United Tractors Company prioritizes sustainable waste management practices. This study investigated their current system, aiming to identify opportunities for improvement in efficiency and environmental impact. The research focused on how effectively United Tractors manages their waste streams, from minimizing generation at the source to responsibly processing and disposing of unavoidable waste.

The analysis revealed a successful integrated waste management system at United Tractors, encompassing practices like composting, recycling, and proper treatment of hazardous materials. This approach demonstrates their commitment to minimizing their environmental footprint. The study went beyond current practices, identifying promising advancements in waste processing technologies like gasification and bioethanol production. These techniques offer exciting possibilities for further reducing waste and potentially even generating valuable resources from waste materials.

The effectiveness of United Tractors' system can be attributed to their comprehensive approach. The study conducted a detailed waste collection study to understand the composition and volume of waste generated across various departments. This data-driven approach allowed for a thorough cost analysis and an evaluation of the operational efficiency within the waste management system. Importantly, the study highlighted the potential benefits of incorporating advanced waste processing techniques for even greater sustainability in the future. While further feasibility studies are needed before full-scale implementation, these findings pave the way for United Tractors to develop and implement even more sustainable waste management practices in the coming years

Keywords: developing, efficient, waste management, United Tractors

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DEVELOPING A STRATEGIC PLAN FOR EFFICIENT MANAGEMENT OF INDUSTRIAL WASTE IN THE MACHINERY SECTOR AT UNITED TRACTORS COMPANY

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1. Introduction

PT United Tractors Tbk (UT), a subsidiary of PT Astra International Tbk, is an Indonesian corporate company with extensive experience in heavy equipment distribution. It has been publicly traded since 1989, with Astra owning 59.5 % of the company [1]. The Company currently holds a significant position in various sectors and industries across the country, including Construction Equipment, Mines Contracting, Mining, Building Industry, and Energy. UT, a company with strong persuasive skills, is committed to efficient waste management, focusing on reducing waste generation, encouraging recycling, and ensuring proper disposal of waste materials [2]. The business has implemented waste management measures to mitigate the negative impacts of industrial and domestic waste.

UT regularly assesses waste production, identifying domestic and industrial waste types. This helps identify areas for waste reduction initiatives and increases waste management involvement. The waste audit results will help focus on waste reduction efforts, streamlining production procedures, implementing inventory control, and raising staff knowledge. Reuse and recycling programs are implemented, promoting proper waste usage and material reuse. UT ensures hazardous waste is handled, stored, and disposed of in compliance with laws.

This study improved industrial waste management, which is crucial for UT for many reasons:

1. Landfills are becoming increasingly expensive, and regulations may restrict their use in the future. Researching alternative methods like converting waste into usable materials or generating energy can create new revenue streams for UT.

2. By identifying valuable materials within waste streams, UT can potentially recover costs and even generate profit through recycling or upcycling initiatives.

3. Landfills contribute to environmental pollution through methane emissions and leachate generation. Researching alternative disposal methods can significantly reduce UT's environmental footprint.

4. Indonesia's waste management regulations are constantly evolving, requiring companies to adapt their practices. The study can help UT stay ahead of the curve and ensure their waste management strategies comply with the latest regulations.

5. Non-compliance with waste management regulations can result in hefty fines and reputational damage. Researching and implementing efficient waste management practices can help UT avoid such risks.

6. Consumers and investors are placing a higher premium on companies that prioritize environmental sustainability. Researching and implementing innovative waste management strategies can give UT a competitive edge.

7. Demonstrating a commitment to responsible waste management can improve UT's brand image and attract environmentally conscious customers and partners.

When it comes to waste management in Indonesia, there are numerous regulations that must be followed [3]: Indonesia's Waste Management Regulations:

1. Law No. 18 of 2008: Provides a comprehensive framework for waste management in Indonesia.

2. Government Regulation No. 81 of 2012: Focuses on managing residential waste, emphasizing public participation and cooperation.

3. Ministry of Environment Regulation No. P.68/MENLHK/SETJEN/KUM.1/10/2018: Outlines requirements for environmental permits, including waste management activities.

4. Special Regional Governor Regulation for Jakarta No. 102 of 2021: Concerns waste management obligations in areas and companies.

5. Government Regulation No. 22 of 2021: Revokes Government Regulation No. 101 of 2014 on Hazardous and Toxic Waste Management.

Non-recyclable waste must be properly disposed of in compliance with local regulations, involving collaboration with waste management service providers. UT complies with regulations, but research is needed for more beneficial waste use. Waste management research is critical for many kinds of reasons, including environmental sustainability, regulatory compliance, resource efficiency, competitive advantage, and knowledge advancement. It contributes to reducing environmental impact, minimizing pollution, and conserving natural resources. This study into best practices helps businesses keep ahead of laws, avoid penalties, and maintain compliance. Innovative waste management solutions may result in cost savings and possibly cash generation. Companies may obtain a competitive edge by showing responsible waste management and adopting sustainable practices. This research on integrated industrial waste management helps to gain a more comprehensive knowledge of sustainable waste management techniques in Indonesia, supporting environmentally friendly manners across the country.

Waste management studies may provide real benefits to industrial settings such as UT. These include increased operational efficiency, financial savings, reduced environmental impact, regulatory compliance, stakeholder involvement, and innovation prospects. The research results may assist in identifying waste reduction projects, optimizing manufacturing methods, implementing inventory control measures, and improving employee understanding. Companies could recover expenses, earn revenues, and save waste disposal costs by recognizing valuable elements in waste streams. Alternative waste disposal strategies may help to minimize environmental pollution and greenhouse gas emissions. The research findings may also assist businesses achieve regulatory compliance, involve stakeholders, and identify new waste management methods, technologies, or methodologies. Overall, waste management research may have a practical impact on industry operations.

Therefore, studies devoted to developing and implementing efficient and sustainable waste management practices in industrial settings hold significant scientific relevance. These studies demonstrate the significance of this issue by examining the existing waste management system of UT, offering significant observations on practical approaches in the actual world. In addition, it enhances scientific advancement by analyzing the waste minimization and resource optimization initiatives at UT, ultimately supporting waste reduction and general sustainability in the industrial sector. Also examines the possibilities of utilizing modern waste processing procedures, hence expanding the limits of innovative waste management solutions. Furthermore, it emphasizes the essential importance of harmonizing waste management techniques with wider sustainability objectives and environmental requirements. This strategy promotes a harmonious combination of environmental accountability, financial sustainability, and compliance with regulations, which is a crucial challenge for industrial activities. Through the examination of these factors, such research plays a crucial role in reducing the ecological impact of industrial operations and advancing a more sustainable future.

2. Literature review and problem statement

UT grapples with diverse solid waste streams requiring unique treatment approaches. Incineration, a common solution, is unsuitable due to the varied waste types. E-waste, containing harmful heavy metals, necessitates separate processing methods like strong acid or solution separation. The research is ongoing to find the most environmentally friendly way to dispose of electronic waste. Organic waste processing is currently limited to composting dry organics due to high emissions from existing methods [4]. Gasification through pyrolysis presents a promising alternative solution. UT has yet to establish solutions for general waste or metal waste, which holds potential for applications like hydrogen production through hydrolysis or use as catalysts. Implementing effective waste management requires validating proposed solutions before deployment to ensure minimized environmental impact, regulatory compliance, and adherence to sustainability practices.

Industrial waste management is a critical concern for companies worldwide, and the heavy equipment industry is no exception. Then, the research has explored various strategies to improve waste management efficiency and sustainability in this sector. In waste minimization and reduction, any studies [5, 6] highlight the importance of implementing lean manufacturing practices and optimizing production processes to minimize waste generation at the source. This can significantly reduce disposal costs and environmental impact. The studies emphasized the importance of lean manufacturing and process optimization to minimize waste generation at the source. This approach holds significant economic and environmental benefits. While the studies highlight waste minimization, they could delve deeper into UT's specific production processes to identify areas for further waste reduction. Analyzing UT's waste streams could reveal opportunities for material substitution, improved production techniques, and product life cycle extension.

Precise trash categorization and segregation are essential for effective waste management. By employing Internet of Things (IoT) devices and sensors to collect data, including waste photographs and moisture levels, it becomes possible to make informed judgments about waste management, specifically in terms of segregating different types of waste [7]. This study highlights the importance of using Internet of Things (IoT) devices and sensors for waste characterization and segregation. This data-driven approach facilitates informed decision-making about waste management strategies. Meanwhile, although it mentions data collection, it does not investigate into the specific data analysis methods needed to effectively translate collected information into actionable insights. Further research could explore the integration of machine learning algorithms for automated waste classification and optimization of sorting processes. This method not only makes waste disposal easier but also decreases the occurrence of incorrect waste handling practices, therefore promoting environmental sustainability.

Furthermore, within the realm of metallic waste management, radiological characterization is crucial in order to optimize waste handling. Methods such as neutron activation estimates, dose rate measurements, and in-situ gamma spectrometry are used to categorize and monitor waste during the dismantling process, guaranteeing appropriate management and disposal [8]. Even though it emphasizes the importance of radiological characterization for safe and efficient handling of metal waste during dismantling processes, it doesn't explore the specific challenges UT might face in managing its metal waste streams. The methods mentioned (neutron activation, dose rate measurements, gamma spectrometry) are essential for proper categorization and disposal. It is supposed to investigate the feasibility of on-site metal recycling or partnerships with specialized metal processing facilities. By implementing thorough waste categorization procedures, it becomes possible to focus on recycling activities, improve resource recovery, and reduce the reliance on landfill disposal.

Further, various technologies and strategies for recycling and reusing industrial waste materials encompass a wide array of approaches. These include the recycling of rare earth elements (REEs), metals, plastic, and glass from secondary sources with a zero-waste strategy. Additionally, the reuse of waste materials in the landscape building of urban industrial sites can contribute to reducing pollution and improving recycling rates. Innovative strategies integrating local urban and industrial wastes into sustainable building materials have been explored, focusing on circular design strategies, re-use, recycle, and waste transformation processes. The recycling of different secondary resources, such as aluminum cans, e-wastes, LCD screens, ferrous and non-ferrous metal wastes, catalysts, effluents, mine tailings, and metallurgical slags, is crucial for metal extraction and resource conservation. Furthermore, the recovery of precious metals from waste electronic components (ECs) through disassembly, enrichment, and various recycling processes like pyrometallurgical and hydrometallurgical methods is essential for efficient e-waste recycling in the circular economy [9]. It provides a comprehensive overview of various recycling and reuse strategies for industrial waste materials. It highlights the potential for recovering rare earth elements, metals, plastics, and glass from secondary sources, promoting a "zero-waste" approach. Conversely, although the source discusses various technologies, it doesn't delve into the economic feasibility and environmental impact of each option for UT's specific waste composition. Further research could involve life cycle assessments to identify the most sustainable recycling and reuse strategies for UT's context.

Regulatory compliance is crucial for industries, including waste management, to ensure adherence to evolving guidelines and avoid penalties. Studies emphasize the significance of compliance frameworks, highlighting the need for effective monitoring systems and continuous education to meet regulatory requirements. While regulatory compliance provides guidelines, it alone does not guarantee security [10]. Understanding the regulatory landscape is essential for companies to adapt their practices, especially in industries like public procurement where compliance tools are utilized to prevent corruption. Additionally, incorporating AI in regulatory processes is suggested to enhance compliance practices. By staying informed about regulatory changes and implementing best practices, companies can navigate the evolving regulatory landscape surrounding industrial waste management effectively. The study [10] emphasizes the importance of regulatory compliance frameworks and ongoing education to ensure adherence to evolving waste management regulations. However, although it emphasizes compliance, it has not explored the potential economic implications of non-compliance for UT. Additionally, it has not studied the specific regulatory landscape surrounding waste management in UT's region yet.

UT has produced numerous types of waste. One of the wastes is organic/biomass waste. In the modern technology, it offers a toolbox for tackling organic waste. Anaerobic digestion, composting, and MBT (Mechanical Biological Treatment) break down waste using microbes, producing biogas (energy), digestate (fertilizer), or efficiently processing waste. Black Soldier Fly Larvae turn waste into biomass, while liquefaction & fermentation create biofuels or chemicals [11]. Hydrothermal Carbonization (HTC) creates a renewable energy source or soil improver, and Waste-to-Energy incineration recovers energy from burning waste [12]. These sources [11, 12] offer a diverse toolbox of modern technologies for organic waste processing, including anaerobic digestion, composting, MBT, insect larvae utilization, liquefaction, fermentation, and hydrothermal carbonization. These methods offer options for waste reduction, biogas generation, fertilizer production, and energy recovery. However, the studies did not analyze the suitability of each technology for UT's specific organic waste composition or infrastructure limitations. Further research could involve pilot studies to evaluate the most efficient and cost-effective organic waste processing methods for UT.

For plastic waste, modern waste processing tackles plastic pollution through a multi-pronged approach. Mechanical and chemical recycling break down plastic for reuse, while pyrolysis and gasification convert it into energy. Solvent-based techniques, biodegradation, and plastic-to-fuel processes offer further options. Upcycling, repurposing, and blending with composite materials aim to extend plastic's lifespan [13]. This study things to see various options for plastic waste management, including mechanical and chemical recycling, pyrolysis, gasification, solvent-based techniques, biodegradation, and upcycling. Further research could explore the feasibility of integrating these technologies for optimal resource recovery at UT. Integrated systems combine these technologies for maximum resource recovery and minimal plastic waste.

Styrofoam is tough to get rid of because it's lightweight and doesn't break down easily. But new ways to deal with it are emerging. These include grinding it up and turning it into new things (mechanical recycling), breaking it down with chemicals (chemical recycling), heating it to make energy (pyrolysis), and using special solvents to separate the materials (solvent-based recycling) [14]. It presents emerging methods for Styrofoam waste management, including mechanical and chemical recycling, pyrolysis, solvent-based recycling, and biodegradable alternatives. Further research could investigate the cost-effectiveness and environmental impact of each technique for UT's specific Styrofoam waste volume. There are even ideas to make Styrofoam that breaks down naturally or can be squished into reusable blocks. While some of these methods are still being worked on, they offer hope for a future with less Styrofoam waste.

Paper bags get a second life through recycling, composting, or even burning for energy. Paper mills turn them into new paper, while composting creates fertilizer. Upcycling and reusables further reduce waste. Research focuses on biodegradable alternatives. Keep cardboard and Duplex clean for optimal recycling, and choose reusable options when possible [15]. White paper waste has a multitude of solutions beyond landfills. Recycling and deinking processes create new paper products. Pulp molding transforms it into packaging materials. Circular initiatives promote reuse, while upcycling breathes new life into paper through crafts [16]. Energy recovery and composting offer additional options. UT, however, also generates hazardous waste requiring specialized treatment beyond traditional methods to minimize environmental impact. The studies [15, 16] highlight recycling, composting, upcycling, and energy recovery as viable options for paper waste management. However, the studies should analyze the paper waste composition and identify the most sustainable and cost-effective combination of these strategies.

Oil is essential for lubricating and cooling industrial devices, and modern waste processing methods are crucial for environmental protection and resource conservation. Common methods include re-refining, distillation, solvent extraction, hydrotreating, on-site oil recycling, energy recovery, and waste-to-fuel conversion [17]. Re-refining removes impurities and contaminants, distillation separates components based on boiling points, solvent extraction separates impurities, hydrotreating removes impurities, on-site oil recycling regenerates used oil for reuse, energy recovery feedstock uses incineration, and waste-to-fuel conversion converts used oil waste into alternative fuels [18]. Proper waste management and recycling of used oil waste are essential for protecting the environment and conserving valuable resources. Discharging used oil into the environment is illegal and harmful. These studies offer a comprehensive overview of various methods for used oil waste processing, including re-refining, distillation, solvent extraction, hydrotreating, on-site recycling, energy recovery, and waste-to-fuel conversion. While the studies outline the methods, they have note explored yet the economic feasibility of each option for UT's specific used oil volume and composition. Additionally, they did not address potential challenges like the availability of specialized re-refining facilities or the environmental impact of energy recovery methods. Further research could involve cost-benefit analysis and life cycle assessments to identify the most sustainable option for UT.

Car factory sludge disposal involves a multi-step process to minimize waste and environmental impact. Dewatering separates liquids, while thermal treatment shrinks the volume and potentially creates usable materials. Stabilization solidifies the sludge for landfills, while resource recovery focuses on extracting valuable elements. Bioremediation utilizes microbes for natural breakdown, and recycling attempts to reuse the sludge within the production process [19]. Electrocoagulation removes pollutants and separates solids, with vacuum evaporation further concentrating the remaining sludge. This comprehensive approach ensures responsible waste management and promotes sustainable industrial practices. The study [19] highlights a multi-step approach for car factory sludge disposal, encompassing dewatering, thermal treatment, stabilization, resource recovery, bioremediation, recycling, electrocoagulation, and vacuum evaporation. This comprehensive strategy ensures responsible waste management and minimizes environmental impact, but the study has not explained yet the specific types of contaminants present in UT's car factory sludge. Further research could involve analyzing the sludge composition to determine the most effective techniques for contaminant removal and resource recovery. Additionally, it could explore the feasibility of implementing on-site bioremediation or identifying partnerships for sludge processing.

Waste processing for used battery waste is crucial to address environmental and human health hazards. It involves recycling, hydrometallurgical processing, pyrometallurgical processing, lithium-ion battery reuse, neutralization and stabilization, and energy recovery [20]. Recycling facilities extract valuable metals like lead, lithium, cobalt, and nickel from batteries, while hydrometallurgical processes leach the waste with specific chemicals. High-temperature treatments like smelting recover metals from battery waste [21]. Extended Producer Responsibility (EPR) programs encourage proper disposal and recycling, while eco-friendly battery technologies focus on developing safer materials. Proper waste management prevents contamination of soil, water, and air, and promotes a circular economy approach. Further, these investigations highlight various methods for used battery waste processing, including recycling, hydrometallurgical and pyrometallurgical processing, lithium-ion battery reuse, neutralization and stabilization, and energy recovery. Additionally, they emphasize the importance of Extended Producer Responsibility (EPR) programs and eco-friendly battery technologies. While the sources discuss processing methods, they have not yet explored the economic viability of establishing on-site recycling facilities for UT. Additionally, they have not investigated the specific battery chemistries present in UT's waste stream and their implications for optimal processing techniques. Further research could involve techno-economic analysis of on-site recycling and identify partnerships with specialized battery recycling facilities.

Modern waste processing for used engine filters involves various techniques to manage hazardous waste responsibly. These include recycling, oil recovery, incineration, solvent extraction, washing and cleaning, landfill disposal, and environmental compliance [22]. This study explains that recycling involves disassembling the filters and separating components, while oil recovery involves recovering oil from the filters. Incineration reduces waste volume and destroys hazardous components. Solvent extraction separates oil and contaminants from the filter media, allowing for reuse. Washing and cleaning remove contaminants, making the filters more recyclable. This approach ensures responsible handling of hazardous waste. Landfill disposal may be necessary for unrecyclable filters. Environmental compliance requires automotive service centers to comply with local regulations. However, the feasibility of on-site oil recovery or filter cleaning for UT has not been explored yet. Additionally, it doesn't address the environmental impact of different disposal options like incineration. Further research could involve analyzing the cost-effectiveness of on-site oil recovery and filter cleaning compared to external processing. Life cycle assessments could also be conducted to identify the most environmentally responsible disposal method for UT.

Modern waste processing for TL lamp waste involves environmentally responsible methods to handle hazardous components and recover valuable materials. These methods aim to minimize environmental impact and promote recycling [23]. Methods include lamp crushing and separation, mercury recovery, phosphor recycling, drum-top bulb crushing units, thermal treatment, recycling centers, Extended Producer Responsibility (EPR) programs, and mercury-free alternatives. These methods help recover glass, aluminum, and other components for recycling. Mercury recovery is captured using emission control equipment during the crushing process, while phosphor recycling focuses on extracting and reusing valuable materials. Recycling centers ensure safe dismantling, recycling, and disposal of lamp components. Encouraging mercury-free lighting alternatives like LED lamps can reduce hazardous TL lamp waste generation. Meanwhile, the study [23] has not determined yet the specific regulations regarding mercury emissions in UT's region. Further research could analyze the local regulations and identify if UT's current practices comply with these standards. Additionally, it could explore the feasibility of partnering with existing recycling centers for efficient TL lamp waste management.

Waste processing for used hazardous packaging involves proper handling of toxic materials to prevent cross-contamination and ensure safe disposal. Common methods include hazardous waste segregation, decontamination, incineration, chemical treatment, mechanical and manual separation, recovery and recycling, secure landfill disposal, and Extended Producer Responsibility (EPR) programs [24]. Proper segregation, decontamination, incineration, chemical treatment, mechanical and manual separation, recovery and recycling, secure landfill disposal, and EPR programs are essential for proper handling, treatment, and disposal of toxic packaging waste. Compliance with local regulations and guidelines is crucial for minimizing environmental pollution and protecting public health. Proper waste processing and recycling are essential for minimizing environmental pollution and protecting public health. However, the study [24] has not explored yet the specific types of hazardous materials present in UT's packaging waste. Further research could involve analyzing the packaging materials and identifying any potential challenges associated with their safe handling and disposal. Additionally, it could explore partnerships with specialized facilities for processing specific hazardous materials.

While UT has implemented waste management practices, there is a need to identify opportunities for further improvement. These are some important aspects to take into account:

1. UT aims to optimize waste minimization and reduction strategies by using leaner manufacturing methods or exploring alternative materials. This approach focuses on reducing waste creation at its source.

2. The existing waste classification process at UT needs improvement to ensure it comprehensively identifies all potential recycling and reuse opportunities.

3. Assessing innovative recycling and reuse technologies that have the potential to be advantageous for UT's particular waste streams.

4. Investigating waste-to-energy conversion involves the transformation of specific types of waste produced by UT into viable energy sources. This process has the potential to decrease disposal expenses and earn extra income.

5. Ensuring up-to-date knowledge of emerging rules, UT remains fully updated about the latest regulations concerning industrial waste management in Indonesia. Regulatory compliance is constantly evolving, necessitating frequent monitoring, periodic assessments, flexibility, and professional advice to ensure firms remain compliant and adapt to new events and processes.

By addressing these challenges, UT can achieve a more efficient, sustainable, and cost-effective waste management system.

All this allows us to assert that it is expedient to conduct a study on ~~an~~ optimizing waste management strategies for the heavy equipment industry, developing a comprehensive and sustainable waste management system for industrial companies, the economic and environmental viability of advanced waste processing technologies for industrial waste streams, and the integration of lean manufacturing principles and innovative recycling techniques to minimize waste generation and maximize resource recovery in industrial sceneries.

3. The aim and objectives of the study

The study aims to develop and evaluate a strategic plan for implementing integrated industrial waste management practices that prioritize resource recovery and minimize landfilling at UT. This plan will aim to achieve both cost-effectiveness and environmental sustainability.

To achieve this aim, the following objectives are accomplished:

– to analyze current waste management practices at UT, identifying different waste categories and their treatment methods by planning the waste management mapping scenario projects to optimize waste treatment and minimize environmental impact;

– to evaluate the effectiveness and financial viability of existing waste management strategies while researching and proposing improved, environmentally friendly, and profitable processing solutions for UT's specific waste types, identify the motivations behind their current waste management efforts;

– to consider other challenges in waste management projects in the future.

4. Materials and Methods

4. 1. Object and hypothesis of the study

The object of the study is integrated industrial waste management. The focus of the research was on the possibilities for controlling waste and ineffective ways to handle garbage and materials that are an acceptable collecting waste. To address these issues, a multi-site case study utilizing garbage collection was conducted. The case study took into account the costs of managing waste, the effectiveness of using materials, operational effectiveness, and flows of waste material. The technique was developed to make scenario mapping and analysis effective with little in the way of on-site time and resources.

The researchers participated in action research for a section of the study with the ultimate objective of improving waste management studies. As the project manager, both a process owner and an active consultant, and 10 writers participated. Therefore, in this study, by optimizing waste management strategies for the heavy equipment industry, developing a comprehensive and sustainable waste management system for industrial companies, exploring the economic and environmental viability of advanced waste processing technologies for industrial waste streams, and integrating lean manufacturing principles and innovative recycling techniques, industrial companies like UT can achieve a more efficient, sustainable, and cost-effective waste management system.

Assumptions of the work include that waste management studies can lead to increased operational efficiency, financial savings, reduced environmental impact, regulatory compliance, stakeholder involvement, and innovation prospects in industrial settings like UT. The other assumption is that compliance with local regulations and guidelines is crucial for minimizing environmental pollution and protecting public health, and proper waste processing and recycling are essential for achieving these goals. Further, by addressing challenges such as waste minimization, waste classification improvement, innovative recycling technologies, waste-to-energy conversion, and staying updated on emerging regulations, UT can achieve a more efficient and sustainable waste management system. Besides, strategic planning and efficient techniques can enhance employee and corporate commitment to waste management, leading to zero waste to landfill and positioning UT as a leader in sustainable waste management in Indonesia. The research focuses on gathering quantitative and qualitative data on waste management systems, considering it as a comprehensive system that includes collection, transportation, storage operations, and interactions between system components.

This study suggests simplifying waste management practices, establishing a sustainable waste management plan, conducting feasibility studies on innovative waste processing techniques, considering financial aspects, exploring new technology, harmonizing waste management techniques with sustainability objectives, implementing waste reduction projects, optimizing manufacturing methods, and analyzing waste composition, volume, and hazardous waste to optimize production processes and reduce environmental impact.

4. 2. Case study

The study at UT Head Office focused on waste project management and purchasing services. It involved mapping locations and understanding waste and material standards. The analysis examined waste fraction volumes at the site level and used performance indicators to compare outcomes to industry best practices. The study identified best practices for managing trash processes, including internal management, operational accountability, and sorting improvement. It also provided suggestions for ongoing development and enhancement of waste services. The study highlights the complex problem of preventing waste formation, involving multiple stakeholders, and highlights the need for future work in technological applications.

4. 3. Data collections

The research focused on waste management by gathering quantitative data on the system's behavior, qualities, and performance, as well as qualitative technical data based on literature analyses. The most efficient approach to waste management involves considering it as a system that includes collection, transportation, and storage operations. Other information, such as investment in equipment and services, waste fraction percentages, and interactions between system components, was also gathered. The analysis of each industrial site considered machinery, management, contracting businesses, people, waste, emissions, efficiency, and the effects on the economy and society. The data collection techniques included environmental reports, environmental studies, walkthroughs, interviews, layouts, and images. The data was collected to understand the recent status and classification of businesses' waste operations.

UT has generated many categories of waste, which are detailed in Tables 1, 2. Table 1 shows the waste composition produced in the UT Head Office in 2022. The data was collected as part of a study to analyze waste management practices in the company. The table shows that the majority of the waste produced is organic waste, both wet and dry. This is followed by paper and plastic. Hazardous waste makes up a small percentage of the total waste produced. The data also shows that the current waste management practices are not very efficient. A significant amount of waste is still being landfilled, which is not only environmentally harmful but also expensive.

Table 2 shows the hazardous and toxic waste compositions produced in the UT Head Office in 2022. The data was acquired as part of a study to examine the company's waste management policies. According to the table, used oil accounts for almost all of hazardous and toxic waste created. This is followed by wastewater treatment plant sludge, used batteries, contaminated waste, filters, hazardous material packaging, TL lamps, and used rags.

The data also demonstrates the effectiveness of current hazardous and toxic waste handling procedures. All waste is disposed of according to applicable regulations. The research suggests that the company continues to examine its hazardous and toxic waste generation and disposal methods to verify they are still effective.

Table 1

Produced Waste Compositions UT Head Office in 2022

No.	Waste	Percentage (%)	Weight* (kg/day)	Current handling
1	Wet organic waste	25.33 %	204.281	Landfill
2	Dry organic waste	7.25 %	58.47	Composting
3	Plastic (PET)	4.00 %	32.259	Plastic grinding
4	Plastic (PP)	1.55 %	12.5	Landfill
5	Plastic (HDPE)	2.47 %	19.92	Landfill
6	Plastic (LDPE)	5.00 %	40.324	Landfill
7	PS/Styrofoam	0.58 %	4.678	Landfill
8	Paper (cardboard box and Duplex)	26.64 %	214.846	Waste bank and landfill
9	White paper	1.69 %	13.629	Landfill

Table 2

Produced Hazardous and Toxic Waste Compositions UT Head Office in 2022

No.	Waste	Waste code	Weight (ton)*
	Major waste		
1	Used oil	B105-d	15.480
2	Sludge WWT	B323-5	0.045
	Minor waste		
3	Used battery	A102d	0.650
4	Contaminated waste	A108d	0.050
5	Used filters	A108d	0.558
6	Used packaging hazardous materials	B104d	0.255
7	TL lamp	B107d	0.245
8	Used Rags	B110d	0.313

5. Results of strategic plan for efficient management at UT

5. 1. Planning of the waste management mapping scenario projects

The study reveals that domestic waste processing at UT is still done using traditional techniques like landfilling, composting, waste banking, and grinding. Hazardous and toxic waste is classified as residual waste, which is handled by third parties with permits. UT disposes of this waste, treating it as residue. Other companies reprocess it to meet their demands, such as lubricating chains, removing corrosion, and fueling heavy-duty vehicles. Filters used before will be cleaned and reused. The waste treatment scenario in UT should be mapped based on different waste treatment methods and research to limit landfill collection, form waste into a stable form, and prevent environmental pollution. The mapping should consider environmental benefits, waste reduction and diversion, low energy consumption, energy savings, waste reduction, economic opportunities, public awareness, and a circular economy approach. However, there is still much thought put into managing waste based on the type of waste produced.

Further, strategic planning as an assignment will help to identify any potential challenges in the system as a whole and will be able to provide efficient techniques and policies for enhancing employee and corporate commitment. UT is highly enthusiastic and will make a significant contribution to handling waste toward zero waste to landfill, with the potential to become the leader among the significant and prestigious industries in Indonesia. Several factors will be carefully taken into account for that.

Fig. 1 exposes the composition of waste generated at UT, categorized by different segments. Paper and cardboard reign supreme, constituting the largest portion at 26.64 %. This suggests a significant use of packaging materials, office paper, or other paper products within UT's operations. Interestingly, organic waste follows closely, with wet and dry organic materials combining for 32.58 %. This could include food scraps, yard waste, or other organic matter. Plastics also play a role, accounting for 10.99 % of the waste stream. The breakdown within plastics reveals a mix of PET, PP, HDPE, LDPE, and PS/Styrofoam, suggesting the use of various plastic types. Notably, white paper stands out as a separate category, representing 1.69 % of the waste. Finally, while not explicitly shown, the presence of metal waste is likely minimal or potentially falls within other categories.

These initial observations highlight potential areas for improvement. Composting the substantial organic waste stream (wet and dry combined) could significantly reduce landfill dependence and create valuable fertilizer. Optimizing paper usage and exploring paper and cardboard recycling programs could also be beneficial. Additionally, investigating the different plastic types used and implementing designated collection bins could increase plastic recycling rates. For a more targeted approach, further analysis is needed to understand the specific activities and materials employed across UT facilities. This comprehensive understanding would allow for the development of effective waste reduction and diversion strategies, ultimately leading to a more sustainable waste management system at UT.

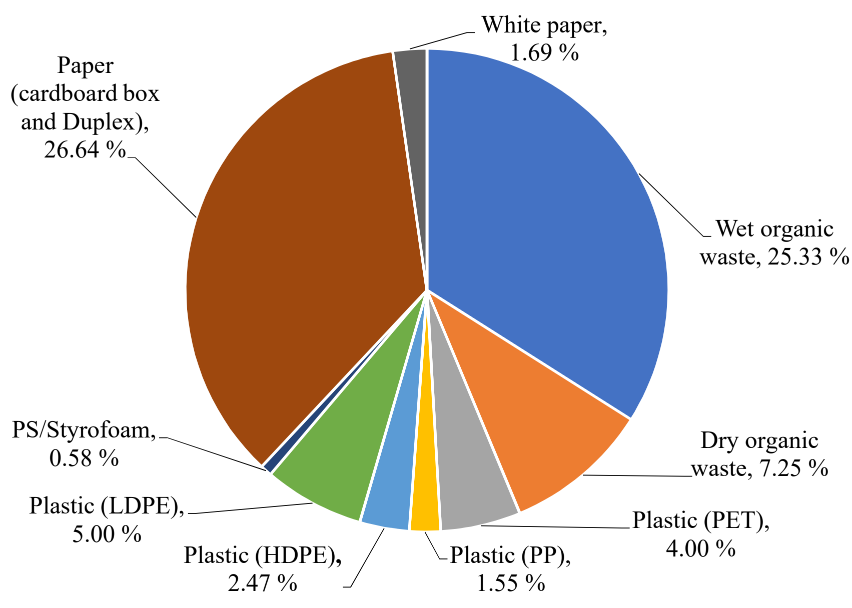

Fig. 1. The percentages of waste volumes in different segments (Data as of 2022)

Fig. 2 reveals the composition of hazardous and toxic waste generated by UT. It categorizes the waste into five primary groups: used filters (55.8 %), contaminated hazardous materials (25.5 %), used batteries (15.48 %), fluorescent tube lights (0.245 %), and contaminated waste (0.05 %).

While the data offers a general breakdown, a more detailed analysis of waste generation and specific improvement strategies requires additional information, which is provided in Table 3 to overcome the developing strategic solution of UT's wastes. A significant portion of used filters (55.8 %) warrants further investigation. Additionally, the broad category of "contaminated hazardous materials" (25.5 %) necessitates a closer look to understand the specific types of materials being disposed of.

Based on common hazardous waste management practices, here are some general recommendations for UT, those are:

– minimize waste generation in which to explore ways to reduce the use of hazardous materials whenever possible;

– improve handling and storage with the implementation of proper procedures for handling and storing hazardous materials to minimize contamination risks.

– implement recycling programs by investigating opportunities to recycle or reuse certain hazardous materials;

– proper disposal with ensuring hazardous waste is disposed of according to regulations to minimize environmental impact.

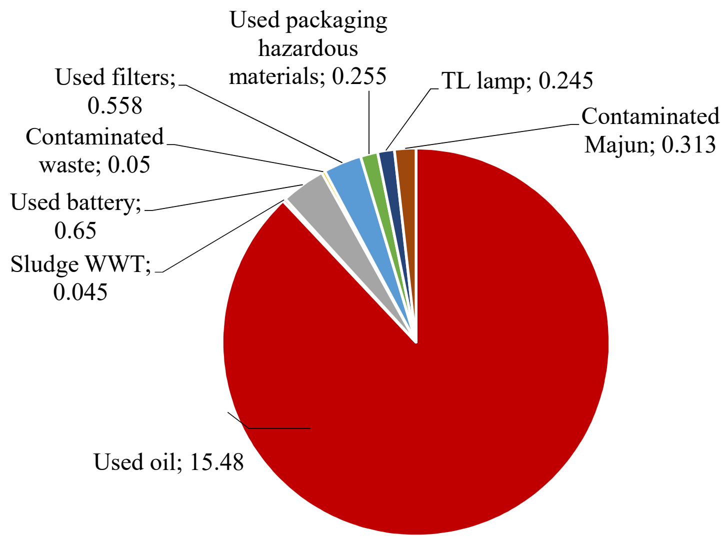

Fig. 2. Hazardous and toxic waste (ton) (data as of 2022)

Table 3

The most effective waste management for mapping scenarios at UT

Waste	Proper scenario	Descriptions	Concern
1	2	3	4
Organic waste	Composting	A natural biological process converts organic waste into nutrient-rich compost, which can be used as a soil amendment to enhance soil fertility and promote plant growth	Composting is a sustainable method that reduces waste sent to landfills and incineration facilities, reducing greenhouse gas emissions and environmental impact. It is a valuable soil conditioner that enriches soil with nutrients, improves structure, and increases water retention. Composting extends landfill life and reduces the need for new disposal sites. It exemplifies a circular economy approach by recycling organic materials back into soil as valuable resources. Composting is low-energy and cost-effective, relying on natural microbial processes. It is accessible and feasible for individuals, households, and communities, fostering environmental responsibility and providing education on waste reduction and sustainable practices
Plastics	Mechanical recycling	Converting plastic waste into new products or raw materials without influencing the chemical structure of the plastic	Reuse mechanically reduces plastic waste's environmental impact by diverting it from landfills and incineration facilities, reducing litter and wildlife harm. It preserves valuable resources and reduces the need for new plastic production from virgin materials, contributing to a circular economy. Recycling plastics consumes less energy and reduces greenhouse gas emissions. It can handle various plastic waste materials like PP, LDPE, HDPE, and PET, and can handle plastic bottles, containers, packing, and films
Styrofoam waste	Mechanical recycling	Reducing the size of residual Styrofoam material into pellets or smaller pieces that can be utilized as raw materials to create new goods	Mechanical recycling reduces waste in the environment, reduces litter and wildlife harm, efficiently compresses and processes Styrofoam waste, saves energy and greenhouse gas emissions, and creates economic opportunities in the recycling industry, generating jobs and supporting local economies
Paper (cardboard box and Duplex) and white paper wastes	Recycling	Converting the used paper into new paper products or materials	This method conserves trees, water, and energy by producing various paper products like paper bags, cardboard, newspapers, and other packaging materials
Used oil	Reuse or Recycling	Reuse involves processing used automotive oil to remove impurities and contaminants, restoring it to a usable condition as a base oil for lubricants	Recycling/reuse of base oil can reduce environmental pollution and ecosystem impacts. Re-refined base oil has similar or better performance than virgin oil, is energy-efficient, and creates a closed-loop system for multiple re-refinements, promoting sustainability and waste reduction in a circular economy approach
Sludge	Stabilization/solidification (S/S)	S/S is followed by disposal in a hazardous waste landfill	(S/S) is a method that immobilizes and encapsulates hazardous components, reducing their leachability and environmental contamination risk. It extends landfill lifespan and has engineered liners to prevent contamination migration

Continuation of Table 3

1	2	3	4
Used battery	Recycling	The process of using batteries involves extracting valuable materials to create new batteries or other products, thereby reducing environmental impact and conserving resources	The reduction of mining and extraction of virgin resources conserves valuable natural resources, while proper recycling minimizes the environmental impact of hazardous battery waste
Used filters	Recycling	Recycling used filters involves recovering valuable materials from the filters and transforming them into new products or materials	Recycling reduces virgin resource extraction, prevents pollution from hazardous materials, and requires less energy, resulting in energy savings and reduced greenhouse gas emissions
Used Tube Luminescent (TL) lamps	Recycling	Recycling TL lamp waste involves the safe and environmentally responsible handling of the lamps to recover valuable materials and prevent the release of hazardous substances	Recycling minimizes pollution and protects ecosystems by preventing the release of hazardous materials like mercury. It conserves natural resources and reduces raw material extraction, while ensuring proper handling and storage of mercury
Used packaging hazardous materials	Treatment by means of specialized facilities	Hazardous waste treatment through specialized facilities. The treatment and disposal of used toxic packaging waste require careful handling and containment to protect the general public's health and avoid environmental contamination	Specialized facilities handle hazardous waste safely, preventing its release into the environment. Proper treatment ensures hazardous packaging waste doesn't end up in landfills or incineration facilities, reducing potential harm to ecosystems. Hazardous waste treatment processes stabilize toxic materials

Waste management practices in UT involve innovative solutions. UT implements green construction methods to enhance environmental sustainability, as seen in Table 3 concern and solutions.

Fig. 3, illustrating UT's waste management policies, indicates that 40.32 % of the entire waste stream is disposed of in landfills. Although this approach is widely used, it gives rise to worries regarding the possible environmental consequences, such as the release of methane and the creation of leachate.

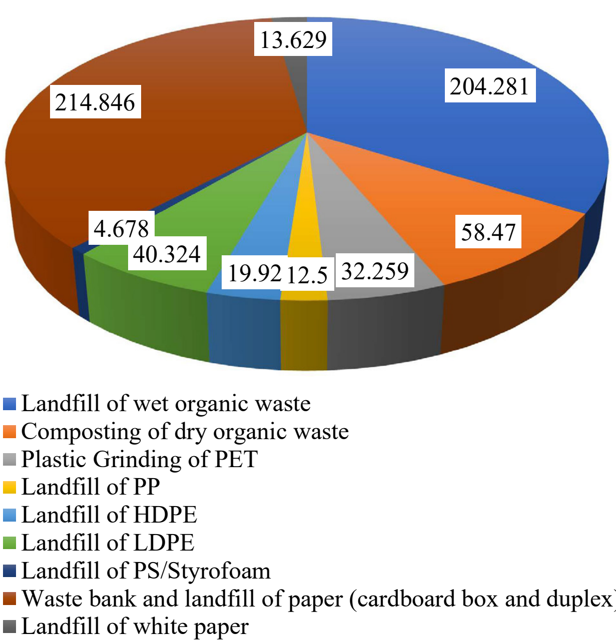

Fig. 3. Existing waste management at United Tractors Company for waste produced (kg/day)

One positive feature is the employment of composting for 20.43 % of the garbage, which involves diverting organic waste from landfills and converting it into a valuable soil supplement. In addition, the presence of plastic grinding, which accounts for 12.50 % of the waste, indicates a deliberate attempt to handle plastic waste. Further, additional explanation is required regarding the final destination and possible uses of the recycled plastic. The category "Waste Bank and Landfill" (27.75 %) necessitates additional clarification. Although "Waste Bank" commonly refers to a facility that collects and sorts recyclable materials, its association with "Landfill" raises issues regarding its precise function within UT's waste management system. However, several areas require attention in order to improve UT's waste management strategy that is minimize dependence on landfills. It will investigate options such as enhanced recycling, extended composting, or waste-to-energy conversion could reduce the need for landfills. To optimize the process of plastic grinding, it is important to ensure that the ground plastic is efficiently recycled or reused in order to maximize the recovery of resources.

5. 2. Identifying factors for effective waste management

Together with all of those challenges, the company will need to invest a significant amount of money in order to carry out its waste management plan. As one of the big industries in Indonesia, the waste treatment plan will be implemented even though it requires a large investment. Even though there is no concern about the financing system, this waste management scenario must be designed as effectively and economically as possible. Recently, UT proactively allocates funds for environmental management, with a primary focus on waste management. Waste management, as part of the company's responsibility to respond to and mitigate the environmental impacts of its business operations, is an important aspect of overall environmental management. This step reflects UT's strong commitment to environmental sustainability.

Effective waste management hinges on a trifecta (the three elements or factors that are crucial or essential for achieving a particular outcome or success); innovative methods, advanced technology, and robust governance. Though landfilling persists, sophisticated waste plants handling segregated waste are key. Challenges include skilled labor, technology adoption, financial incentives for innovation, and refined decision-making. Weak enforcement by governments further complicates matters. A dedicated, qualified team is crucial to identify implementation gaps and enforce regulations. Public awareness of waste separation at the source is vital, though stricter segregation at transfer stations remains a hurdle. The future demands R&D investment, technological solutions, public-private partnerships, and strong governance for a sustainable waste management system.

5. 3. Other challenges in waste management projects in the future

Beyond the initial hurdles of feasibility studies for advanced waste processing techniques like gasification, bioethanol production, and others, several challenges lie ahead for successful implementation in UTC's future waste management projects.

These advanced methods often require specialized expertise and infrastructure that may be beyond UTC's current capabilities. Operating and maintaining these technologies might necessitate significant investments in personnel training and facility upgrades. Finding qualified personnel with the necessary knowledge and experience in these specific areas could be challenging. Additionally, constructing or retrofitting existing facilities to accommodate these new processes could be time-consuming and expensive.

Determining the economic feasibility of these advanced techniques is crucial. While they offer environmental benefits, the initial investment costs for acquiring and installing the necessary equipment can be substantial. Ongoing operational expenses, such as energy consumption and waste pre-treatment, need careful consideration. Additionally, revenue generation from the recovered resources or generated energy needs to be factored in. Conducting thorough feasibility studies can help UTC assess if the long-term cost savings or revenue generation from these techniques outweigh the initial investment and ongoing expenses.

While these advanced methods are touted for their sustainability benefits, their environmental impact needs thorough assessment. While they typically result in reduced landfill dependence, processes like gasification and pyrolysis might generate emissions that require sophisticated control systems to minimize environmental risks. Ensuring proper waste pre-treatment and implementing effective post-processing steps to minimize emissions and manage any potential residuals are crucial. Additionally, the environmental impact of sourcing the energy required for these processes needs to be considered to ensure a truly sustainable solution.

Overall, integrating advanced waste processing techniques presents exciting possibilities for UTC's future waste management strategy. However, navigating the technical complexities, ensuring economic viability, and mitigating potential environmental risks through careful planning and infrastructure development will be critical for successful implementation.

6. Discussion of the strategic plan of waste management efficiency by optimizing procedures, exploring technological advancements, ensuring compliance, effectively managing expenses for future sustainability

Then, the scenario mapping of strategic planning of waste management based on waste categories and appropriate technology is presented in Table 3. This approach aims to maintain environmental integrity through environmentally friendly waste management. The company and the community are responsible for designing, assembling, operating, maintaining, and owning the waste processing system. The process involves several steps, including waste characterization, regulatory compliance, waste minimization and source separation, waste audits, feasibility studies, technology selection, infrastructure and facilities, waste processing partnerships, training and awareness, monitoring and evaluation, and continuous improvement:

1. Waste characterization helps identify waste streams, their composition, and potential hazardous components. Regulatory compliance ensures compliance with local and national regulations for responsible waste handling and processing. Waste minimization practices encourage source separation of recyclable and non-recyclable materials. Waste audits are conducted periodically to assess waste generation patterns and evaluate the effectiveness of waste management initiatives.

2. Technology selection is based on the feasibility study's findings, ensuring the most suitable waste processing technologies for different waste streams. Infrastructure and facilities must comply with environmental and safety standards. Waste processing partnerships with specialized entities can enhance efficiency. Training and awareness campaigns are also essential to foster a culture of responsible waste management.

3. Monitoring and evaluation track waste management performance, waste diversion rates, and environmental effects. Continuous improvement is achieved by reviewing and updating waste management strategies based on monitoring results, technological advancements, and changing regulatory requirements.

When developing a strategic plan for efficient industrial waste management at UT in the machinery sector, several key areas will likely be the focus of discussion:

1. Waste minimization and optimization.

UT uses a combination of traditional and innovative waste management methods to reduce environmental impact and recover resources. However, improvements include reducing landfill reliance, optimizing plastic grinding, clarifying waste bank roles, and conducting detailed waste analysis. Waste stream analysis helps understand waste composition and volume, addressing hazardous waste through reducing generation, improving handling and storage, implementing recycling programs, and proper disposal. Process optimization involves optimizing production processes, utilizing efficient machinery, and minimizing material waste during manufacturing. Life-cycle analysis helps identify design modifications that minimize waste throughout the product's lifespan.

2. Effective waste management practices.

Recycling and resource recovery can be improved by putting in place stricter rules for collecting waste and working with companies that specialize in managing waste. These companies can easily sort things that can be recycled from things that are unable to be recycled. This makes recycling and resource recovery go effectively. Investing in technology like automatic sorting systems or more advanced recycling methods can also help get more resources back into circulation and keep waste out of landfills. The goal of these methods is to make sure that waste is handled well and resources are reused. Sustainable and effective waste management: improve methods, look into new technology, follow the rules, and keep prices in check. UT needs to think about other ways to deal with waste in the future.

3. Advanced waste processing techniques (future-oriented).

UT is now conducting feasibility studies to include innovative waste processing techniques such as gasification, bioethanol generation, and fuel cells into its waste management system. These studies will assess technical feasibility, economic viability, and environmental effect. The construction of new facilities may need substantial capital investment and considerable planning. To reduce environmental concerns, deploy emission control systems as well as adequate waste pre-treatment and post-processing activities.

4. Sustainability and regulatory compliance.

UT is establishing a waste management plan that is consistent with its sustainability objectives, with the goal of minimizing environmental impact via waste reduction and responsible waste management. The plan also assures compliance with environmental rules by remaining up to speed on developments and changing methods as necessary.

5. Financial considerations and cost-effectiveness.

The cost analysis entails determining the costs associated with different waste management choices, such as waste collection, transportation, disposal, investments in new technology, and possible income production from recovered resources. The long-term cost savings should be calculated, taking into account decreased landfill use, greater resource recovery, and possible income from waste-derived resources. This will be critical in building a strategy plan for effective industrial waste management at UTC, with a focus on present practices, resources, and long-term objectives. Financial considerations for adopting an enhanced waste management system include looking into government subsidies, tax breaks, and collaborations with waste management businesses. By addressing these issues, UT may reduce its environmental impact, increase resource recovery, and contribute to a more sustainable future.

Along with the above-mentioned issues, another challenge is converting waste to energy. However, the company must develop the necessary infrastructure for such projects. Specific project examples are described in the following explanations.

Gasification.

The last few decades have seen a rise in the use of gasification as a WTE approach for gaining energy from MSW or organic waste. It describes the process of heating in situations of partial oxygen pyrolysis [25]. The partial oxidation process known as gasification typically occurs at temperatures between 750 and 1100 °C. Since the gasification process needs external energy or heat to start and continue, this reaction is thought to be endothermic. Additionally, sorting is a crucial stage in the gasification process because it allows inert elements like metals and glass to be eliminated. The primary yields of gasification is a producer gas, also known as synthesis gas or syngas, mostly consisting of CO, H_2, and CH_4, with small quantities of other minor non-combustible gases (CO_2 and N_2). Prior to producing energy, the producer gas must be cleaned/recovered of pollutants like small char particles. Syngas has a high heating value and is capable of producing electricity. It has a prospect in the future due to how effortlessly UT constructs infrastructure. It only requires the top management's commitment and the legality of the rules that will be implemented potency.

Pyrolysis.

Organic waste is treated to thermal decomposition through the thermochemical conversion process of pyrolysis at a high temperature between 300 °C and 80 °C in an inert atmosphere. How the temperature changes will depend on the materials utilized in the process. Pyrolysis requires pretreatment in order to remove glass, inert chemicals, and metals [26]. The first step in this process is the 300 °C thermal breakdown of pretreatment waste in heated, oxygen-free chambers. Then, in a non-reactive environment, the temperature rises to 800 °C. Pyrolysis may additionally generate carbon dioxide, hydrogen, and biochar or bio-oil, depending on the heating rate, long-term temperature, and length of solid residence time.

Pyrolysis is separated into two types: slow pyrolysis, which produces charcoal, and fast pyrolysis, which produces bio-oil [27]. Pyrolysis is commonly considered an acceptable replacement for the incineration process due to its ability to recover considerable amounts of energy and resources. Recently, there has been a lot of concern about pyrolysis because of its high energy efficiency. It also eliminates some of the challenges related to incineration, like transportation issues and the challenge of locating new, suitable sites for incinerators and landfills.

Bioethanol production.

The increasing demand for fossil fuels, such as oil and gas, has led to an energy crisis, increasing fuel prices and demand. Bioethanol, an environmentally friendly alternative, can be produced using lignocellulose materials like MSW, harvest wastes, sawdust, grass, and wooden chips [28]. MSW is a significant source of cellulosic abundance, making it an effective raw material for fuel generation. However, the biological conversion of MSW to bioethanol can lead to harmful chemicals and contaminants. Bioethanol can be produced through fermentation using three different forms of biomass: direct fermentation of sugar beet in Europe, starch crops like maize in the USA, and MSW cellulosic biomass. Using MSW biomass for ethanol production is expected to take the lead in the future. Different technologies, including hydrolysis, fermentation, and distillation, can be used to produce bioethanol.

Hydrogen and microbial fuel cells.

Microbial fuel cells (MFCs) offer a sustainable way to generate electricity from organic waste. Bacteria in an MFC break down organic matter, releasing electrons and protons [29]. Electrons travel through an external circuit, while protons pass through a membrane, both ultimately contributing to electricity generation at the cathode [30]. This technology presents a promising avenue for converting waste into a valuable resource. In a separate but related field, research is exploring the use of waste materials like used batteries to create catalysts for hydrogen production. These catalysts, often containing transition metals like cobalt, can facilitate reactions that split water into hydrogen gas and oxygen, offering another potential solution for clean energy generation [31]. By harnessing the power of microbes and transforming waste materials, these advancements hold significant promise for a more sustainable future.

While advanced waste processing methods like gasification, pyrolysis and bioethanol production, microbial fuel cell, and H_2 production offer environmental advantages, integrating them presents hurdles for UTC. These technologies require specialized skills and infrastructure beyond UTC's current capacity, potentially necessitating investment in personnel training and facility upgrades. Furthermore, economic feasibility is crucial, demanding in-depth studies to assess initial investment costs, ongoing operational expenses, and potential revenue generation from recovered resources. Finally, although these methods represent a step towards sustainability, their environmental impact requires thorough assessment. Implementing emissions control systems and proper waste treatment processes is essential to minimize potential risks. In conclusion, while promising, comprehensive evaluation and strategic planning are vital before pursuing these advanced techniques.

The study also suggests several recommendations for enhancing the practical applicability of waste management solutions. These include conducting comprehensive pilot studies, involving key stakeholders, establishing continuous monitoring and evaluation mechanisms, fostering knowledge sharing and collaboration, designing waste management strategies that are adaptable to changing circumstances, conducting thorough risk assessments, investing in capacity building, and developing long-term planning. These measures aim to identify potential challenges, refine strategies, optimize processes, and ensure the long-term sustainability and success of waste management initiatives. By incorporating these recommendations, the study aims to improve the practicality and relevance of waste management solutions in real-world scenarios.

However, the study presents several difficulties, including challenges in implementing advanced waste processing techniques like gasification, bioethanol production, and fuel cells; potential difficulties in determining economic feasibility; environmental risks; and complexity in technical aspects. It also highlights the need for continuous monitoring and evaluation of waste management performance, finding qualified personnel, the time-consuming and expensive nature of constructing or retrofitting facilities, and potential limitations in the study's scope, such as focusing on specific waste management strategies without considering broader systemic issues or external factors.

The research will involve in-depth feasibility studies, collaboration with specialized entities, and exploring innovative waste management strategies. It will also focus on waste minimization, optimization, and compliance with regulations. The research will also evaluate waste management performance, address challenges, and invest in research and development. The scope will expand to consider broader systemic issues and emerging trends in waste management practices. The collaboration will involve stakeholders, regulatory bodies, and industry experts to exchange knowledge and best practices for sustainable waste management.

7. Conclusions

1. From organic waste composting to the recycling of plastics, paper, and used oil, a sustainable waste management strategy can significantly reduce environmental impact. Composting offers a natural solution for organic waste, creating nutrient-rich soil amendments and reducing reliance on landfills. Mechanical recycling offers a practical solution for plastics, Styrofoam, and paper products, diverting waste from landfills and reducing the need for virgin materials. Used oil can be reused or recycled, creating a closed-loop system that minimizes environmental pollution. For specific waste streams like sludge, stabilization and solidification methods ensure safe disposal, while hazardous materials like batteries, used filters, TL lamps, and packaging require specialized treatment facilities for responsible handling and resource recovery.

2. UT is committed to a significant investment in waste management, adopting a circular economy model that prioritizes minimizing waste generation and maximizing resource utilization. Through cost analysis, securing government subsidies and tax breaks, and forging collaborations, UTC's plan aims to promote economic opportunities within the recycling industry. This long-term strategy emphasizes creative methodologies, cutting-edge technologies, and strong governance to overcome challenges such as trained labor, technological adoption, and public awareness. Ultimately, this comprehensive approach will ensure efficient waste processing, environmental compliance, and pave the way for a more sustainable future.

3. Modern waste processing techniques including gasification, pyrolysis, bioethanol, fuel cells, and hydrogen generation will be possible in the future with a developed infrastructure. Additional feasibility studies need to be conducted in order to determine the long-term readiness of this modern waste management system at UT.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

Data cannot be made available for reasons disclosed in the data availability statement.

The data are not accessible to the public since they contain confidential and sensitive information regarding the company's operations and strategies. This has the potential to jeopardize the company's competitive edge and give rise to social conflicts. The organization is willing to consider alternative data sharing arrangements for qualified researchers, assessing each request individually. The study relies on an extensive examination of publicly accessible data sources and internal corporate data. The company is dedicated to performing conscientious research that follows ethical principles and emphasizes the well-being of stakeholders.

Use of artificial intelligence

In this study, AI has been used to improve waste management communication at UT. The paper uses AI-powered grammar and style checkers to refine sentence structure, punctuation, and readability, ensuring proper English grammar and native fluency. This helps eliminate grammatical errors, maintain a professional tone, and refine native fluency. The paper effectively communicates UT' commitment to sustainable waste management practices, fostering a clear understanding for a global audience.

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