Identification, Classification and Minimization of Industrial Waste based on The Basel Convention and RCRA (Case Study: Parsian Gas Refinery)

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Article Info	ABSTRACT
	Petroleum refineries generate significant industrial waste, posing environmental risks that necessitate effective management strategies to ensure compliance with international standards, such as the Basel Convention and RCRA. This study aimed to develop an integrated waste management system for Parsian Gas Refinery by identifying, classifying, and proposing minimization strategies for industrial waste. Implementing targeted waste management practices will reduce environmental impact and enhance compliance with global standards. A cross-sectional analysis was conducted using questionnaires, site visits, and document reviews to categorize process and non-process waste. Quantitative and qualitative studies, alongside a semi-quantitative risk assessment, were employed. The refinery produces approximately 804.25 tons of industrial waste annually, with 23.63% classified as hazardous, 68.80% recyclable, and 45.44% suitable for landfilling. Current practices revealed deficiencies in storage, handling, and disposal of hazardous materials. An integrated waste management system is proposed, emphasizing recycling, high-temperature incineration for dangerous waste, and engineered landfilling to minimize environmental impact and costs. Long-term monitoring is recommended to evaluate the system's effectiveness and scalability.

INTRODUCTION

The oil and gas industry faces significant environmental challenges due to the generation of diverse industrial waste streams—gas, liquid, and solid—resulting from its extractive nature (Pashmi et al., 2025; Zafari et al., 2025). These wastes contribute to environmental pollution, including contamination of water, air, and soil, while imposing economic burdens through material losses and the high costs of pollution control (Golzary et al., 2025; Golzary & Zarei, 2025). Effective waste management is crucial for mitigating these impacts, ensuring compliance with international standards such as the Basel Convention and the Resource Conservation and Recovery Act (RCRA), and aligning with global best practices. For instance, refineries in countries such as Canada and Germany have adopted circular economy principles, which have significantly improved recycling rates and reduced waste generation (Digitemie et al., 2025; Mora Peris et al., 2024).

Parsian Gas Refinery, a critical facility in Iran, processes natural gas from the Tabnak, Varavi, Shanoul, and Homa fields, with a nominal capacity of 82 million cubic meters per day, contributing 17% of the country's gas consumption and 10.5% of its energy basket (Boostani

et al., 2024; Habibi et al., 2024). The refinery's operations generate substantial industrial waste, necessitating systematic strategies to address environmental and operational challenges. Previous studies on waste management in refineries, such as those at Isfahan and Bandar Abbas, have highlighted the importance of waste segregation, risk assessment, and engineered disposal methods, including incineration and landfilling with environmental monitoring systems (Kasani et al., 2022; Mousavi et al., 2023; Zarnegar et al., 2023). These studies provide a foundation for developing tailored waste management solutions for Parsian Gas Refinery.

This study aims to develop an integrated waste management system for Parsian Gas Refinery with the following objectives: (1) to identify and classify industrial waste generated at the refinery, (2) to propose strategies for waste minimization, recycling, and reuse, and (3) to design incineration and landfill systems to reduce environmental risks and operational costs. The methodology involves a cross-sectional analysis, incorporating questionnaires, site visits, and document reviews, along with quantitative and qualitative studies, as well as a semi-quantitative risk assessment, to evaluate waste characteristics and management practices.

METHODOLOGY

This study employed a streamlined methodology to identify, classify, and assess waste management practices at Parsian Gas Refinery, aligning with international standards Rules; Peiry, 2013). The approach consisted of three main phases: data collection, waste identification and classification, and risk assessment, as described below. To characterize waste generation sources, the following steps were undertaken. A structured questionnaire was distributed to refinery personnel to collect data on process and non-process waste, including generation sources, causes, current management practices, and disposal methods (Hester & Harrison, 2013). Inspections were conducted across key units—Laboratory, Maintenance, Workshop, Warehouse, Process, and Operations—to verify questionnaire responses and identify waste sources.Operational documents, site plan drawings, process descriptions, and records of feedstock consumption and material output were analyzed to map waste generation across units, including Parsian One (Units 400, 500, 800) and Parsian Two dehydration units (Kianous & Karimzadegan, 2018). Discussions with unit supervisors and follow-up site visits incorporated feedback to validate findings and refine waste classification.A semi-quantitative risk assessment was conducted to evaluate environmental and health risks associated with waste management, following established methodologies (Codes & Rule). Hazardous wastes (e.g., oily sludge, spent catalysts, expired chemicals, contaminated filters) were classified per Basel Convention and RCRA guidelines (Peiry, 2013). Key risks were identified, including groundwater contamination, worker exposure to hazardous materials, fire hazards in storage areas, and toxic gas emissions during incineration (Hester & Harrison, 2013). A 5×5 risk matrix was used, assessing consequence severity (1 = minor, 5 = catastrophic) and likelihood (1 = rare, 5 = very likely). Wastes with a risk score ≥16 were prioritized for specialized management. Recommended actions included mechanized collection systems, resistant containers with standardized labeling, worker training, high-temperature incineration with gas treatment, and engineered landfilling with impermeable layers and leachate drainage (Bryant & Moores, 2018; Tchobanoglous et al., 1993).The overall research methodology, summarized: consisted of three main phases: data collection, risk assessment, and risk mitigation. The types and quantities of industrial waste: All waste generation locations have been identified, and the causes of waste generation have been discussed and analyzed for each unit separately. Furthermore, the quantity and quality of generated waste at the production source have been determined, and the waste generation rate has been specified.

Industrial waste can be divided into two categories. The first category consists of process waste directly produced during manufacturing. This waste is generated through the normal

operation of the production process and is typically called industrial waste, comprising various components depending on the specific process.

The amount of each component depends on the characteristics of the process and how it is operated. Changes in this waste during operation often indicate shifts in the process or its functionality, which should usually be investigated. This type of waste is generally produced consistently throughout the process's operation, and its generation may be continuous or intermittent, depending on the process. The key feature of this waste is its predictable quantity and type, enabling effective planning for recycling or reuse. Such waste includes packaging materials, barrels, containers, material cans, pallets, shearings, ends of metal and plastic rolls, process sludge, wastewater treatment sludge, spent catalysts, among others. The second type is non-process waste, which results from support activities that do not directly involve product manufacturing. This includes maintenance, technical inspections, laboratory work, warehouse storage of goods and parts, central workshops, transportation, and firefighting operations. Based on current processes within the refinery, visits to production lines, and a review of relevant documents, the types of process waste generated by each unit are listed in Table 1. Waste produced within the maintenance and central workshop units is detailed in Table 2, while waste from safety and firefighting, technical inspection, transportation, and laboratory units is presented in Table 3.

At Parsian Gas Refinery, several key factors contribute to industrial waste generation, with maintenance and repair programs playing a central role. Well-structured preventive maintenance significantly reduces equipment failure, thereby minimising unexpected breakdowns and the associated waste streams. In contrast, older equipment tends to operate less efficiently and is

Table 1. Types of Waste Generated in Refinery Process Units

Row	Unit Name	Generated Waste
1	Wellhead Facilities and Gathering Pipelines	Waste resulting from equipment and pipeline repairs
2	Catch Basin	Gaskets - Used Oil
3	400 and 500 Dehydration Units	Gaskets - Filters - Molecular Sieve - Slag – Insulation
4	400 and 500 Stabilization Unit	Used Oil
5	800 Dehydration Unit	Oil - Gaskets - Molecular Sieve – Filters
6	400 and 500 Auxiliary Units	Gaskets – Oil
7	Parsian 1 O.W.S Unit	Oil - Hydrocarbon Deposits – Solids
8	Parsian 1 Water Unit	Oil Filters - Air Filters - Radiators - Fuel Filters - Batteries - GCS - Oil - Deposits - Packing - Bolts and Nuts – Bearings
9	Parsian 1 Service Water Unit	Deposits - Gaskets - Bolts and Nuts - Packing – Bearings
10	Parsian 1 Nitrogen Unit	Oil - Gaskets - Various Filters - Molecular Sieve - Bolts and Nuts
11	Parsian 1 Air Unit	Oil - Gaskets - Various Filters - Bearings - O-rings
12	Parsian 2 Catch Basin	Liquids – Sludge
13	Parsian 2 Dehydration and Outlet Gas Metering Unit	Used Oil - Sludge - Hydrochloric Acid
14	Parsian 2 Gas Condensate Stabilization Unit	Liquids - Sludge - Oil - Used Oil – Gaskets
15	Parsian 2 Flare and Hot Oil Unit	Liquids - Sludge - Oil - Petrotherm Oil
16	Parsian 2 Diesel Fuel Unit	Bolts and Nuts - Gaskets - Diesel Fuel - Sludge - Various Filters
17	Parsian 2 Water Unit	Bolts and Nuts - Gaskets - Packing - Sludge – Deposits
18	Parsian 2 Air Unit	Bolts and Nuts - Gaskets - Various Filters - Oil – Deposits
19	Pressure Boosting Station Unit	Oil - Various Filters - GTE - Batteries - Gaskets - Liquids - Molecular Sieve - Tanks - Diethylene Glycol - Capco Oil - Empty Barrels - Used Oil
20	Power Distribution Unit	Oil - Various Filters - Gaskets - Batteries - Grease - H2SO4 - ZOK - PVC - Diesel Fuel - Engine Oil
21	Biological Treatment Plant Unit	Biological Sludge - Gaskets - Grease - Washers - Various Filters - Activated Carbon

Table 2. Types of Waste Generated in Maintenance and Central Workshop Units

Row	Unit Name	Waste Name
1	Instrument Repair	Fittings - Gauges - Tubes – Transmitters
2	Central Workshop	Scrap Iron
3	Electrical Repair	Wire, Cable, Battery, Alkaline, Switch and Fuse, Transformer Oil, Bearing and Anode, Sulfuric Acid, Lamp Holder, Various Lamps, Voltmeter and Ammeter, Overload, Bushing and Selector, Electric Motor Impeller, Heater and Slag
4	Construction Operations	Construction Debris
5	Mechanical Repair	Oil, Gaskets, Bolts and Nuts, Seal Tube, Ironmongery, Plate, Tank Bottom Sediment, Filter, Activated Carbon, Silica Gel, Resin, O-ring, Insulation, and Paint Containers

Table 3. Types of Waste Generated in Non-Process Units

Row	Unit Name	Generated Waste
1	Transportation Unit	Changed Oil, Worn Tires, and Batteries
2	Real Estate Unit	Cable - Transmitter - Welding Workshop Waste - Wire - Insecticide Cans - Paint and Thinner Containers
3	Firefighting Unit	Foam - Protein Foam – Powder
4	Laboratory	Organic Materials, Solid Materials, Aqueous Materials, and Mercury

more prone to producing higher volumes of waste due to outdated systems lacking the precision of modern technologies. Another critical factor is the variability in feedstock composition, as the chemical makeup of incoming gas fluctuates depending on its source field, directly affecting both the type and quantity of waste produced during processing. Additionally, sudden and unplanned increases in production can overwhelm the existing waste management infrastructure, leading to disproportionate waste generation and placing added pressure on treatment and disposal systems. Addressing these variables is essential for improving operational efficiency and reducing environmental impact.Waste management involves coordinated and systematic regulations for controlling the generation, storage, collection, transportation, processing, and disposal of solid waste. It ensures compliance with optimal public health principles, economic factors, resource conservation, aesthetic standards, and other environmental needs. This section describes the industrial waste management status at the refinery in accordance with the Waste Management Law.For statistical waste analysis, the central industrial waste-generating units were divided into five groups: Process, Maintenance and Central Workshop, Clinic, Laboratory, and Other Units (Safety and Firefighting, Technical Inspection, and Transportation). The most notable current deficiencies in Parsian Refinery's industrial waste management system are summarized as follows.Long-term storage of generated waste,Disposal of some waste in unapproved locations,Storage of waste (especially hazardous waste) under non-standard conditions,Lack of labelling of waste containers, especially for hazardous waste,Lack of use of appropriate containers for some waste, especially hazardous waste,Burning of some waste in a non-standard manner,Lack of information on how solid waste is recycled (especially hazardous waste).

This paper emphasizes the importance of addressing waste management in Parsian Gas Refinery,highlighting the company's commitment to solving waste issues in its refinery, industrial, and production processes. Waste management was approached by separately identifying the wastes and their sources for each unit, based on existing processes. The study analyzed both the quantitative and qualitative aspects of these pollutants, summarizing the findings in various tables. After conducting waste identification and reviewing the current situation, a comprehensive waste management system was designed for the refinery, incorporating essential waste management elements. The first stage of environmental monitoring involved identifying

process and non-process waste from each unit, along with their sources, and analyzing their characteristics. Proper implementation of these steps is crucial for effective waste management system design and operation. Accordingly, this process was divided into three parts: identifying waste pollutants, classifying wastes based on specific criteria, and preparing a quantitative list of industrial wastes per unit using the tables developed. The subsequent sections presented their standard disposal pathways. The wastes were then classified and coded according to the Basel Convention and RCRA criteria within the refinery. Waste minimization measures were discussed, highlighting significant waste streams. Suitable containers and collection methods were determined, along with transportation practices. Finally, waste disposal methods were evaluated, including the construction of a landfill and the purchase of an industrial incinerator, subject to the refinery's current conditions. In this paper, the Basel Convention classification, which is presented in two lists Y (from Y1 to Y47) and Annexes A and B, as well as the list of chemical substances published by the US Environmental Protection Agency, has been selected as a criterion for identifying and classifying hazardous industrial wastes. The corresponding method for each has been presented.

RESULTS AND DISCUSSION

This section will present solutions for reducing and controlling pollutants released from the Parsian Gas Refinery. Both general solutions and those specific to each unit are discussed while reviewing and summarizing the results obtained. Therefore, reduction strategies are first outlined for each part, followed by separation and recycling methods. Techniques for reducing and controlling refinery pollutant streams can be classified into four basic groups: On-site reduction, with the help of modifying and re-engineering process equipment in a unit; Separation and segregation of potential pollutant streams; Utilizing recycling opportunities; Implementing management and training strategies. Specific techniques are listed in Tables 4 and 5.

After coding and providing minimization solutions, suitable containers were identified for storing various types of waste, including hazardous and non-hazardous materials. Incompatible wastes that cannot be stored together were also recognized. Furthermore, storage, labelling, handling procedures, collection schedules, necessary equipment, and final waste disposal

Table 4. Techniques for Reducing and Controlling Refinery Pollutant Streams

Row	On-site Reduction of Pollutants	Row	On-site Reduction of Pollutants
1	Eliminating the use of chromates as an anti-corrosion agent	6	Removing unnecessary storage tanks from service
2	Modernizing and replacing underground pipelines	7	Controlling the amount of oily sludge resulting from heat exchanger cleaning
3	Controlling the entry of solids into the wastewater system	8	Controlling surface-active agents in effluent streams
4	Thermal processing of some sludges	9	Reducing the generation rate of sludge accumulated at the bottom of the tanks and raw materials
5	Sealing and resealing product and raw material tanks	10	Repairing seals and packing of pumps and compressors

Table 5. Techniques for Reducing and Controlling Refinery Pollutant Streams

Row	Personnel Training	Substitution of Hazardous Materials	Separation, Segregation, and Recycling of Pollutants
1	Training to reduce the entry of solids into the wastewater system	Using non-hazardous degreasers	Increasing the efficiency of separating petroleum compounds from oily sludges
2	Training to prevent soil contamination	Using higher quality filters	Separating process wastewater streams from non-process wastewater streams
3	Training to maintain a clean work environment	Using oils with a longer lifespan	Separating oily waste streams from non-oily waste streams

methods were outlined.

The current condition of the refinery's waste storage area highlights the need to review the storage and separation of different waste type. The refinery must undertake the design, supply, and purchase of necessary equipment for a waste incinerator to burn industrial and special wastes at the site. This should be based on existing equipment and conditions, technical specifications, and current approved international standards, with the goal of procuring an incinerator. A preliminary cost estimate for constructing a refinery incinerator has been prepared, outlining the main cost components. The total estimated cost is 400,000 million Rials, including 350,000 million Rials for design and equipment, and 50,000 million Rials for construction activities. This initial financial assessment provides a basis for project planning and budgeting. Additionally, a preliminary cost estimate for building a refinery incinerator shed and related equipment has been developed, highlighting key expenditure components. The total estimated cost is 50,000 million Rials, which includes 48,000 million Rials for constructing a 200-square-meter facility with a control room and auxiliary infrastructure, as well as 2,000 million Rials allocated for firefighting equipment. This budget serves as a foundational estimate for the development and implementation of the incineration facility at Parsian Gas Refinery.

Following extensive evaluations at Parsian Gas Refinery, the design and installation of an industrial-grade incinerator was identified as a strategic priority for effective hazardous waste management. The technical characteristics of the proposed unit are as follows: Primary combustion chamber temperature: ≥850°C; Secondary combustion chamber temperature: >1100°C with a minimum residence time of 2 seconds to ensure complete breakdown of organic compounds; Annual processing capacity: between 300 and 400 tons of industrial waste. The incinerator is equipped with a suite of pollution control technologies, including: Bag filters; Wet scrubbers; Flue gas cooling units; Energy recovery systems. Additional key features include: Real-time emissions monitoring to regulate dioxins, nitrogen oxides (NOx), and carbon monoxide (CO); A mechanized system for collecting and transporting ash to engineered landfills; Construction of a 200-square-meter facility fitted with laboratory and safety equipment; Estimated total project cost: 400 billion IRR. This incinerator has been specifically designed to handle highly flammable and hazardous wastes and incorporates advanced filtration systems to minimize its environmental footprint. Supplementary treatment systems and considerations include: A wet scrubber system for neutralizing acidic compounds and capturing hazardous particulates; Continuous flue gas monitoring, particularly for secondary pollutants such as dioxins; Safe disposal of residual ash in engineered landfills featuring impermeable liners and leachate drainage systems; Prioritized use of the system for high-risk, combustible wastes, in full compliance with RCRA regulations and the Basel Convention.

The refinery must undertake the "design, supply, and purchase of necessary equipment for the construction of a landfill for the sanitary disposal of special industrial wastes" at the complex site, considering existing equipment and conditions based on technical specifications and up-to-date, internationally approved standards. If the waste incinerator project is implemented at the refinery, the significant reduction in waste volume will mean that a dedicated engineered landfill will not be necessary for the refinery. Instead, it can utilise facilities that will be developed for the Asaluyeh region in the future. In this case, only a temporary storage site will be required. The total amount of industrial waste generated by the refinery is approximately 804.25 tonnes annually, with 253.36 tonnes (45.44%) being disposable. The amount of disposable waste is estimated to be a minimum of 300 tonnes per year, with a total capacity of roughly 4,000 tonnes over the ten-year plan. A preliminary cost estimate for the landfill design at Parsian Gas Refinery has been prepared, outlining key expenditure components needed to develop a safe and environmentally compliant disposal facility. The total estimated cost is 142,250 million Rials, which includes 25,000 million Rials for design services, 53,250 million Rials for construction activities, and 64,000 million Rials for equipment procurement. This financial assessment

provides a baseline budget for implementing an engineered landfill system that features impermeable liners, leachate drainage, and monitoring infrastructure to minimise environmental impact and ensure long-term operational safety. The preliminary cost estimate for constructing the refinery waste disposal site includes electricity (10,000 million Rials), telephone services (500), gas collection and disposal systems (2,500), laboratory equipment (10,000), firefighting equipment (500), spraying equipment (500), and machinery such as a Nissan pickup and an excavator (4,000), amounting to a total of 64,000 million RialsThe preliminary cost estimate for equipping the refinery waste disposal site includes drainage, culverts, waterways, and access bridges (6,000 million Rials); fencing and walls (5,000); sanitary facilities (1,050); a laboratory building (container) (8,000); green space (2,000); leachate drainage (7,000); final cover (7,500); excavation (9,000); and an impermeable layer (25,000), totaling 71,050 million Rials.

Technical Specifications of the Engineered Landfill Site.include:Protective Base Layers: A high-density polyethylene (HDPE) liner, 2 mm thick, to ensure impermeability; A geotextile layer to prevent leakage; A drainage layer composed of sand and gravel, integrated with leachate collection pipes.Leachate Management System: Automated pumps for continuous leachate extraction; Monthly inspections of storage tanks; Primary treatment using sand filters and activated carbon to remove contaminants.Final Covering System: A compacted clay cap with permeability of less than 10^{-7} cm/sec; A surface sealing layer and protective berm to block surface water infiltration.Long-Term Environmental Monitoring: Groundwater observation wells placed around the site; Documentation and reporting by ISO 14001 and BS 8576 standards

In addition to conventional methods such as sanitary landfilling and incineration, modern solutions like energy recovery and chemical recycling offer promising opportunities to optimize the refinery's waste management system. These technologies include:Waste-to-Energy (WTE):Controlled combustion, gasification, or pyrolysis processes convert organic and hazardous waste into usable heat or electricity,In tandem with traditional incineration, WTE reduces waste volume while producing energy,Given the refinery's existing infrastructure, this technology can help meet part of its energy demand:Chemical Recycling:Processes such as molecular breakdown, dissolution, and chemical treatment can convert oily, resinous, and plastic waste into reusable raw materials,,Especially effective for facilities generating large quantities of specialized organic waste,Can serve as a sustainable alternative to incineration. Incorporating these technologies into an integrated waste management system requires careful technical and financial evaluation.

A comprehensive feasibility study was conducted to evaluate the proposed waste management strategies at Parsian Gas Refinery from economic, environmental, and social perspectives. The key findings are summarized below. From an economic perspective, the estimated cost for constructing an industrial-grade incinerator is 400 billion IRR and the cost of building the engineered landfill is 142.25 billion IRR. Recycling and selling recoverable materials is the most cost-effective approach and offers income potential. A hybrid model combining recycling, incineration, and landfilling is the most viable both operationally and economically. From an environmental perspective, incineration, if unmanaged, can emit greenhouse gases and toxic substances like dioxins. Poorly managed landfills risk contaminating groundwater. Recycling poses the least environmental risk. With effective, ongoing monitoring, potential hazards can be minimized. From a social perspective, the project expects creation of 25 to 40 direct jobs, improved health conditions for both employees and the surrounding community, and increased environmental awareness through educational and outreach programs. A summary is provided in Tables 6 and 7.

Environmental Impact Assessment (EIA)
Social Impacts of Waste Management at Parsian Gas Refinery   .
The job creation potential includes positions in the sorting station (sorting workers, shredder

Table 6. Operational and Environmental Costs

Row	Option	Environmental Cost	Benefits	Considerations
1	Recycling/Sales	Low	generating, Low Impact	Requires Waste Segregation and Sales Contracts
2	Engineered Landfill	Medium	Simple Technology, On-site Feasible	Leachate Leakage Risk, Long-term Monitoring Needed
3	Incineration	High	Rapid Waste Volume Reduction	Greenhouse Gas Emissions, High Operational Costs

Table 7. Proposed Options for Parsian Gas Refinery

Row	Criterion	Incineration (Industrial Waste Burner)	Engineered Landfill
1	Greenhouse Gas Emissions	High (CO_2, NO_x, Dioxins, CO)	Medium (Methane, CO_2 in Long-term)
2	Air Pollution	High (Requires Filtration Systems)	Low (If Properly Covered)
3	Soil Pollution	Low (If Ash Collected)	High (Leachate Leakage Risk)
4	Groundwater Pollution	Low	High (Toxic Leachate Risk)
5	Energy Consumption	Very High	Low
6	Biodiversity Impact	Localized (Heat/Smoke)	Widespread (Land Use Change)
7	Land Requirement	Low	High
8	Secondary Waste	Yes (Ash Requires Disposal)	No (If Properly Managed)
9	Setup Cost	400,000(Billion IRR)	142,250 (Billion IRR)
10	Long-term Maintenance Cost	High (System Upkeep)	Low to Medium
11	Social Acceptance	Low (Pollution Concerns)	Medium (If Isolated)

operators, and warehouse staff), waste collection and transport (drivers, loading labor, and supervisors), the oil and metal recycling unit (technicians and quality control experts), the incineration plant (operators, safety officers, and laboratory staff), and the engineered landfill (operational workers and environmental monitors). To choose the best way to manage the waste, both economic and environmental aspects were checked. For burning waste (Incineration), it needs a high initial cost (around 400 billion IRR), can quickly reduce the amount of waste, has high running and maintenance costs, and works well, especially for dangerous (hazardous) waste. For using sanitary landfills, it costs less to build (about 142 billion IRR), is good for non-hazardous (normal) waste, needs a lot of land, and must be checked and controlled for a long time. For recycling and selling waste, it is the cheapest method overall, needs careful waste separation, depends on having markets to sell the recycled stuff, and has the lowest negative effect on nature. The final suggestion is to use a mixed (hybrid) method that combines all three options. This has these benefits: Lower total costs, Better and easier operations, Helps protect the environment, Covers all types of waste in a full plan.

The Parsian Gas Refinery produces approximately 804.25 tons of waste each year, which equals 26.9 tons per million cubic meters of processed gas (Figure 1). This rate is higher than that of most international refineries, where waste generation usually ranges from 15 to 20 tons/MMm³ (Aldossary, 2025; Mianzan et al., 2025). For example, Canadian gas processing plants report an average of 17.5 tons/MMm³ (Aldossary, 2025), and European refineries typically generate around 15 tons/MMm³ (Mianzan et al., 2025). In Iran, the Bandar Abbas Refinery has a similar but slightly higher rate of 28.5 tons/MMm³, indicating a broader national trend of inadequate waste minimization strategies.(Figure 2). In terms of composition, hazardous waste makes up 58.7% of Parsian's waste, which is higher than the global average (40–45%) but close to domestic benchmarks (Bandar Abbas: ~61%). This higher proportion of hazardous waste may indicate limited use of cleaner production strategies, insufficient preventive maintenance, and the lack of integrated waste-to-energy (WTE) technologies. Conversely, refineries in Europe
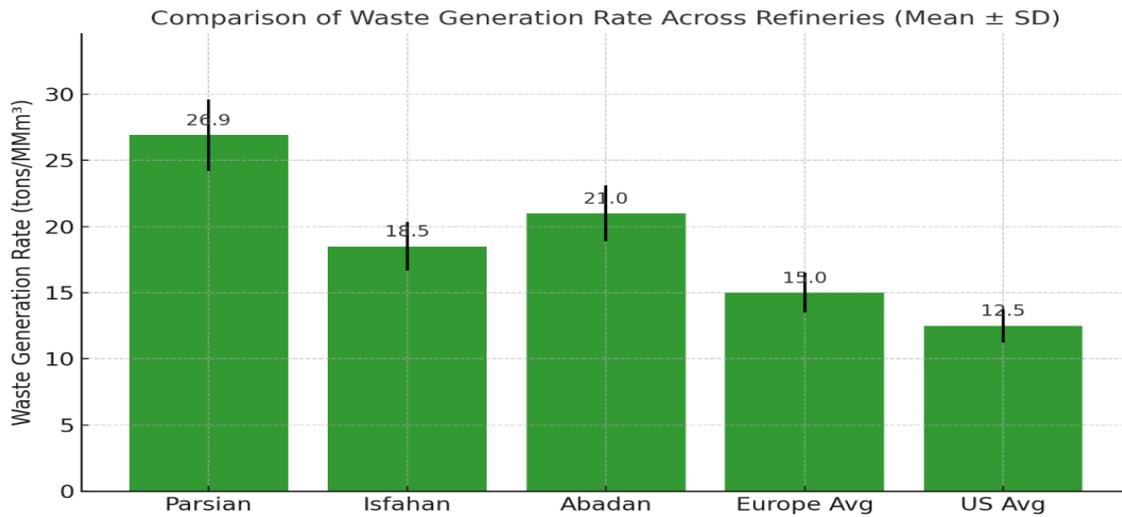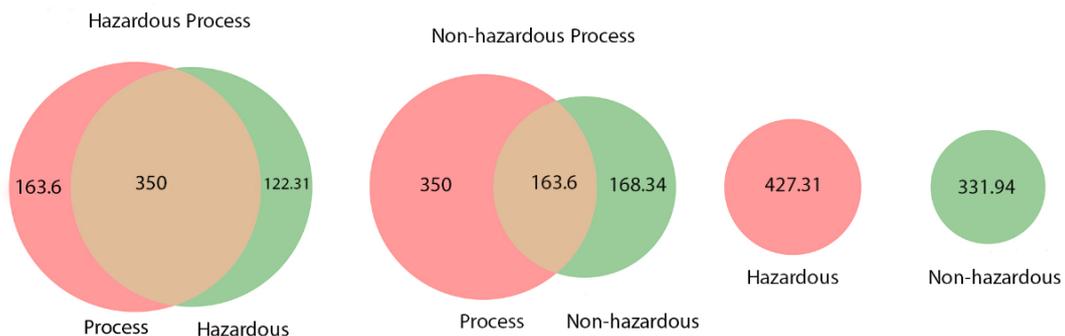
Fig. 1. Waste generation rate analysis

Fig. 2. Overlap between different waste categories.

and Canada focus on proactive maintenance, advanced recycling systems, and energy recovery to reduce both hazardous and total waste generation (Aldossary, 2025; Mianzan et al., 2025) (Figure 3)

The waste management hierarchy at Parsian indicates that while 68.80% of total waste is technically recyclable and 73.37% is sellable, practical implementation faces restrictions due to limited infrastructure and informal waste trading channels. Similar challenges are reported in Iranian refineries, where non-standard disposal methods result in environmental risks and legal liabilities (Khajeh Hoseini et al., 2020).

Conversely, international facilities are increasingly adopting circular economy models by establishing industrial symbiosis networks, where by-products of one facility are used as feedstock for another (Mianzan et al., 2025). compares hazardous and non-hazardous waste, showing that non-hazardous waste represents 64% of the total, while hazardous waste accounts for 36%. A mixed waste management model—prioritizing recycling, followed by incineration of hazardous fractions, and final landfilling of residuals—appears to be the most balanced solution for Parsian. This aligns with global best practices but requires significant investment in advanced incineration with gas-cleaning systems and engineered landfills. Without such measures, the refinery risks not only higher environmental burdens but also financial liabilities from improper waste handling, as noted in other regional studies(Al-Salem et al., 2009) . Table
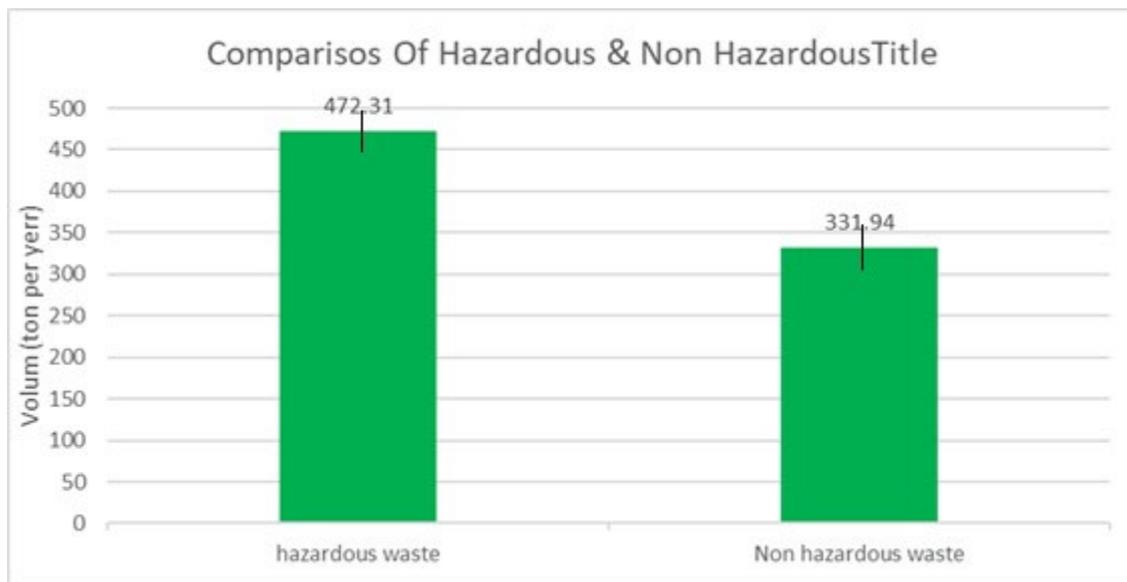
Fig. 3. Composition of Type

Table 8. Comparison of Waste Generation with Global Benchmarks

Refinery / Benchmark	Waste Generation Rate (tons/MMm³)	% Hazardous Waste	Key Management Practices	Reference
Parsian Gas Refinery	26.9	58.7%	Limited recycling, non-standard disposal	This Study
European Refinery Avg.	15.0	~45%	Advanced recycling, WTE integration	(Mianzan et al., 2025)
Canadian Gas Plant	17.5	42%	Proactive maintenance, circular models	(Aldossary, 2025)
Bandar Abbas Refinery	28.5	61%	Similar to Parsian; lack of minimization	(Ebrahimi et al., 2011)
Iranian Refineries (avg.)	25–30	55–65%	Weak regulation, reliance on landfilling	(Khajeh Hoseini et al., 2020)
Global Best Practices	<20	35–45%	Waste prevention, industrial symbiosis, digital WMS	(Al-Salem et al., 2009)

8 below synthesizes the comparative findings, emphasizing the gaps and opportunities for Parsian relative to both national and international benchmarks.

This comparison suggests that while Parsian's performance is broadly similar to other Iranian refineries, it lags behind international standards, particularly in hazardous waste minimization and circular economy integration. Addressing these gaps requires systematic reforms in technology, regulation, and training, as outlined in the subsequent section on long-term solutions. The comparative analysis revealed that the Parsian Refinery generates higher waste intensity and a larger proportion of hazardous waste compared to international benchmarks. These challenges, coupled with reliance on non-standard disposal and limited recycling, highlight the need for systematic, long-term interventions. The following strategies are aligned with global best practices(Al-Salem et al., 2009; Mianzan et al., 2025) and adapted to the refinery's operational context:

One major difference between Parsian and European/Canadian refineries is the absence of real-time digital monitoring. Implementing waste mapping systems with online monitoring and smart sensors will allow the refinery to: Track waste generation rates, types, and locations in real time, Optimize collection routes and reduce handling inefficiencies, Detect early signs of risks (temperature spikes, leaks) and respond proactively and Provide verifiable data to ensure compliance with environmental regulations. This approach mirrors the circular monitoring

frameworks adopted in Europe, where digital tools directly support waste minimization and recycling efficiency. With 58.7% of Parsian's waste classified as hazardous, reducing this share is critical. International case studies show that proactive maintenance, process optimization, and substitution of hazardous inputs significantly lower hazardous waste intensity (Aldossary, 2025). Parsian should: Establish preventive maintenance programs to avoid leakages and material losses; Introduce chemical substitution where feasible and Invest in advanced incineration systems with gas-cleaning technologies, ensuring compliance with emission standards. Such measures will gradually align hazardous waste levels with the global benchmark of 35–45%.

Although 68.8% of Parsian's waste is recyclable, the infrastructure for formal recycling is underdeveloped, and informal trading remains common. To address this: Develop on-site sorting and recycling facilities to capture value from recyclable fractions; Collaborate with other refineries to establish regional recycling hubs, reducing costs through shared infrastructure and Promote industrial symbiosis by linking with nearby industries that can use refinery by-products as raw materials, as practiced in EU circular economy models (Mianzan et al., 2025). Compared to international refineries, Iranian facilities often face gaps in regulatory compliance and staff training (Khajeh Hoseini et al., 2020). Parsian can overcome these limitations by: Conducting specialized training on waste management laws, particularly for warehouse and disposal units, to reduce legal and financial risks; Organizing continuous education programs for engineers, operators, and managers, updating them on best practices and emerging technologies and Establishing dedicated waste management task forces to oversee implementation, monitor performance, and ensure accountability.

Global leaders in refinery waste management continuously invest in R&D partnerships with universities and technology providers (Al-Salem et al., 2009). Parsian should adopt a similar strategy by: Launching pilot projects to test emerging recycling and treatment technologies under controlled conditions; Collaborating with academic institutions to assess the environmental impact of different waste streams and Attracting environmentally conscious investors by demonstrating commitment to innovation and sustainability.

CONCLUSION

This study assessed waste management at Parsian Gas Refinery, which generates 804.25 tons of industrial waste annually, with 23.63% classified as hazardous per Basel Convention and RCRA criteria. Current practices show deficiencies in storage, labeling, and disposal, posing environmental and health risks. To address these issues, an integrated waste management system is proposed, prioritizing recycling (68.80% of waste), high-temperature incineration for hazardous waste, and engineered landfilling for non-recyclable waste. This approach reduces environmental impact, ensures regulatory compliance, and lowers costs. Long-term strategies include adopting digital tools for waste tracking, collaborating with other refineries for shared practices, and partnering with academia for innovative waste treatment solutions. Implementing this framework will position Parsian Gas Refinery as a leader in sustainable waste management within the energy sector. Further research should focus on: Conducting a Life Cycle Assessment (LCA) to evaluate the environmental impact of the proposed system; Performing a techno-economic analysis to support funding for incineration and landfill infrastructure and Exploring advanced technologies, such as pyrolysis or gasification, to enhance waste recovery and minimize disposal.

GRANT SUPPORT DETAILS

CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

REFERENCES

Al-Salem, S., Lettieri, P., & Baeyens, J. (2009). Recycling and recovery routes of plastic solid waste (PSW): A review. *Waste management, 29*(10), 2625-2643.

Aldossary, H. (2025). Effective Circular Economy in Gas Processing Facilities Projects.

Boostani, F., Golzary, A., Huisingh, D., & Skitmore, M. (2024). Mapping the future: Unveiling global trends in smart waste management research. *Results in Engineering, 24*, 103485.

Bryant, J. S., & Moores, C. W. (2018). Disposal of hazardous wastes from petroleum refineries. Proceedings of the 45th Industrial Waste Conference May 1990, Purdue University,

Codes, D. O., & Rule, F. Environmental Protection Agency (EPA).

Digitemie, W. N., Onyeke, F. O., Adewoyin, M. A., & Dienagha, I. N. (2025). Implementing circular economy principles in oil and gas: addressing waste management and resource reuse for sustainable operations. *International Journal of Multidisciplinary Research and Growth Evaluation, 6*(1), 99-104.

Ebrahimi, S., Shayegan, J., Malakouti, M., & Akbari, A. (2011). Environmental evaluation and assessment of some important factors of oil contamination in soil around sarkhoun gas refinery of Bandar Abbas. *Journal of Environmental studies, 37*(57), 9-26.

Golzary, A., Sabet, N. S. M., & Faramdehi, M. R. (2025). Understanding carbon emission and minimizing its footprint via algal biomass-based biorefinery technologies. In *Algal Biorefinery* (pp. 1-17). Elsevier.

Golzary, A., & Zarei, Z. (2025). Advances in technologies for biotransformation of algal biomass into high-value products. In *Algal Biorefinery* (pp. 289-305). Elsevier.

Habibi, A., Bamshad, O., Golzary, A., Buswell, R., & Osmani, M. (2024). Biases in life cycle assessment of circular concrete. *Renewable and Sustainable Energy Reviews, 192*, 114237.

Hester, R. E., & Harrison, R. M. (2013). *Waste as a Resource*. Royal Society of Chemistry.

Kasani, A. A., Esmaeili, A., & Golzary, A. (2022). Software tools for microalgae biorefineries: Cultivation, separation, conversion process integration, modeling, and optimization. *Algal Research, 61*, 102597.

Khajeh Hoseini, L., Jalilzadeh Yengejeh, R., Mohammadi Rouzbahani, M., & Sabz Alipour, S. (2020). Planning the decision-making process and strategic management of ROP wastewater treatment system in Abadan Oil Refinery with a combined benefit of SWOT and AHP. *Journal of Advances in Environmental Health Research, 8*(4), 250-259.

Kianous, A., & Karimzadegan, H. (2018). The effect of strategic management to minimize pollution for oil refinery (the case of Tehran oil refinery). *Ukrainian Journal of Ecology, 8*(1), 240-248.

Mianzan, A., Odle, W., Oehrig, J. H., Sakkalis, K., & Vaiopoulou, E. (2025). Sustainability Assessment of Traditional and Emerging Treatment Techniques for Refinery Oily Sludges. *Circular Economy and Sustainability*, 1-28.

Mora Peris, P., de la Flor, J. P., Sánchez-Martín, L., Barettino, D., & García-Franco, E. (2024). Circular Economy of Petroleum-Based Industrial Wastes. In *Circular Economy on Energy and Natural Resources Industries: New Processes and Applications to Reduce, Reuse and Recycle Materials and Decrease Greenhouse Gases Emissions* (pp. 183-191). Springer.

Mousavi, S., Hosseinzadeh, A., & Golzary, A. (2023). Challenges, recent development, and opportunities of smart waste collection: A review. *Science of the Total Environment, 886*, 163925.

Pashmi, Z., Chamehsara, M., Parsi, S., & Golzary, A. (2025). Sustainable site selection for biomass refineries: an analytic network process model for optimizing bioenergy production in Iran. *Recent Progress in Sciences*, *2*(1), 14-14.

Peiry, K. K. (2013). The Basel Convention on the control of transboundary movements of hazardous wastes and their disposal: The Basel Convention at a glance. Proceedings of the ASIL Annual Meeting,

Tchobanoglous, G., Theisen, H., & Vigil, S. (1993). *Integrated solid waste management: engineering principles and management issues*.

Zafari, Z., Golzary, A., Rouhi, K., & Mansourihanis, O. (2025). From Conventional Approaches to Circular Systems: Evolution of Waste Management in Mega-Sporting Events. *Journal of the Air & Waste Management Association*(just-accepted).

Zarnegar, M., Khalili, H., & Golzary, A. (2023). Anaerobic Digestion for Effective Waste Management: A Case Study for Sustainable Rural Development in a Moderate Climate Region. *Pollution*, *9*(4), 1355-1373.