Comparative Analysis of Waste Management between Masaro and Refuse-Derived Fuel (RDF) Technologies in West Java

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Abstract. In 2023, the amount of waste from five large cities in West Java could reach more than 1 million tons. This creates the need for proper waste management. There are several technologies used, i.e. zero waste management (Masaro) technology and also refuse-derived fuel (RDF) technology. Masaro employs various methods to process all types of waste while RDF technology utilizes combustible and plastic waste to produce solid fuel. This study intends to compare the waste processing performance of the two technologies from the potential, environmental impact, and economic aspects. Based on the results, raw materials, utilities, and target markets are all comparable. Besides, environmental impact analysis shows that waste processing with Masaro and RDF has low emissions and is below quality standards. Actually, RDF has a faster processing time than Masaro, but the economic analysis from Masaro shows a higher GPM than RDF (99.21% vs. 89.38%). This happens because the products from Masaro are much more differentiated than RDF. In the end, the integration of waste processing with Masaro and RDF is even more promising because apart from solving the waste problem it also produces a higher GPM (99.22%).

1 Introduction

In West Java, there are several large cities with dense populations, including Bandung, Bekasi, Bogor, Cirebon, and Depok. With the accumulation of these five major cities, the population exceeds 4 million people. The generated waste is mainly sourced from household activities, local markets, small businesses, hotels, restaurants, and industries. Following the National Waste Management Information System, there were approximately 1,066,275.83 tons of waste in West Java in 2023 [1]. Indeed, the accumulation of unmanaged waste has negative impacts on human health, damages the surrounding environment, and reduces the esthetical value of the city [2].

The research community at Bandung Institute of Technology offers the solution of waste processing through zero waste management (Masaro) technology [3]. It transforms the paradigm of waste from being a cost center to becoming a profit center. Waste management with the cost center concept involves the process of “collect-transport-dispose”, while the profit center concept involves the process of “sort-transport-process-sell” [4,5]. Hence, the implementation of Masaro can change the mindset of society, viewing waste not as a burden and valueless item but as a valuable asset.

Masaro has several objectives, i.e. resolve the current waste issues, transform waste into useful and economically valuable products, alleviate the burden on society, industry, and government, boost the economy, and create job opportunities through Integrated Processing Site (IPS), Urban Processing Site (UPS), and industrial processing and production outlets (IPPO), and strengthen the agriculture and livestock sectors and meet the demand for fuel [3].

Additionally, another technology can convert waste into solid fuel, known as refuse-derived fuel (RDF) technology. It is a fuel produced from various types of combustible waste from household, commercial waste, or industrial sectors. It is based on waste such as paper, wood, branches, and plastic [6,7]. Waste sorting and drying are important to reduce the moisture content to increase its calorific value [7]. The products in the form of shards can be further applied for co-firing purposes in the cement industry [8,9].

West Java aims to implement both of them in the hope of reducing the amount of waste or eliminating waste accumulation. However, processing waste using Masaro and RDF technologies certainly produces different raw materials requirements, utility, number of employees, products, target customer goals, and other aspects. Therefore, the objective of this study is to compare the performance of the two waste processing technologies in terms of potential, environmental and economic impacts.
2 Materials and Methods

2.1 Waste Processing Using Masaro Technology

In Masaro, waste separation is divided into five categories: organic waste, plastic film waste, combustible waste (wood, tissue, paper, cloth), recyclable waste, and hazardous waste. Masaro processes organic waste, plastic film waste, combustible waste, and recyclable waste. Hazardous waste is excluded because it will be processed by the local government through an incineration process. On the other hand, recyclable waste is sorted according to its type, including hard plastics, metals, paper, and glass. Subsequently, the waste is handed over to third parties for further processing in recycling industries.

Organic waste was processed into special liquid organic fertilizer (POCI), concentrated liquid organic animal feed (KOCI), planting media, solid livestock feed, and solid organic compost. In IPPO Masaro, 1 kg of organic waste can produce 10 L of POCI and KOCI products [10]. Plastic film waste and combustible waste were processed in a unit named Masaro Plastic Refinery to produce fuel, ash for planting media, and biopesticides. Masaro fuel can be used as fuel for the food industry, oil stoves, and generators. The diagram for waste processing using Masaro technology is given in Figure 1.

![Figure 1. Process Treatment of Waste in Masaro Technology.](image)

2.2 Waste Processing Using RDF Technology

The process of making RDF involves initial sorting, shredding, drying, and packaging. Waste is sorted to separate combustible materials from non-combustible ones [11]. Non-combustible materials such as glass and metal were removed. Combustible waste was shredded into smaller sizes to reach the perfect combustion of RDF [12–14]. Reducing the moisture content by drying was also aimed to increase its calorific value [15–17]. The product was finally pelletized and packaged for easy transportation and storage.

RDF can be used as a substitute or supplement for fossil fuels in power plants and cement industries. In other words, waste processing by RDF provides a solution for waste management while simultaneously reducing dependence on fossil fuels [7,8,18]. The diagram for waste processing using RDF technology is shown in Figure 2.

![Figure 2. Diagram for Waste Processing Using RDF Technology.](image)
2.3 Comparative Analysis

The aspects to be compared are potential, environmental, and economic. The potential analysis involves raw material, utility, and target customer goals. The environmental analysis encompasses liquid, solid, and gas that are generated from each process. Meanwhile, the economic analysis employs simple economic calculation that involves determining expenditures and income. The parameter which is then compared is gross profit margin (GPM).

3 Results and Discussion

3.1 Potential Analysis of Masaro

The Masaro technology can process various types of waste, providing significant assistance to the government and society in waste management. The largest source of waste comes from Bogor Regency, which houses two large industrial areas, resulting in an increased waste generation rate. At this regency, the waste generation in 2023 reached 2,800 tons/day. However, the handled waste remains at 700 tons/day.

The main reasons for the incomplete collection and handling of all waste are the insufficient waste transportation fleet and inadequate waste disposal sites. The continuously increasing amount of waste, combined with the lack of advanced waste processing, leads to overcapacity in the existing waste disposal sites in Bogor Regency. Therefore, a study and implementation of competent technology are needed to reduce the waste accumulation volume in West Java, especially in Bogor Regency.

The application of Masaro technology presents a viable alternative to address the waste accumulation issue in West Java. The implementation of Masaro technology through the Integrated Waste Processing Installation (IPST) Masaro can assist in reducing waste by processing up to 2,400 tons/day. In addition to addressing the waste accumulation problem, the implementation of Masaro technology can also benefit the community by creating job opportunities and producing products that support the local population. Masaro products such as POCI and KOCI can aid the people of West Java, who predominantly engage in agriculture and livestock farming, to enhance their agricultural and livestock activities.

Another product, ash, can be utilized by the surrounding community as a new business opportunity. These products are also affordable priced, making them accessible to people from various backgrounds to experience their benefits. In its process, IPST Masaro requires utilities such as electricity and water. Electricity needs can be adequately met in West Java, which has PT. PLN ULP Cibinong. Meanwhile, water requirements can be fulfilled by drilling on the IPST Masaro site to obtain a water source.

3.2 Potential Analysis of RDF

The potential production and application of RDF have their own advantages. By converting waste into a source of energy or additional energy using dual raw materials, RDF reduces dependence on open waste burning or landfilling in landfills. It further has the potential to reduce greenhouse gas emissions so it can lead to a more sustainable environment [19,20]. In terms of sustainability, RDF can serve as a source of income for waste management companies and has the potential to reduce operational costs for industries, as well as decrease reliance on fossil fuels.

In the context of waste processing in West Java, the use of RDF can be employed as a heating fuel for communities, such as conventional water heaters, fuel for stoves, and even as fuel for small-scale power plants. These benefits can be directed towards rural areas and small towns like Cimahi, Cianjur, Lembang, and Sukabumi, where infrastructure or building density and
population density are not as high as in the cities of Bandung and Bogor. With electricity consumption that can cover rural and small-town areas, the use of RDF as a fuel for power generation can be applied to minimize waste and generate electrical power.

One example of the implementation of RDF technology is at the Integrated Waste Disposal Site in Tritih Lor Village, Jeruklegi Subdistrict, Cilacap, Central Java (Figure 3). It can process 140 tons/day of waste as fuel for cement industries, aiming to reduce dependence on coal as a combustion fuel in the industry and provide an environmentally friendly waste management solution.

![Figure 3](image-url) RDF Processing in Tritih Lor Village, Jeruklegi Subdistrict, Cilacap, Central Java.

### 3.3 Environmental Analysis of Masaro

Waste processing with Masaro technology generates waste in the form of solid waste and exhaust gas. It does not include recyclable materials such as metal, glass, rocks, and wood. Therefore, this waste becomes solid waste that will then be handed over to a third party for further processing. Meanwhile, the exhaust gas waste is obtained from the incineration process in the combustion unit, in the form of an incinerator. The exhaust gas, in the form of smoke, will be processed into pesticides before being released into the atmosphere [21]. The composition of the exhaust gas produced by one of the IPST Masaro at Cirebon is 49.6 mg/Nm$^3$ particulate matter, 6.2 mg/Nm$^3$ SO$_2$, 4.1 mg/Nm$^3$ NO$_2$, and 11.3 mg/Nm$^3$ CH$_4$ as hydrocarbon compounds [22]. Based on the test results, it can be stated that the exhaust gas waste from waste processing with Masaro technology falls into the safe category for release into the atmosphere because, in general, it complies with national standards for exhaust gas composition.

### 3.4 Environmental Analysis of RDF

The use of RDF as a fuel generates emission gases released into the atmosphere. The combustion results can produce gases and ash or combustion by-products. The exhaust gas from RDF usage has concentrations of carbon dioxide and various organic compounds in concentrations that can be neutralized in nature. It is also assumed that the emission results can release below 50 mg/Nm$^3$ particulate matter, below 150 mg/Nm$^3$ organic compounds (S compound, N compound, and methane), and negligible amounts of plastic and metal derivative compounds.

For the combustion results, the ash produced from the combustion can be utilized as fertilizer or soil ameliorant for agricultural purposes [23,24]. This is because the combustion yields ash-containing compounds such as carbon, sodium, sulfur, potassium, calcium, and phosphorus [25–27] which can be consumed by plants for growth and serve as food for decomposer organisms that play a role as natural stabilizing agents [10,28].

### 3.5 Economic Analysis of Masaro

Waste management with Masaro technology requires other materials. With a target of processing 2,400 tons/day of waste, the required materials follow Table 1. From the waste processing, the obtained products will include compost, biopesticides, POCI, and animal feed supplements. These products will be sold to third parties and the surrounding community. The production quantity and selling prices of the products are summarized in Table 2. From this simple calculation, the GPM value can be obtained by finding the percentage of profit to income which is 99.21%.

#### Table 1. The Cost Requirements for Waste Management with Masaro Technology (processing capacity 2400 tons/day).

<table>
<thead>
<tr>
<th>Raw Materials</th>
<th>Amount</th>
<th>Price</th>
<th>Cost (Rp/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molasses</td>
<td>743.74 L/day</td>
<td>Rp7,500/L</td>
<td>Rp2,036,015,625</td>
</tr>
<tr>
<td>Water</td>
<td>242.2 kL/day</td>
<td>Rp19,000/m$^3$</td>
<td>Rp1,679,362,160</td>
</tr>
<tr>
<td>POCI Masaro</td>
<td>672 L/day</td>
<td>Rp80,000/L</td>
<td>Rp19,622,400,000</td>
</tr>
</tbody>
</table>

#### Employees

<table>
<thead>
<tr>
<th>Job Description</th>
<th>Number of Employees</th>
<th>Minimum Wage of Bogor Regency (2023)</th>
<th>Cost (Rp/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste Transporter</td>
<td>2</td>
<td>Rp4,330,249</td>
<td>Rp467,666,892</td>
</tr>
<tr>
<td>Shredder Operator</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incinerator Operator</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IPPO Operator</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IPSA Operator</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td></td>
<td></td>
<td>Rp 23,805,444,677</td>
</tr>
</tbody>
</table>

#### Table 2. Products from Waste Management with Masaro Technology.
3.6 Economic Analysis of RDF

As a reference to demonstrate the profits and costs of operating an RDF technology, the facilities in Tritih Lor Village are used as an example. For a moisture content of less than 25% as well as a maximum processing capacity of 140 tons/day, the RDF shard can be produced at 48.40 tons/day with a calorific value of 13.45 MJ/kg. This results in a total potential energy production of 650.84 GJ/day. The potential as a substitute for coal and with the RDF production of Cilacap Regency utilized by PT. Solusi Bangun Indonesia (cement industry) at Rp 300,000/ton, the daily income can reach Rp 14,520,000 and the total income can generate Rp 5,299,800,000/year. With the annual minimum wage for Bogor Regency and the sum of employees for RDF operators, the annual expenditure for the RDF production plant is served in Table 3. Hence, the GPM value for this process is 89.38%.

Table 3. The Cost Requirements for Waste Management with the RDF (processing capacity 140 tons/day).

<table>
<thead>
<tr>
<th>Raw Materials</th>
<th>Amount</th>
<th>Price</th>
<th>Cost (Rp/Year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignin Industrial (Fuel)</td>
<td>500 kg/day</td>
<td>Rp24,500/kg</td>
<td>Rp147,000,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Employees</th>
<th>Number of Employees</th>
<th>Minimum Wage of Bogor Regency (2023)</th>
<th>Cost (Rp/Year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste Transporter</td>
<td>2</td>
<td>Rp4,330,249</td>
<td>Rp415,703,904</td>
</tr>
<tr>
<td>Shredder Operator</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magnet Operator</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sorter Operator</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Briquetting/Peletting Operator</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production</td>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total Cost: Rp562,703,904

3.7 Integration of Masaro with RDF

The methods involved in waste processing using Masaro technology and RDF share similarities. They go through the same processes such as waste sorting, shredding, washing, and drying. The difference lies in the type of waste used as the feedstock. In waste processing with Masaro technology, almost all types of waste, both organic and non-organic, are used as feedstock.

Meanwhile, waste processing with the RDF method utilizes only non-organic waste as the feedstock. In terms of processing, RDF can a faster time than Masaro. Nevertheless, the GPM of waste processing using RDF is lower than Masaro. Therefore, the integration of two methods into a single waste processing can be more attractive.

The integration process begins with waste sorting. Biodegradable waste will be directed to produce organic products in the IPPO, while non-biodegradable waste is divided into two streams: waste processing in the IPSA and RDF processing stream. In the IPPO and IPSA, waste undergoes an incineration process in the incinerator.

In the RDF process, waste is dried and compacted to form plastic brick waste. Integration can be achieved by utilizing the heat generated from the incineration or incinuation process in the incinerator as a heat source for the drying process in the RDF process. The benefits obtained from integrating the RDF method with Masaro technology include efficient use of utilities or fuel, production of a more diverse range of products, and increased revenue. By integrating the Masaro and RDF systems as in Figure 5, the GPM analysis is tabulated in Table 4.
4 Conclusion

Based on the evaluation of potential, environmental effects, and economic factors, the implementation of RDF tends to process a single type of product from organic materials and a small amount of plastic waste. It has the advantage of requiring fewer materials to process waste into finished products. RDF technology can achieve a GPM of 89.38%, with RDF itself used as a solid fuel for co-firing in cement industries. The remaining ash can be used as fertilizer by agricultural entrepreneurs. For Masaro, with various processing units and implementations, Masaro is capable of processing a large amount of waste in West Java, up to 2,400 tons/day, much more than RDF technology. Additionally, the implementation of Masaro technology can produce various types of products, such as POCI, KOCI, planting media, fuel, and compost. These products will greatly help communities in developing entrepreneurship and everyday life. With these products, waste management using Masaro technology can achieve a GPM value of up to 99.21%. Both technologies are excellent for waste management. Therefore, it is highly recommended to create a waste management system that integrates both of these systems to make the process more effective and efficient (GPM 99.22%). This way, the waste management goal of reducing waste volume in Bogor Regency can be achieved successfully, yielding optimal benefits.

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