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Characterization of municipal solid waste in Vietnam: Case study in Nghe An province

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ABSTRACT

Municipal solid waste (MSW) management remains a significant challenge in Vietnam, largely due to rapid urbanization and the heterogeneous characteristics of waste. This study provides a node-specific characterization of MSW in Nghe An Province based on the analysis of seven composite samples collected at generation sources, transfer stations, and landfill cells. Material composition, physico-chemical properties, and energy potential were analyzed according to international standards. Results reveal strong spatial variability: biodegradable fractions dominate at source, up to 66% in market waste—whereas transfer-station samples are enriched in recyclables and ash due to compaction, partial degradation, and inert contamination. Moisture contents ranged 42.4–51.4%, which is consistent with or slightly lower than national averages, and volatile solids averaged 70% of total solids (TS). Net heating values (NHV) varied from 4.5 to 11.9 MJ kg^{-1} (average 9 MJ kg^{-1}). Only dry, plastic-rich fractions are suitable for refuse-derived fuel (RDF) production; high-moisture, organic-rich streams are more appropriate for composting or anaerobic digestion. The observed heterogeneity indicates that province-scale mass-burn incineration is not technically justifiable. Our findings provide an empirical basis for differentiated, node-specific treatment strategies and for planning integrated MSW management in lower-middle-income regions.

1. Introduction

Municipal solid waste (MSW) generation in Vietnam has increased rapidly over the past decades as urbanization, population growth, and changing consumption patterns accelerate. National MSW generation now averages 0.79 kg/person/day, with organic materials typically accounting for 50–70% of the waste stream [1]. Despite this growth, waste management infrastructure has not kept pace. Landfilling remains the predominant treatment method, often with limited environmental controls, resulting in persistent challenges related to greenhouse gas emissions, leachate contamination, and the loss of recoverable resources [2]. Moving toward integrated and sustainable waste management requires a detailed understanding of MSW characteristics to implement biological treatment technologies effectively [3]. This requirement is particularly important because waste composition and properties vary substantially by income level, urban–rural context, and along the waste management chain.

Existing research underscores that MSW characteristics are not static; they evolve from the point of generation to transfer stations and finally to disposal sites, with each node shaped by waste handling practices, degradation processes, and selective material losses. Studies in other countries have shown notable node-dependent variation in moisture, ash, and combustible fractions—factors that directly influence technology selection, treatment performance, and energy recovery potential [4-6]. However, despite Vietnam's diversity in settlement patterns and regional waste profiles, node-specific data remain limited, and most provinces still rely on generalized national averages when planning treatment technologies. This gap risks misaligned investments, particularly for energy recovery systems that depend heavily on feedstock quality.

Nghe An province represents a critical case in this context. As one of Vietnam's largest provinces, it generates approximately 1,486 tons of MSW per day [7], yet detailed information on the material composition and physicochemical and energy properties of its MSW has been lacking. The province exhibits pronounced urban–rural disparities in waste generation and collection rates, and it continues to depend heavily on landfilling. Compared with provinces such as Ho Chi Minh City or Binh Duong, where waste-to-energy and fuel production initiatives have advanced [2], Nghe An lacks the empirical foundation needed to assess technological suitability or envision transitions toward circular models.

This study aims to characterize the MSW composition and properties in Nghe An across the current solid waste management system. The samples were collected and analyzed at key points in the management chain, including generation sources, transfer stations and landfills. The study examined waste composition, physical and chemical properties and energy potential, revealing node-dependent variability. These findings establish an important basis for MSW management in

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Nghe An and contribute to the broader evidence base needed to promote integrated and sustainable waste management strategies in Vietnam.

2. Materials and Methods

2.1. Sampling strategy

To capture the diversity of municipal solid waste (MSW) in Nghe An, samples were collected from various points along the waste collection chain, including source, transfer, and disposal nodes. A total of seven composite samples were analyzed: three from waste gathering points (residential, commercial, and market areas), three from compactor truck deliveries from Vinh Ward (urban), Cua Lo Ward (tourism), and Do Luong Commune (rural) to the Nghi Yen landfill, and one aged waste sample from landfill cells. The waste classification process follows the order summarized in Figure 1. The sampling procedure adhered to ASTM D5231-92 and comprised four steps: confirming the waste origin, preparation, sample size reduction (to 75–100 kg), and classification with weighing.

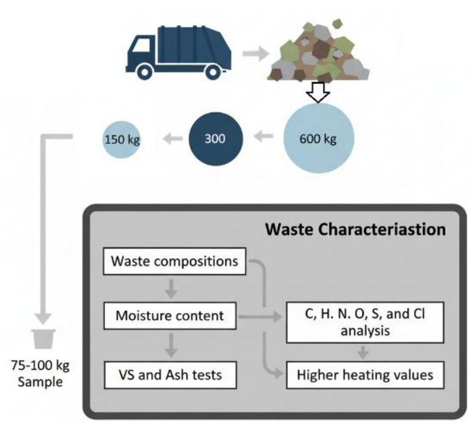

Figure 1. Diagram of waste sampling.

2.2. Waste composition analysis

Waste composition was determined by manual sorting into six major categories according to classification standards (Environmental Protection Agency, Ireland) [8]: (i) biodegradable waste (food and garden waste), (ii) recyclable materials (paper, plastics, rubber, metals, glass/porcelain), (iii) other burnable fractions (diapers, textiles, leather), (iv) non-recyclable/non-combustible inerts (soil, sand, shells, ceramics), (v) hazardous fractions (e.g., batteries, medical waste, light bulbs, ink cartridges), and (vi) other minor fractions. Each category was weighed separately and expressed as a percentage of the total wet weight.

2.3. Physico-chemical and energy analysis

Key parameters relevant to treatment and energy recovery were analyzed following standardized methods. Total solids (TS) and volatile solids (VS) were determined in accordance with EPA Method 1684 (2001), while elemental composition (C, H, N, S, O) was analyzed according to ISO 16948:2015 using a FlashSmart Elemental Analyzer (Thermo Scientific, USA). Chlorine content was determined by ASTM E776-87 (2009). The higher heating value (HHV) was measured following ASTM D5468-02.

From HHV, the lower heating value (LHV) and net heating value (NHV) were calculated to account for the influence of elemental composition and moisture:

- LHV (kJ/kg) is estimated using the equation below [9]:

$$LHV = HHV - 212 \times X_H - 0.8 \times (X_o - X_N) \text{ (Eq.1)}$$

Where HHV is high heating value (kJ/kg);

X_H, X_O, and X_N are hydrogen, oxygen, and nitrogen contents on a dry basis (%).

- NHV (kJ/kg) is LHV when accounting for moisture content, written as below:

$$NHV = LHV \times \left(1 - \frac{M}{100}\right) - 24.5 \times M \text{ (Eq. 2)}$$

Where M is moisture content (%).

3. Results and discussions

3.1. Situation of municipal solid waste management in Nghe An Province

Nghe An province, with a population of 3.42 million in 2022, generated approximately 1,486 tons of MSW per day [7]. Accordingly, the per capita MSW generation in Nghe An (0.43 kg/capita/d) is significantly lower than the north central and central coastal regions (0.70 kg/capita/d). It is also below the national average for Vietnam (0.79 kg/capita/day) and far below the global average of 0.74 kg/capita/d [1, 10]. This value is comparable to that of low- and lower-middle-income countries, which typically generate 0.3–0.6 kg/capita/day [10]. In Nghe An, the rural area consists of 119 communes compared to only 11 wards, leading to an uneven waste distribution: 37% from urban areas and 63% from rural communities [7]. This explains the particularly low value of waste generation per capita in Nghe An.

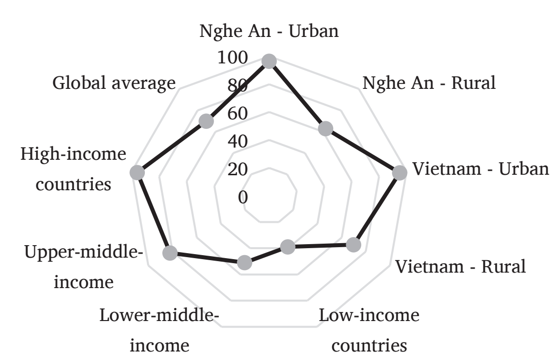

Figure 2. Waste collection rate in Nghe An, Vietnam, and different countries [10, 11].

The overall collection rate in Nghe An is 75% with a significant difference between urban and rural areas: 96.5% in urban areas compared to only 63% in rural areas [7]. This rate of collection is also lower than the regional (85%, North Central and Central Coast) and the general levels of Vietnam (92%). However, the collection rate of Nghe An urban area could be compared to that of major urban areas in Vietnam, such as Hai Phong (97%) and Can Tho (96%) [1].

Waste management practices also diverge markedly across income levels. In Nghe An, landfilling remains the predominant treatment method, often with minimal environmental safeguards. This pattern mirrors conditions in many low- and middle-income countries, where 33% of waste is openly dumped and 37% landfilled, compared to high-income contexts where 35% is recycled or composted and 22% incinerated with energy recovery [10]. Meanwhile, other provinces in Vietnam, such as Binh Duong, Hanoi, and Ho Chi Minh City, have invested in waste-to-energy and material recovery facilities.

The generation of household solid waste (MSW) in Nghe An reflects the characteristics of a typical lower-middle-income region with a high dependence on landfills. The province faces two structural challenges: (i) narrowing the urban-rural collection gap, and (ii) transitioning from landfill dependence to integrated systems with biodegradation, recycling, and waste-to-energy conversion. Drawing on lessons from both developed economies and leading Vietnamese provinces can help Nghe An align its waste management roadmap with sustainable development goals.

3.2. Waste composition

The composition of MSW in Nghe An changes systematically along the waste management chain, reflecting both the nature of waste generation and the transformations that occur during collection and handling. At the source, biodegradable materials dominate, especially in market waste (66%) and, to a lesser degree, in residential streams (47%). Even the commercial sample retains nearly one-third of biodegradables (30%). These figures are consistent with national trends in which organics comprise 50–70% of MSW [1]. At the same time, recyclables at source are unusually prominent, at 42% in the commercial area and 43% in residential waste, indicating substantial use of paper, cardboard, and plastic packaging in everyday activities.

As waste moves to the transfer stations, the composition shifts toward a more recyclable-rich profile. Biodegradable fractions decline to roughly 28–32%, while recyclables consistently exceed 62% across all station samples. This shift does not necessarily reflect reduced generation of organics; rather, it likely results from compaction, partial degradation, and moisture loss during transport, which reduce the apparent mass of biodegradable waste. The strong presence of recyclables downstream also suggests that informal recovery activities, combined with changes in mass distribution during handling, concentrate persistent materials such as plastics and paperboard.

The old landfill sample represents the endpoint of this progression. Here, biodegradables have fully disappeared, and recyclables account for 90% of the remaining mass. This composition reflects long-term biological decay of organics and the persistence of non-degradable materials, as well as continued scavenging at the disposal site. Rather than illustrating current MSW inputs, the landfill sample reveals the stabilized residues that accumulate after extended decomposition.

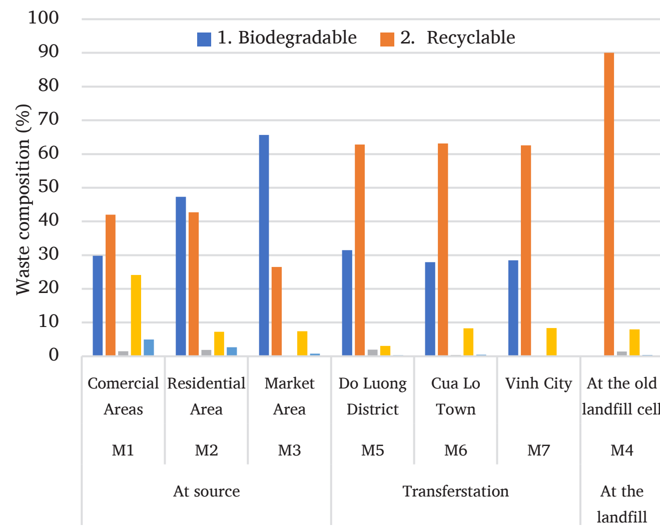

Figure 3. Waste composition in Nghe An.

Overall, the node-by-node pattern illustrates a clear transformation: waste begins as an organic-rich mixture at source, becomes increasingly dominated by dry recyclables as it passes through the collection system, and ultimately stabilizes into an inorganic residue at the landfill. This trajectory highlights both the potential for biological treatment of upstream waste streams and the opportunity for enhanced recovery of recyclables at intermediate nodes, while reaffirming that landfill residues offer limited further resource value.

At the international scale, the waste composition observed in Nghe An, in general, and Vietnam, in particular, reflects a hybrid profile that aligns with patterns documented across lower- and lower-middle-income economies. The predominance of biodegradable materials is consistent with global evidence linking high organic content (typically 50–60%) to countries at these income levels, in contrast to the much lower organic shares reported in high-income contexts, where organics average around 32% of MSW [10]. The substantial organic fraction in Nghe An's household and market waste closely resembles the composition of several regional peers, including Thailand, where organics range from 39–57% [12], and India, where they comprise 40–55% of MSW [13]. Similar levels have also been reported in several Chinese cities, where food and kitchen waste account for approximately 50–70% of total waste generation [11].

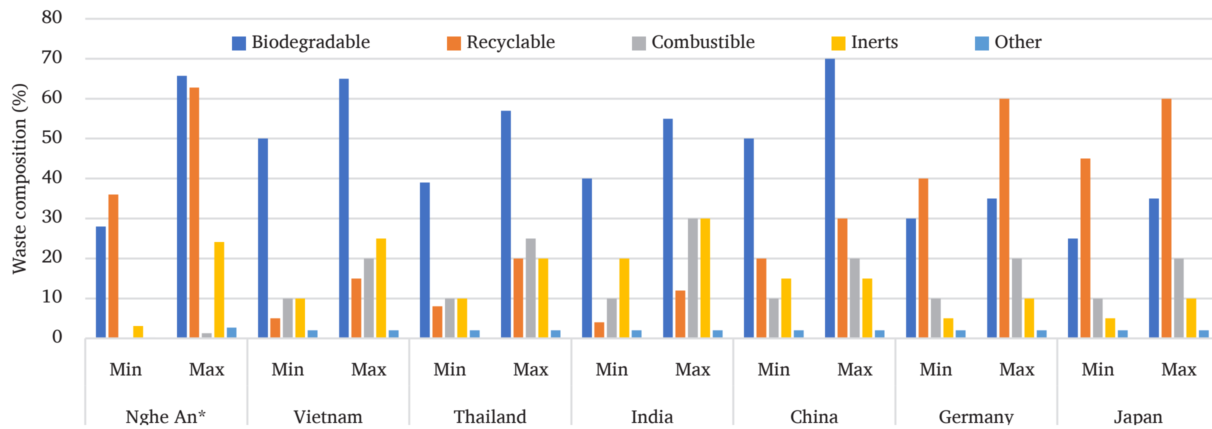

Figure 4. Waste composition in Vietnam vs other countries [11-14].

3.3. Physico-chemical characteristics

The physico-chemical properties of MSW in Nghe An exhibit clear variation across sampling nodes, reflecting differences in waste composition, levels of inert contamination, and the degree of biological degradation (Figure 5). Total solids across fresh waste samples range from 49% to 58%, corresponding to moisture contents of roughly 42–51%, which is comparable to the average of 50.1% (ranging 41–60%) reported in previous studies [15-20].

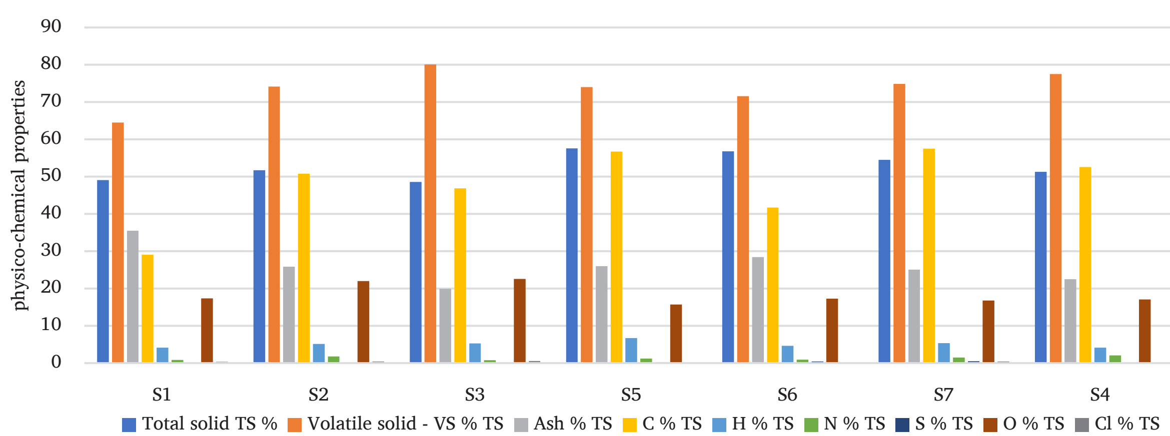

Figure 5. Physico-chemical characteristics of MSW.

Volatile solids (VS) constitute a substantial proportion of the total solids, ranging from 65% to 80% TS, indicating that biodegradable organic matter remains a dominant component even in samples containing significant plastics or other combustibles. Ash contents vary widely—from 20% TS in the market sample (S3) to 36% TS in the commercial-area sample (S1)—revealing the differing levels of soil, fines, and inert materials that enter the waste stream depending on local handling practices.

The elemental composition further distinguishes the samples. Carbon content spans 29–58% TS, with higher values observed in drier, plastic- and paper-rich samples such as S5 and S7, which correspondingly demonstrate the highest heating values. Hydrogen content (4–7% TS) follows a similar pattern, while nitrogen levels remain relatively low (1–2% TS). The landfill sample (S4) contains elevated nitrogen (2% TS), consistent with partial stabilization and carbon loss over time.

Sulfur contents across samples remain low (0.087–0.499% TS), suggesting a limited presence of industrial or rubber-derived materials. Oxygen percentages (16–23% TS) align with the presence of food waste and paper, while chlorine concentrations (0.13–0.57% TS) remain moderate but relevant for thermal treatment due to their potential to generate HCl emissions or dioxin precursors, particularly in samples with higher plastic or salt-rich food residues.

The landfill sample (S4) shows a distinct profile: although its TS (51%) and VS/TS (78%) remain within the range of fresh samples, its elevated carbon and nitrogen—combined with altered proportions of inerts—indicate long-term selective degradation and should not be considered representative of fresh MSW entering the system.

3.4. Energy characteristics

The energy profile of municipal solid waste in Nghe An displays substantial heterogeneity, shaped by the interplay between moisture, ash, and the relative abundance of easily combustible materials. The calorific values derived from the seven samples illustrate this variability clearly. HHV ranged from 12,666 kJ/kg-TS in S1—where elevated ash and moisture suppress thermal performance—to 23,875 kJ/kg-TS in S5, with the stabilized landfill residue (S4) reaching 24,609 kJ/kg-TS. Corresponding LHV values show a similar pattern, from 11,779 to 22,439 kJ/kg-TS in fresh waste and 23,717 kJ/kg-TS in the landfill sample (Figure 6). When expressed on a wet basis, NHV varies even more distinctly, from only 4.537 MJ/kg in S1 to 11.886 MJ/kg in S5, yielding an average of approximately 9.0 MJ/kg across samples.

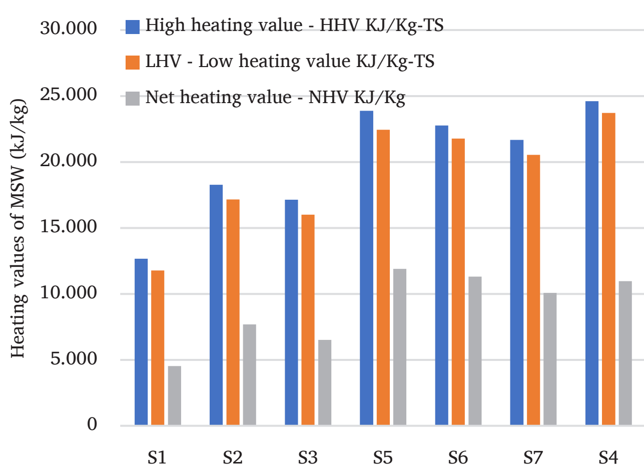

Figure 6. Heating values of MSW in Nghe An.

These calorific characteristics follow the underlying physico-chemical structure of each waste stream. The best-performing samples—such as S3, with volatile solids constituting 80% TS, or S5, where plastics and paper dominate the combustible fraction—retain both low ash contamination and moderate moisture. Samples such as S1, by contrast, contain 36% TS ash and substantial mineral fines, reducing their heating values considerably. In essence, the calorific variability across nodes reflects not only differences in composition but also the extent of degradation and the degree of inert contamination encountered along the waste pathway.

Positioning these findings in a wider context reveals both opportunities and limitations for energy recovery. At the national scale, NHV in Nghe An (~9 MJ/kg) is broadly consistent with, and occasionally higher than, the typical Vietnamese range of 6–9 MJ/kg [1]. However, the variation between sampling nodes limits the practicality of a uniform thermal treatment strategy. Only the driest, plastic-rich fractions (S5, S6, S7) approach the thresholds typically required for refuse-derived fuel (RDF) production, while wetter samples fall far below levels conducive to self-sustaining combustion.

A comparison with other Southeast Asian countries places these values within the regional norm—commonly 5–10 MJ/kg; in some cases, these values are above those reported for Thailand, Lao PDR, or Myanmar [21]. Conversely, when situated against higher-performing waste streams such as those in China, where average calorific values approach 19 MJ/kg [11], or in high-income contexts where paper and plastics routinely elevate heating values above 12–15 MJ/kg [10], the energy potential of fresh MSW in Nghe An remains modest.

The comparison becomes even more instructive when considering the condition of degraded waste in landfills. The stabilized sample S4 from Nghe An exhibits an NHV of 10.974 MJ/kg, reflecting the selective persistence of plastics and other slow-degrading materials. Yet landfill residues elsewhere in Vietnam can display a far lower thermal quality. For example, at the Gò Cát landfill in Ho Chi Minh City, long-decomposed waste exhibits an LHV of just 5.95 MJ/kg (wet basis), a value that underscores the substantial energy depletion caused by prolonged biodegradation [2]. This contrast highlights how strongly calorific values depend on the stage of decomposition and the composition of residual materials—a reminder that “landfill waste” is not a uniform category and cannot be assumed to provide a viable fuel source without detailed characterization.

Taken together, these observations portray a waste system whose energy landscape is not defined by a single representative value but by a spectrum shaped by node-specific features. Nghe An contains pockets of high-energy waste suitable for RDF or co-incineration, but the province also produces streams that are too wet, too inorganic, or too biologically active to support thermal conversion. This distribution underscores the importance of differentiated strategies: biological processing for the organic-rich fractions [3, 22]; targeted recovery of combustibles for RDF; and a cautious, evidence-based approach to any province-wide incineration proposals.

4. Conclusions and recommendations

This study demonstrates that municipal solid waste in Nghe An is highly heterogeneous and strongly dependent on the node from which it is collected. Source samples contain dominant biodegradable fractions with high VS (80% TS), while transfer-station samples exhibit increased ash and recyclable materials, and landfill residues reflect long-term selective preservation of plastics and other recalcitrant components. The province’s moisture content (47%), which is consistent with the national average moisture levels, results in a moderate energy profile with HHV between 12,666–23,875 kJ/kg-TS and NHV from 4.5–11.9 MJ/kg. Only the driest, plastic-rich fractions (S5–S7) have calorific values suitable for RDF or co-firing; the other streams are more appropriate for biological treatment or controlled disposal.

These characteristics carry clear implications for technology selection. High-moisture, organic-rich waste requires biological pathways such as composting or anaerobic digestion; mixed or inert-contaminated waste at transfer stations offers limited potential for either thermal or biological conversion; and only well-sorted dry fractions should be directed toward energy recovery. A province-wide mass-burn incineration approach is unlikely to be technically or economically viable given the average NHV of 9 MJ/kg and the variability between nodes.

Based on these findings, several recommendations emerge. First, improving source separation—particularly between organics, recyclables, and residuals—is crucial to enhance feedstock quality for both biological treatment and RDF production. Second, decentralized composting or AD facilities near markets and residential clusters would reduce transport burdens and increase treatment efficiency. Third, RDF production from the S5–S7-type fractions should be explored through partnerships with cement kilns or other industrial co-firing systems. Finally, residual waste will continue to require landfilling; thus, investment in sanitary landfill upgrades, including leachate and gas management, remains essential to minimize long-term environmental impacts.

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