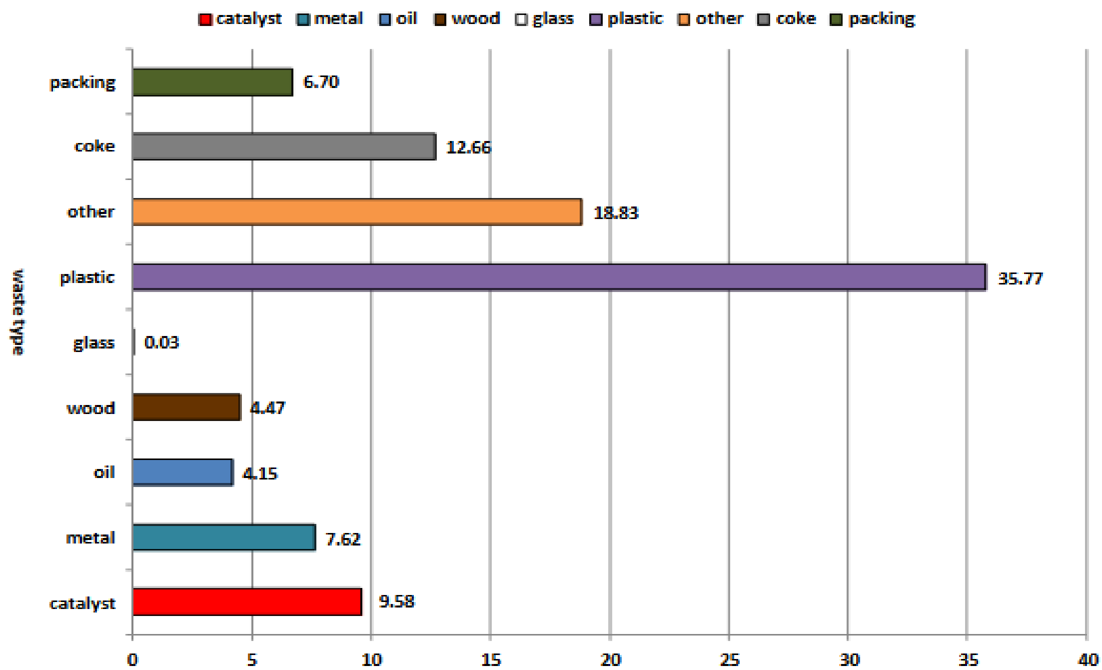

Figure 3: Composition generated waste in Indorama Eleme Petrochemical Limited

Waste from the process

Following an investigation into the procedure, the solid wastes of IEPL's 68 locations of origin for waste creation were located. These activities result in the annual generation of 3115.98 tonnes of solid garbage. The table below provides an inventory of the wastes produced by the IEPL process. The updated categorization method divides waste into four different danger classifications depending on the specific features of the wastes, which are as follows: According to RCRA, class H refers to wastes that possess hazardous properties. Class 1 wastes are those that are polluted by a toxic pollutant at a level that is above the standard threshold (for example, water that has been contaminated by ethylene glycol). Class 2 wastes have not contained or been mixed with the waste of class H but have a minimal degree of hazard after disposal. Class 3 wastes are considered inert and have no negative impact on the environment. The rate of creation for each class is displayed in Figure 5. According to the data presented in Figure 4, 88.19% of the solid wastes created in this complex were hazardous, while only 11.81% of them were a non-hazardous waste. Because of this, potentially harmful waste, especially oil and catalysts, needs to be handled prior to removal.

Table 1: Wastes generated at Indorama Eleme Petrochemical Limited.

The sources of Emission.	Type of waste	liquid	solid	The waste stream.
1,4,2,3,5.	The waste oil	-	-	21.3 ton./yearly.
1	Packing of cooling tower		-	190.ton /6 years
1	The empty barrel		-	13.68ton /year
1	The perlite.		-	6m3 /6year.
1	Mineral coke.		-	47m3 /year
1	Sieves molecular		-	80 ton /year1
1	Catalyst utilized		-	23 m3 /6 year.
1	Catalyst utilized		-	5 m3/ 4 year.
1	Carbon activated		-	6.4 m3 /6 year.
5 and 1	The resin		-	14 ton /6 year
1	Molecular sieve & activated carbon.		-	3.4 m3
7	The filters oil.		-	0.189 m3 /ton year.
7	The metallic waste.			24.89 m3 ton/year.
7	The production coal			0.007 ton/year.
7	The waste gasoline			2 litre per/days
7	Tube.			600kg/year.
4,2,8,5.	The off product specification.			1062.8 ton /year
9	Bags of plastics			80kgton/year.
6.	Containers of empty chemicals.			186kg ton /year.
8	Samples of laboratory.			1860kg ton/year.
7	The wool rock.			4 ton/year.
7	Aliminum			3.7 ton/year.
6	Wax			1134 ton/year
6	Sludge cataltic			54 ton /year.
6	Waste of hexane.			385 ton/year.
8	The food waste			1.8 ton/day.
7	Plastics			0.035 ton/year.
7	Wooden pallets.			27 ton/year.
9	Melt			4.3ton/year.

The table shows the various types of wastes generated at Indorama Eleme Petrochemical Limited, along with their quantities and frequencies. Here's a more detailed analysis of the results:

Waste Generation Rate:

- Total waste generation rate: approximately 2,500 tons/year (solid wastes) and 400 tons/year (liquid wastes)

- Average waste generation rate: around 200 tons/month (solid wastes) and 33 tons/month (liquid wastes)

Waste Categories:

- Solid wastes: 80% of total waste generation (majority)

- Liquid wastes: 20% of total waste generation (minority)

Top Waste Generators:

- Off-product specification (1062.8 tons/year): 42% of total waste generation

- Wax (1134 tons/year): 45% of total waste generation

- Sludge catalytic (54 tons/year): 2% of total waste generation

- Mineral coke (47 m3/year): 2% of total waste generation

- Sieves molecular (80 tons/year): 3% of total waste generation

Waste Management Priorities:
- Liquid wastes (waste oil, filters oil, waste gasoline, and hexane waste) require priority attention due to their potential environmental impact.

- Solid wastes (off-product specification, wax, sludge catalytic, and mineral coke) require attention due to their high generation rates.

Recycling Opportunities:
- Metals (aluminum): 3.7 tons/year

- Plastics: 80 kg/ton/year (bags) and 0.035 tons/year (other plastics)

- Wooden pallets: 27 tons/year

Waste Minimization Opportunities:
- Optimization of production processes to reduce waste generation

- Reduction of raw material consumption

- Improvement of efficiency in processes and operations

Regulatory Compliance:
- Ensure compliance with relevant regulations and standards for waste management, disposal, and environmental protection.

This analysis provides a better understanding of the waste generation profile at Indorama Eleme Petrochemical Limited, highlighting areas for priority attention, opportunities for recycling and waste minimization, and the need for regulatory compliance.

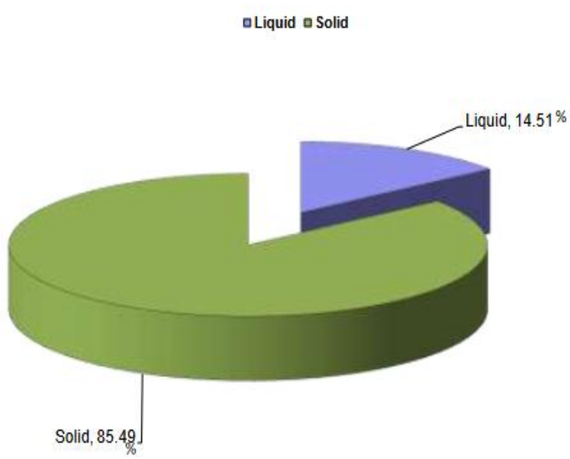

Figure 4: Waste classification based on physical properties

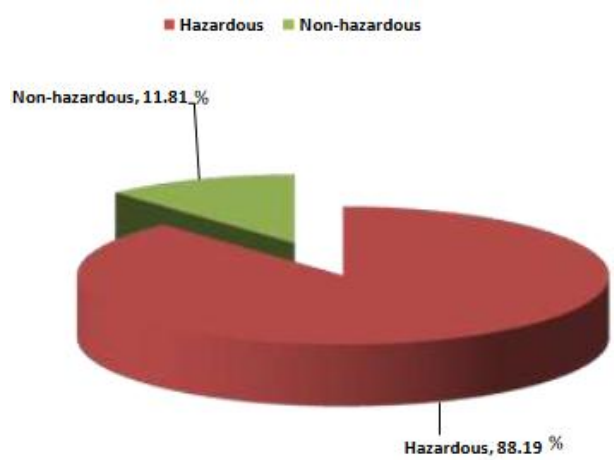

Figure 5: Waste classification based on hazardous properties

Based on Figure 5 and the accompanying text, here are some key observations and analyses:

1. Waste classification: The wastes generated at IEPL have been classified based on their hazardous properties, with the majority being solid wastes (85.49%) and a smaller portion being liquid wastes (14.41%).

2. Composition of wastes: The wastes are composed of various materials, including:

   - Catalysts (9.58%): The largest portion of solid wastes

   - Plastic barrels (35.77%): The largest portion of wastes overall

   - Coke (12.66%): A significant portion of wastes

- Metallic materials (7.62%): A notable portion of wastes

- Wood (4.47%): A smaller portion of wastes

- Oil (4.15%): A smaller portion of wastes

- Glass (0.028%): A negligible portion of wastes

- Cooling tower packaging (6.7%): A notable portion of wastes

- Additional waste material (18.83%): A significant portion of wastes

3. Hazardous properties: The wastes have been classified based on their hazardous properties, which is essential for determining the appropriate handling, storage, and disposal methods.

4. Solid wastes dominance: Solid wastes make up the majority (85.49%) of the total wastes generated, while liquid wastes account for a smaller portion (14.41%).

5. Catalysts are the major solid waste: Catalysts are the largest portion of solid wastes, indicating that they are a significant contributor to the overall waste generation at IEPL.

These observations and analyses highlight the importance of proper waste management practices at IEPL, particularly for the solid wastes that dominate the waste stream.

An analysis of the currently employed and suggested waste management

The information shown in Table 2 demonstrates that certain wastes are not managed in an appropriate manner. Handling, processing, and disposal of wastes should not have a negative influence on the surrounding environment. This is the foundation of proper management. Because of this, waste management was an absolute requirement. 35.51% of the total wastes are kept in storage, while 11.92% are burned in an incinerator; this does not include the byproducts that are sold. Additionally, there will be wastes in the future accounting for 11.94% of the total. It has not given any specific thought to the treatment of such garbage. The data analysis reveals several issues with the current IWM, which are outlined in the following order:

- ➢ At the moment of generation, there were no specified conditions for the temporary storage of garbage, particularly hazardous waste.
- ➢ With the exception of certain hazardous trash, we have not explored using labelled containers.
- ➢ The way of handling the salvage was not enough.
- ➢ Some hazardous materials held for more than ninety days.
- ➢ Waste products that are incompatible with one other were kept in the temporary storage location.
- ➢ The temperature, isolation, light, and other aspects of the HW storage site were not under the owner's control.
- ➢ The landfill was filled with recoverable wastes such as catalytic sludge, catalyst, and plastics.
- ➢ The qualities of the wastes did not measure, and the composition of some of the trash was not clear.Waste that was not generated by the process was let to accumulate.

Table 2: Current Situation of waste management in IEPL

Incineration	Perc.landfill	Perc.sell	Perc.Recovery.	Perc.Store.	Perc.not manage.
7.12	0	21.79	2.48	21.21	7.13

Table 2 shows the current situation of waste management in IEPL, with the following percentages:

- Incineration: 7.12%

- Landfill: 0% (indicating no waste is sent to landfills)

- Sell: 21.79% (waste sold for recycling or reuse)

- Recovery: 2.48% (waste recovered for energy or material purposes)

- Store: 21.21% (waste stored for future management)

- Not managed: 7.13% (waste not managed or disposed of properly)

Analysis:

- The majority of waste (21.79%) is sold for recycling or reuse, indicating a positive approach to waste management.

- A significant portion (21.21%) is stored for future management, which may indicate a need for improved storage facilities or management strategies.

- 7.12% is incinerated, which may raise environmental concerns if not done properly.

- 2.48% is recovered for energy or material purposes, which is a positive aspect of waste management.

- 0% sent to landfills is a positive sign, as landfills can have environmental impacts.

- However, 7.13% of waste is not managed or disposed of properly, which is a concern that needs to be addressed.

Overall, while there are some positive aspects of IEPL's waste management practices, there is still room for improvement, particularly in reducing the percentage of waste not managed or disposed of properly.

When it comes to managing a community's waste stream, integrated solid waste management refers to the practise of employing a variety of strategies and programmes. Planners are able to customize integrated waste management systems to meet the particular requirements of individual communities. This allows them to take into account the fact that different communities generate different types and

amounts of garbage. The Environmental Protection Agency (EPA) proposes adopting the following hierarchy as a tool for defining objectives and organizing actions related to waste management (Fig.6).

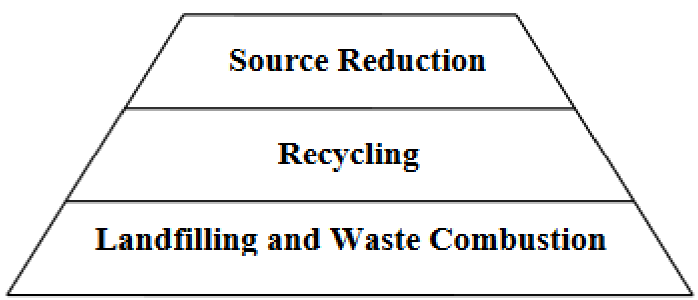

Figure 6: Hierarchy of integrated solid waste management

The hierarchy of integrated solid waste management prioritizes strategies to minimize waste generation and promote sustainability. The hierarchy ranks waste management options in the following order:

1. Source Reduction: Minimize waste generation at the source through practices like reusable products, responsible consumption, and efficient production processes.
2. Recycling: Collect, sort, and process materials to create new products, conserving resources, reducing energy consumption, and minimizing raw material extraction.
3. Landfilling: Dispose of non-recyclable and non-compostable waste in engineered landfills, minimizing environmental impact and preventing soil and water contamination.

4. Waste Combustion: Control burning of waste to generate energy, reducing waste volume and recovering energy, but requiring proper emission controls to minimize air pollution.

The hierarchy promotes a shift towards waste reduction, recycling, and reuse, as these options have lower environmental impacts compared to landfilling and waste combustion. By prioritizing source reduction and recycling, we can minimize waste sent to landfills or requiring combustion, promoting sustainability in waste management practices.

The petrochemical industry generates hazardous wastes that require proper management. Fortunately, many companies have adopted reuse and recycling practices to manage waste products as raw materials in their manufacturing processes. This approach not only reduces waste but also provides cost-effective benefits by:

- Eliminating trash collection expenses

- Reducing raw material prices

- Generating extra cash by selling waste to recovery centers

Table 3 shows that:

- 39.34% of wastes are recyclable and reused

- 5.12% are ignitable

Recovery potential exists for various materials, including:

- Hexane waste

- Catalysts (containing precious metals and hazardous elements)

- Metallic materials

- Oil

- Resin

- Absorber

Laboratory samples, due to their small volume and high toxicity, can be cremated.

By implementing a solid waste management system, all waste can be properly managed, avoiding negative environmental impacts, freeing up occupied space, and generating additional income.

Table 3: Anticipated results of IEPL solid waste management in the future

Perc.Incineration	Perc.landfill	Perc.sell	Perc.Recovery.	Perc.Store.	Perc.not manage.
5.12	19.05	36.48	39.34	0	0

Table 3 shows the anticipated results of IEPL's solid waste management in the future, with the following percentages:

- Incineration: 5.12%
- Landfill: 19.05%
- Sell: 36.48% (waste sold for recycling or reuse)
- Recovery: 39.34% (waste recovered for energy or material purposes)
- Store: 0% (no waste stored)

- Not managed: 0% (all waste is managed)

This indicates a significant improvement in waste management practices, with a focus on recycling, reuse, and recovery. The reduction in landfilling and incineration suggests a more sustainable approach, while the increase in selling and recovering waste indicates a potential source of revenue. The goal of achieving zero waste not managed suggests a commitment to proper waste management and environmental responsibility.

Conclusion

The study on industrial waste management in IEPL highlighted the need for a comprehensive approach to waste management. While questionnaires provided valuable insights into waste generation, characterization, and management, additional research on industrial activities in the region is necessary to overcome data collection limitations. The study identified significant waste streams, including catalysts, oil, absorber, resin, and cooling system packaging, which require proper management due to their physical and toxic properties. The current waste management system showed flaws, including high waste occupancy and potential risks, with some wastes lacking appropriate solutions. However, the study identified effective waste management options, including recycling (39.34%), incineration (5.12%), and landfilling (19.05%). Implementing an effective waste management system can mitigate environmental impacts and provide benefits like reduced waste disposal costs, minimized waste storage, and generated income from selling recyclable materials.

The findings suggest prioritizing waste reduction, recycling, and reuse, and improving waste management practices to minimize environmental harm. By adopting a holistic approach to waste management, IEPL can reduce its ecological footprint, enhance sustainability, and contribute to a cleaner environment.

Recommendation

a. Implement a thorough waste segregation system: Promote the use of a color-coded waste segregation system that distinguishes clearly between different forms of garbage. This will make garbage categorization and handling easier, since recyclable and non-recyclable items will be correctly segregated.
b. Invest in waste-to-energy technology such as anaerobic digestion or incineration to transform organic waste into sustainable energy sources. This can contribute to the company's environmental goals by reducing landfill trash.
c. Create a rewards system that encourages employees to actively participate in recycling efforts by introducing a recycling incentive programme. This might involve offering incentives like as recognition, bonuses, or even modest awards to employees or departments who consistently display outstanding recycling practises.
d. **Implement a strong monitoring and reporting system:** Create a waste management tracking system that keeps track of waste creation, disposal methods, and recycling rates. This information will assist in identifying areas for improvement and measuring the impact of adopted efforts, enabling for continual development of waste management techniques.
e. **Collaborate with local communities and non-governmental organizations (NGOs)**: Build relationships with local communities and non-governmental organizations (NGOs) that specialise in waste management and sustainability. This collaboration may give significant insights, resources, and knowledge-sharing opportunities, allowing the complex to use collective expertise and promote good change.
f. **Educate and create awareness**: Provide frequent training sessions, workshops, and awareness campaigns to staff to educate them on the importance of waste management and sustainable practises. Provide them with the information and resources they need to make sound decisions and actively participate to the complex's sustainability initiatives.

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The Authors declare that they have no conflict of interest.

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