

# Review of refuse-derived fuel as a municipal solid waste treatment in developing Asian Countries: current conditions and challenges

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**Abstract.** Countries are required to rely on the most cost-effective Waste-to-Energy (WTE) technique. Consequently, utilizing municipal solid waste (MSW) as an alternative fuel (AF), such as refuse-derived fuels (RDF), is favored. RDF is the most cost-effective alternative fuel due to its high heating value, making it ideal for developing countries. However, the optimal RDF composition includes a high number of polymers, yet developing countries have high moisture MSW, which may compromise RDF quality. This research seeks to evaluate the recent condition of RDF in developing nations, particularly in Asia. A desktop evaluation of electronic reference sources was conducted to assess RDF feasibility from MSW through a semi-systematic methodology, exploring various aspects and matching recent RDF adoption and challenges in developing Asian countries. According to this review, RDF adoption is increasing in developing countries. However, obstacles remain, such as product shipping costs, waste composition, RDF chlorine content, and limited interest in RDF use. RDF has promise as a WTE technology in emerging Asian nations, but technologies must be enhanced before widespread use.

## 1 Introduction

Municipal Solid Waste (MSW) can be used to generate heat, electricity, manufactured gas, charcoal, and bio-oil. These methods minimize the amount of MSW sent to landfills without recovering energy and encourage the utilization of substitute materials and energy sources, thereby enhancing resource efficiency, reducing environmental impacts, lowering greenhouse gas emissions, and supporting sustainable waste management and energy recovery strategies, particularly in regions facing rapid urbanization and increasing waste generation [1]. International fuel management is evolving through strategies such as optimizing domestic fuel production and substituting traditional fossil fuels with more cost-

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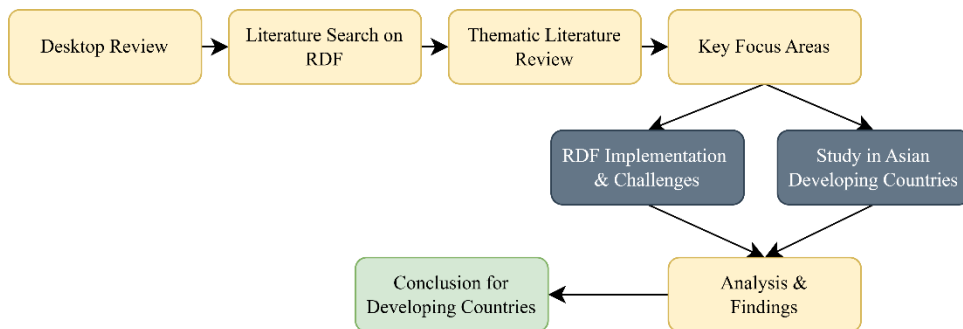
effective alternatives. Countries should prioritize the utilization of MSW, such as refuse-derived fuels (RDF), as a viable alternative fuel (AF) due to its cost-effectiveness in comparison to other fuel production options, while also reducing landfill dependency and supporting sustainable energy transitions, improving energy security, enhancing resource efficiency, and contributing to long-term environmental and economic resilience. Refuse-derived fuel (RDF) represents a cost-effective alternative fuel due to its relatively high heating value, making it particularly suitable for developing countries with increasing energy demand and limited access to conventional fossil fuels.

RDF has gained popularity in developing countries, highlighting its merits in waste reduction, energy recovery, and alternative fuel substitution for various industrial applications. Furthermore, there has been a significant rise in its prevalence among developing countries. RDF manufacturing facilities have been constructed in many countries, including Egypt, Turkey, and Pakistan. Moreover, a multitude of studies have been conducted to evaluate the available materials of RDF in diverse developing countries, focusing on waste composition, calorific value, processing technologies, and their potential suitability for energy recovery and industrial fuel applications [2]. The optimal composition of RDF typically includes a significant amount of paper/cardboard, polymeric containers, textiles, wood, and other organic components, as these fractions contribute to higher calorific value, improved combustion efficiency, reduced moisture content, and enhanced suitability for industrial energy recovery applications [3]. Due to this composition, these materials can serve as viable alternative fuels for reducing CO<sub>2</sub> emissions by partially substituting fossil fuels, improving energy efficiency, and supporting sustainable waste management practices within industrial and waste-to-energy systems. According to reference [3], Waste composition varies depending on income level. The high-income demographic has comparatively lower proportions of both food waste and green waste in comparison to other income groups, primarily due to higher consumption of packaged products, improved waste segregation practices, greater recycling rates, and more efficient collection systems, which significantly influence the quality and suitability of waste streams for RDF production and energy recovery applications [4]. Increasing green waste in MSW necessitates increased energy for its removal. According to several writers, the elevated moisture content of MSW in developing countries causes RDF production difficult, as additional drying and pretreatment processes are required. As a result, they propose an alternative biological treatment method for managing the organic portion more effectively and sustainably. A notable difference exists between the content of trash in developing nations and the methods employed for waste management, particularly in the context of waste-to-energy (WTE) technology. This study aims to review recent developments in RDF adoption in developing Asian countries and to discuss the key technical, economic, and institutional challenges associated with its implementation. It also discusses the challenges these countries will likely encounter in implementing RDF, including technical limitations, economic feasibility, policy frameworks, infrastructure readiness, and environmental considerations influencing large-scale deployment and long-term sustainability.

## **2 Methodology**

A desktop review of electronic reference sources was conducted to assess RDF's feasibility and potential applications derived from MSW, as present in Fig. 1. Relevant literature was identified through a targeted search of peer-reviewed journal articles and authoritative reports focusing on RDF applications in developing Asian countries. This study adopts a thematic review approach to synthesize and discuss recent literature on the implementation, challenges, and current status of refuse-derived fuel (RDF) in developing Asian countries. The study explored various aspects of RDF, including its implementation, challenges, and

status of RDF in developing countries in Asia. Additionally, the study examined the implementation of RDF and its application in MSW management in developing Asian countries. Publications on RDF were primarily discovered in journals such as *Waste Management and Research*, *Waste Management*, *Waste Disposal*, and *Sustainable Energy*, *Polish Journal of Environmental Studies*, *Journal of Cleaner Production*, and *Cleaner Engineering and Technology*. The inclusion criteria comprised studies discussing RDF production from municipal solid waste (MSW), research addressing technical, economic, or environmental aspects of RDF, and case studies conducted in developing countries, particularly within Asia. Only peer-reviewed journal articles and recognized institutional reports were considered to ensure data credibility and academic rigor.



**Fig. 1.** Methodology flow chart

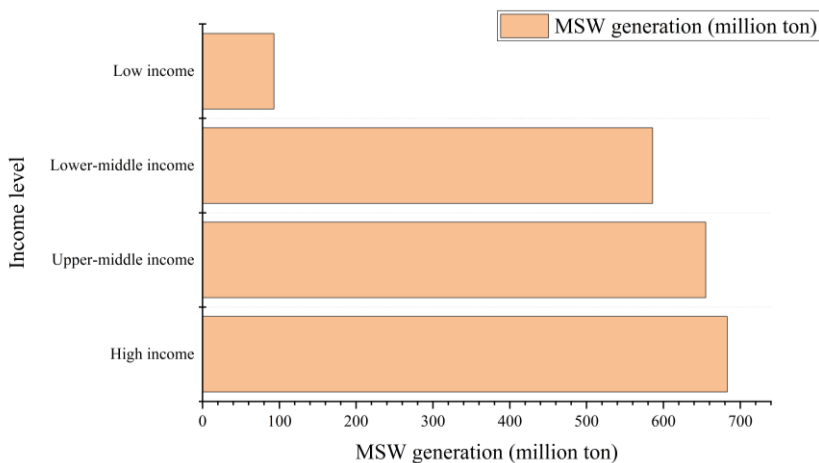
The collected publications were screened based on titles and abstracts to assess their relevance to the research objective. Selected articles were then reviewed in full to extract key information regarding MSW characteristics, RDF processing technologies, industrial applications, economic feasibility, and implementation challenges. The findings were subsequently grouped into major thematic categories, including waste composition and calorific value characteristics, RDF production technologies and pre-treatment methods, industrial utilization and fuel substitution potential, and technical, economic, and institutional barriers. These themes were analyzed qualitatively to identify common trends, recurring constraints, and region-specific factors influencing RDF implementation in developing Asian countries.

### 3 Results and discussion

Numerous studies have explored the application of RDF and the implementation of this technology across various sectors. Literature surveys also highlight RDF processes and performance outcomes under different operational conditions. The authors note that the adoption of alternative fuel (AF) from RDF faces several challenges. This research builds on established literature by contextualizing RDF applications within the characteristics of developing countries, including waste composition variability, economic constraints, policy readiness, technological limitations, and regional infrastructure differences, thereby providing a more comprehensive and region-specific perspective on RDF feasibility. Furthermore, this study synthesizes recent findings to identify common barriers, assess technological adaptability, and evaluate policy implications, offering practical insights to support decision-makers, industry stakeholders, and researchers in advancing RDF deployment strategies and improving sustainable waste-to-energy practices in developing regions.

### 3.1 Global waste generation

Accurate prediction of global waste generation requires analysing several variables, incorporating national economic development, population rise, income, and commercial partnerships, technological advancements, increased awareness of sustainable consumption, and cultural influences [5]. Fig. 2 represents the distribution of MSW generation among various income levels. High-GDP countries have average income per capita over \$12,476. Modest-income countries have a GDP per capita of \$1,026–\$4,035, whereas upper-middle-income countries have \$4,036–\$12,475. Low-income countries have per-person GDP below \$1,025. According to projections, worldwide trash production is projected to grow significantly, with estimates indicating that total global municipal solid waste could reach approximately 2.59 billion tons by 2030 and may increase further to 3.40 billion tons by 2050.



**Fig. 2.** Waste generation categorized by income level, measured in millions of tons

MSW generation and content are directly influenced by societal income levels. The treatment of MSW and its potential for recycling and reuse are strongly impacted by the variation of MSW across various sites. Higher income levels have less of the waste categories associated with food and green waste than do lower income levels do. High-income countries produce more paper and cardboard. However, prior to treatment, moisture is eliminated through drying. More power is required to remove more food and green waste from MSW.

Based on the income level, more than 50% countries in Asia are developing countries in the middle- and low-income categories. MSW from developing countries are dominated by wet organic waste due to the high consumption of fresh fruits, vegetables, and unpacked food. This trend is very different with the high-income countries which consume more packaged and processed food, causing a high percentage of packaging materials waste, such as plastics and papers [6].

Municipal solid waste (MSW) generated in economically developed countries, such as the United States and Portugal can yield RDF with lower moisture content than RDF from low-income countries. The high moisture content in municipal solid waste (MSW) in developing countries presents significant challenges in the production of refuse-derived fuel (RDF), as noted by several researchers. As a result, they propose an alternative biological treatment method for managing the organic portion of MSW.

### 3.2 Municipal solid waste management

MSW management in many growth-stage nations commonly still relies on open dumping or open landfill method as its final processing site without any properly technical processing of the emissions to water, air, and land. Due to poor management techniques, the amount of MSW generated globally is rising quickly, posing serious risks to both human health and the environment [7]. An efficient way to manage MSW is through energy recovery from waste. Reducing the quantity of trash transported to landfills through WTE conversion, which is regarded as a renewable energy source, can help lower greenhouse gas emissions [7]. Thermal conversion and biological conversion are the two primary techniques for recovering energy from MSW [8]. Refuse-derived fuel (RDF) can be classified as an option of sustainable waste management and reduce the landfill’s load. RDF is a type of fuel that can be sourced from non-recyclable MSW [9].

Due to disparities in the availability of goods and services, high- and low-income nations' waste composition differs greatly. Determining the most appropriate and effective typology for creating RDF requires consideration of the variety in the content of MSW. **Table 1** presents RDF typologies proposed for different compositions of MSW. Certain high-income countries, including Finland, possess industrial-scale gasification and pyrolysis facilities, enabling them to convert RDF into liquid and gaseous fuels. Middle-income countries, such Mexico and Brazil, are presently facing significant waste handle obstacles. These countries progressively embracing thermal technology (gasification and pyrolysis) technologies [5].

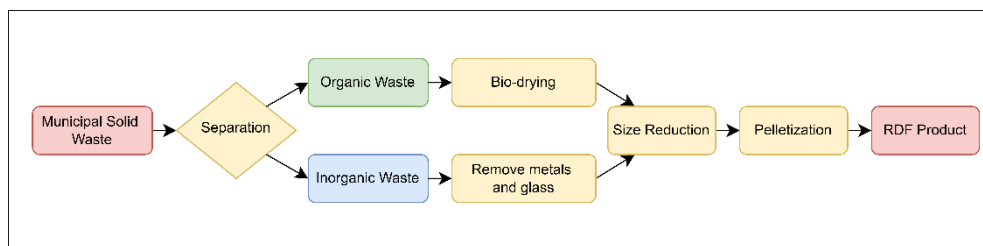
**Table 1.** Recommendation of RDF typology for different composition MSW

Income Level	RDF Typology	Process	Fuel Type	Potential Use
High-Income Countries	RDF-7, RDF-6	Separate food waste, remove metals/glass, palletize, pyrolysis/gasification	Liquid and Gas Fuels	Industrial use (gasification, pyrolysis)
Upper-Middle-Income	RDF-5, RDF-4	Segregate food/green waste, remove metals/glass, palletize	Combustion	Cement kilns, power plants
Lower-Middle-Income	RDF-5, RDF-4	Similar to upper-middle income but less advanced processing	Combustion	Power generation, local industries
Low-Income Countries	RDF-3, RDF-2	Simple sorting, reduce particle size to 50 mm	Combustion	Small-scale industrial use

### 3.3 Implementation of RDF

Developing countries like India, Indonesia, and Thailand have also shown concern with utilizing energy extraction from MSW as RDF [10]. In the cement sector, RDF is mostly utilized as an alternative fuel (AF). Jeruklegi Landfill in Cilacap City, Indonesia has transformed MSW into RDF that can be used as AF in the cement plant located around the landfill [2]. The RDF Plant can produce 120 tons each day, and bio-drying is chosen as the pre-treatment method due to the waste containing around 50% organic waste. Research indicates that Semen Gresik in Tuban City and Semen Holcim Indonesia are willing to replace some of their fuel with RDF. Semen Gresik is considering a substitution rate of up to 10%, while Semen Holcim is considering a substitution rate of up to 15%. Indonesia's cement industry requires 3,000 Kcal/kg. According to the research, the bio-drying technique is very efficient in raising the calorific content of MSW to a level of 4,000 Kcal/Kg.

In addition to Jeruklegi Landfill, Semarang City Material Recovery Facility (MRF) in Denpasar City has also adopted pelletized RDF, as is illustrated in **Fig. 3**. The MSW used is mixed waste with bio-drying processing technique. The waste may be cut into printed pellets of 12 mm in diameter after a ten-day bio-drying procedure [11]. Each kilogram of pellet produced by Semarang City's waste processing system generates around 1 kWh of electrical energy. The calorific value of the substance is 3,904 kcal/kg or 16.34 MJ/kg, indicating a high level of satisfaction.



**Fig. 3.** Process flow diagram for the production of Refuse-Derived Fuel (RDF) from Municipal Solid Waste (MSW). The diagram illustrates the key steps involved, including waste separation, organic waste treatment, inorganic waste processing, and the final RDF product creation

In India, RDF plant is capable to produce up to 7.5 MW of power. RDF is primarily used to managing waste in pulp, paper, wood, and sawmill industries. India produces over 6.0 lakh MT (600,000 tons) of waste per day. The RDF fuel capacity per day would be 120,000 tons (1.2 lakh MT) if the usage rate for RDF were 20%. If the Gross Calorific Value (GCV) of coal is assumed to be 50% greater than that of RDF, theoretically this might lead to a daily replacement of 240,000 tons (2.4 lakh MT) of coal. India is capable of producing 15,000 MW of power when all RDFs are used. However, just 2% to 4% of the nation's overall energy consumption would be fulfilled [12].

RDF has been used by Iran as a substitute fuel source for its cement factory. Lowshan Cement Factory utilizes RDF from the waste residue of Rasht City. RDF production involves two units and a pre-calciner following the dry process. Each unit has a daily calciner capacity of 2,000 tons. Gasoline and natural gas are used for production in the pre-calciner and main oven flare. Our analysis indicates that the waste of Rasht City has the potential to produce RDF 168 tons per day for Lowshan's cement production. The plant produces fluffy RDF by processing waste, which involves the removal of metals, glass, and other inorganic materials. The substance may pass through a sieve with a 2-inch square mesh. This option centers on the combustion of RDF in a cement kiln, specifically focusing on RDF particles that are smaller than 25 mm. About 21.1% of the cement factory's energy needs would be satisfied by the supply of 168 tons of RDF with a thermal value of 17,790 KJ/kg [13].

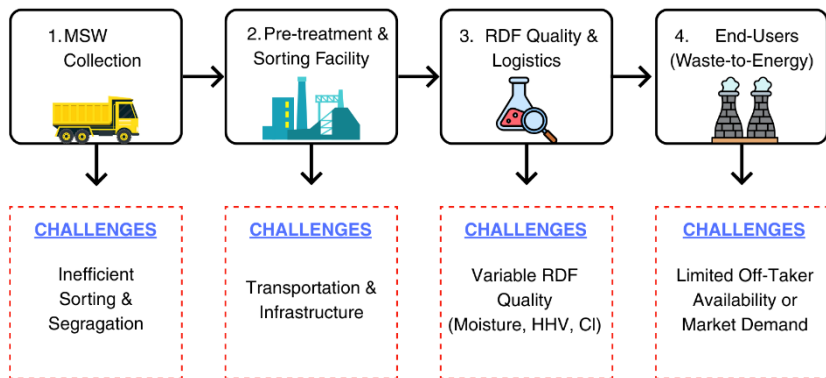
### 3.4 Challenges

The implementation of RDF utilization in developing countries may encounter challenges despite its widespread usage, as shown in **Fig. 4**. RDF has demonstrated positive outcomes in certain countries. The price of RDF in the JerukLegi Landfill demonstrates its competitiveness when compared to the industry's maximum willingness to pay. RDF is economically feasible only when its price is lower than coal's. However, this study demonstrates that RDF remains competitive compared to rice husk. The utilization of RDF in the Piyungan Landfill demonstrates the economic viability of RDF. It is important to address certain aspects of the final product's distribution. The analysis did not include RDF product transport costs from Piyungan Landfill to off-takers. If the RDF plant location has

no off-takers, such as electric steam power plants or cement factories, the goods must be delivered elsewhere. Incorporating transportation expenses into the economic evaluation of the project renders it unviable [14].

The composition of MSW is greatly influenced by demographics and income level, which also has an impact on the price of manufacturing RDF. Municipal solid waste (MSW) with high moisture levels, particularly food waste and green debris, incurs higher handling costs [3]. Developing nations encounter increasing difficulties in waste management, including issues related to waste collection, transportation system enhancement, and the implementation of homemade waste pre-sorting methods. Additionally, due to the diverse backgrounds of RDF users, different industries, sectors, and companies may have their unique approaches to implementing the RDF specification. The lack of proper testing and evaluation of different types of RDF by waste management companies has made customers need more certainty about its composition. Consequently, some industrial boilers and power industries hesitate to utilize RDF [3].

A study at Metro Vancouver Waste Management evaluated the effects of employing RDF as an AF in cement production [15]. Chlorine in RDF poses a serious environmental risk due to its potential to cause corrosion in the system by vaporizing and condensing alkali chlorides, which can damage kiln components, reduce operational efficiency, increase maintenance requirements, and limit long-term adoption without adequate pretreatment and quality control measures. Consequently, controlling chlorine content through improved waste segregation, pretreatment technologies, and fuel quality standards is considered essential to ensure stable kiln operation and environmental compliance.



**Fig. 4.** Key challenges in the implementation of refuse-derived fuel (RDF) utilization

## 4 Conclusion

A recent study demonstrates that emerging Asian countries like India, Indonesia, and Iran have huge RDF production potential, notwithstanding MSW composition. Bio-drying increases MSW calorific value and cement plants can use RDF product as fuel. From a study at Jeruklegi Landfill and Semarang Landfill, Indonesia, RDF from each landfill may exceed the cement industry's minimal calorific value of 3,000 Kcal/kg. In India, RDF creates 7.5 MW all by itself. Pulp, paper, and wood waste get the most RDF, followed by sawmills. Lowshan Cement Factory in Iran generates 168 tons of Rasht residue RDF with a thermal value of 17,790 KJ/kg to reach 21.1% of its energy needs. Several challenges may significantly hinder the large-scale implementation of RDF in developing countries. RDF's economic viability depends on the plant's proximity to RDF off takers. The composition of MSW is influenced by demographics and economic conditions, which in turn impact RDF prices, as the pre-treatment of high-moisture food and green waste is more expensive.

Developing nations also require assistance with garbage collection, improved transportation systems, residential waste pre-sorting, and RDF classification, which leaves consumers unsure of its content. High chlorine content in RDF may lead to corrosion and operational deterioration in industrial combustion systems if not properly controlled. Thus, it is important to conduct in-depth research to address the issue.

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