Potential And Characteristics Of Eichhornia Crassipes Biomass And Municipal Solid Waste As Raw Materials For RDF In Co-Firing Coal Power Plants

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Abstract. The government has regulated the use of RDF biomass for coal co-firing in power plants. This paper examines biomass (Eichhornia Crassipes and municipal solid waste) characteristics and its potential use as RDF for co-firing in CPP. The method includes the analysis of the composition, supply of raw materials, and biomass characteristics. These results will compare with the coal's characteristics in CPP. The density of Eichhornia Crassipes in Lake Tondano was 25 kg/m$^2$, with the wet mass of 45,350 tons. The results of the Eichhornia Crassipes sample test for parameters of moisture content, volatile matter, ash content, fix carbon and gross calorific value have a value range of 93%, 5.8-7.1%, 60.21-63.5%, 17.9-22%, 11.4% and 2681-3068 kcal/kg. Amurang CPP uses coal with 4200 kcal/kg calories as much as 1056 tons/day. The co-firing target of 5% requires 52.8 tons of biomass per day. The existing Eichhornia Crassipes biomass in Lake Tondano only supplies the CPP for 62 days. MSW typically has calorific values and moisture with Eichhornia Crassipes biomass, about 3766-4194 kcal/kg and 31.7-87.1%. The use of MSW to cover the lack of Eichhornia Crassipes will ensure the sustainability of the supply of biomass raw materials in the co-firing program at CPP.

1. Introduction
Currently, the use of coal still ranks first in the supply of primary energy in Indonesia. In 2020, the share of coal was 38.46% or around 553 million BOE of Indonesia's total primary energy, followed by oil and natural gas at 32.82% and 17.44 [1]. The installed capacity of coal-fired power plants in 2019 was around 30,406.17 MW or 43.64% of the total national capacity, while biomass-based power plants were only around 1758.54 MW or 2.52% [2]. Burning coal in power plants will emit CO$_2$, which is a greenhouse gas and has an impact on climate change. Therefore, massive efforts have been made to reduce CO$_2$ emissions from the use of fossil fuels [3,4]. Through Law Number 16 of 2016, Indonesia is committed to contributing to the reduction of greenhouse gas emissions by 29% from its efforts and 41% through international assistance. The energy sector targets GHG emission reductions equivalent to 314-398 million tons of CO$_2$ by 2030, which is carried out through renewable energy, energy efficiency, low-carbon fuels, clean generation technology, and post-mining reclamation [5].

Indonesia also faced environmental problems such as silting of lakes/reservoirs due to the growth of Eichhornia Crassipes and urban waste generation. Sanitary landfill is still the most popular method, but it will occupy land resources and cause secondary pollution to soil and underground water. Uncontrolled growth of Eichhornia Crassipes can reduce lake water quality, such as preventing the transfer of oxygen from the air to the water, reducing DO in water, decreasing water pH, reduce bio-diversity [6,7,8].
Refused Derived Fuel (RDF) is the preferred technology for managing biomass waste (urban waste and Eichhornia Crassipes) used as raw material for co-firing in thermal power plants [9]. RDF is a mixture of heterogeneous materials composition, such as plastic, paper, wood, textiles and organic materials. Variations in physical properties such as density differences raise their problems. Efforts to overcome this are by pelletizing or briquetting [10,11]. RDF can be applied by direct combustion or by co-combustion systems in cement plants, pulp and paper industries, steel industries and thermal power plants. RDF can replace the use of coal in boilers [9,11,12]. Replacing coal with RDF can reduce ash handling, flue gas emission and air pollution related to the use of fossil fuels [12]. RDF has the advantage of being able to produce significant calorific value with low production costs. Utilizing organic materials as raw material for RDF makes RDF an alternative fuel in reducing CO₂ emissions. The calorific value of Eichhornia crassipes is lower than coal, but it could be co-fired to reduce the greenhouse gases released by coal-fired power plants. RDF from MSW emits 247-993 g-CO₂/kg depending on the type of waste material [11,13]. This value is smaller when compared to CO₂ emissions in coal combustion, which is 1200-2600 g-CO₂/kg [14]. Hamid et al. (2020) conducted an RDF test of several material compositions with a wood content consistency of 10%. The test results of the calorific value between 21.8 - 46.5 MJ/kg(db) [10]. Mutiara (2019) tested the manufacture of RDF with five raw materials (paper, rubber/leather, wood, cloth and plastic). The calorific value is 3973.45 kcal/kg, water content is 4.68%, ash content is 11.64%, volatile content is 7.81%, and fixed carbon is 75.87% [15]. The calorific value of wood, leather, food waste, market waste, plastic, rubber, textile, and paper are 16.58 MJ/kg, 19 MJ/kg, 21.2 MJ/kg, 1.74 MJ/kg, 33.7-46.5 MJ/kg, 22.1 MJ/kg, 17.47 MJ/kg, and 14.1-15.8 MJ/kg [10,16,17].

Manufacturing biomass (waste and Eichhornia Crassipes) into RDF on co-firing coal in power plants requires considering several properties, such as calorific value, moisture content, particle size, and ash content [18,19]. This paper examines the characteristics of biomass, especially waste and Eichhornia Crassipes, and the potential use of RDF biomass as an alternative fuel for co-firing in coal power plants.

2. Method

There are two types of biomass samples, namely Eichhornia Crassipes and municipal waste. Eichhornia crassipes sampling is in the Tondano Lake and Saguling reservoirs, while the municipal waste sampling location is in the Sumompo TPA. The waste composition of the Sumompo TPA is assumed to be typical and representative of the Minahasa district. The method of the waste composition refers to the best practice from the National Standard of Indonesia (SNI) 19-3964-1994 and takes for 3 days representing working days and holidays. The waste composition includes organic parameters (food waste, garden waste, market waste, etc.) and inorganic parameters (plastic, rubber, paper, metal, etc.). The characteristic tests include proximate and ultimate analysis, which were carried out in the P3TEKBTKE laboratory and the SUCOFINDO laboratory. The analysis refers to the ASTM test standard, as shown in Table 1. Analysis of raw material supply for RDF biomass considers the amount of waste and Eichhornia Crassipes and compares it with the need for coal co-firing at the PLTU.

| Parameter                  | ASTM Standards          | Parameter                  | ASTM Standards          |
|----------------------------|-------------------------|----------------------------|-------------------------|
| Total Moisture, % ar       | ASTM E 949-88 (2004)    | Ultimate Analysis          | ASTM E 777-08           |
| Proximate Analysis         |                         | Carbon (C), %              |                         |
| Moisture, % ad             | ASTM E 897-88 (2004)    | Hidrogen (H), %            | ASTM E 777-08           |
| Volatile Matter, % ad      | ASTM E 830-87           | Nitrogen (N), %            | ASTM E 778-08           |
| Ash Content, % ad          | ASTM D 3172-07a         | Suphur (S), %              | ASTM E 775-87 (2008)    |
| Fixed Carbon, % ad         | ASTM E 711-81 (2004)    | Oxygen (O), %              | ASTM D 3176-09          |
| GCV, kcal/kg               |                         |                           |                         |

2
3. Results and discussion

3.1. Eichhornia Crassipes
The Eichhornia Crassipes coverage in the Saguling reservoir and Lake Tondano is 156.5 hectares (2.8%) and 181.4 hectares (4.07%) of the reservoir/lake area. The density levels of Eichhornia Crassipes in the Saguling reservoir and Tondano lake are 16 kg/m² and 25 kg/m² (Table 2), so the wet weight of Eichhornia Crassipes can be calculated as 25,048 tons and 45,350 tons. Figure 1 shows the cover of Eichhornia Crassipes and the physical size of Eichhornia Crassipes in 2 locations.

| Parameter                  | Unit      | Saguling | Tondano |
|----------------------------|-----------|----------|---------|
| Area                       | Hectare   | 5600     | 4460    |
| Eichhornia Crassipes Coverage Area | Hectare   | 156.5   | 181.4   |
| Density                    | kg/m²     | 16       | 25      |
| Wet Eichhornia Crassipes   | tons      | 25,048   | 45,350  |
| Water Temperature          | °C        | 27.78    | 27.3    |
| pH                         |           | 7.2      | 7.22    |

Table 2. Eichhornia Crassipes Characteristics (Source: P3TEKBTEKE, 2021)

![Figure 1](image1.png)

(a) Saguling Reservoir, (b) Tondano Lake

3.2. Municipal Solid Waste (MSW)
Municipal waste is heterogeneous, classified into organic waste, cans, aluminum, glass/glass, plastic, paper, metal, cloth, and other materials. Komposisi sampah di TPA Sumompo seperti pada Figure 2. The composition of municipal waste in TPA Sumompo is still dominated by organic waste at 62%, followed by plastic and paper at 15% and 10%. The result shows that 87% of MSW raw materials from organic waste, plastics, and paper are potential for RDF. The MSW composition in the Sumompo landfill was typically the same as others cities in Indonesia, with organics waste at 54-62% and anorganic waste at 38-46% (Figure 2). The obstacle to getting a homogeneous RDF quality lies in the initial waste sorting process. The daily tonnage of municipal waste that goes to landfills in Sumompo Landfill is 287 tons/day.

![Figure 2](image2.png)

Figure 2. MSW Composition in Sumompo Landfill and Others Cities in Indonesia
3.3. *Eichhornia Crassipes* and MSW Characteristic Test

A characteristic test is needed to compare the quality of *Eichhornia Crassipes* and municipal waste to see the potential and opportunities for its use as fuel for power plants either directly or through co-firing. The results of the proximate and ultimate analysis of *Eichhornia Crassipes* and municipal waste can be seen in Table 3 and Table 4. Table 3 shows that the sample test results from Saguling and Tondano are relatively similar except for the calorific value of Tondano, which is 14% larger than Saguling, which will affect the amount of fuel to generate electricity at the same capacity.

### Table 3. Proximate and Ultimate Analysis of *Eichhornia Crassipes*

| Parameter                  | Unit     | WH Saguling | WH Tondano |
|----------------------------|----------|-------------|------------|
| Total Moisture             | % ar     | 93.66       | 93.83      |
| Proximate Analysis         |          |             |            |
| Moisture                   | % ad     | 7.12        | 5.82       |
| Volatile Matter            | % ad     | 63.5        | 60.21      |
| Ash Content                | % ad     | 17.9        | 22         |
| Fixed Carbon               | % ad     | 11.4        | 11.45      |
| Gross Caloric Value        | kcal/kg  | 2681.86     | 3068.64    |
| Ultimate Analysis          |          |             |            |
| Carbon (C)                 | %        | 34.12       | 34.4       |
| Hydrogen (H)               | %        | 5.07        | 5.28       |
| Oxygen (O)                 | %        | 39.95       | 36.81      |

Typically, the proximate test value of *Eichhornia Crassipes* biomass is not different from municipal waste (Table 4). The use of *Eichhornia Crassipes* biomass and municipal waste will ensure the availability of co-firing PLTU fuel supply. Table 4 shows the test results for mixed waste, combustible waste, and organic waste. The combustible waste consists of paper, plastic, rubber, and cloth/textiles, while organic waste consists of garden waste, food waste, vegetables, and fruits. The moisture content in mixed waste and organic waste samples is still relatively high at around 60.27% and 87.10%, so it is necessary to pre-treat it to reduce the moisture content to increase the calorific value. The results of this characteristic test will compare with the RDF specifications required at the power plant.

### Table 4. Proximate and Ultimate Analysis of MSW

| Parameter                  | Unit     | Sumompo Landfill |
|----------------------------|----------|------------------|
|                            |          | Mix waste        | Combustible Waste | Organics |
| Total Moisture             | %,ar     | 60.27            | 31.70             | 87.10    |
| Proximate Analysis         |          |                  |                   |          |
| - Moisture Analyst         | % ad     | 6.13             | 4.10              | 7.10     |
| - Volatile Matter          | % ad     | 69.53            | 77.40             | 67.30    |
| - Ash Content              | % ad     | 11.87            | 14.30             | 9.70     |
| - Fixed Carbon             | % ad     | 11.13            | 4.20              | 15.90    |
| Gross Caloric Value        | kcal/kg  | 3766             | 4194              | 4095     |
| Ultimate Analysis          |          |                  |                   |          |
| Carbon (C)                 | %        | 38.96            | 45.66             | 31.70    |
| Hydrogen (H)               | %        | 5.95             | 6.25              | 6.59     |
| Oxygen (O)                 | %        | 33.04            | 33.10             | 37.15    |

3.4. *Amurang Coal Power Plant*

Amurang CPP has a 2 x 25 MW capacity and is ready to conduct biomass co-firing. Amurang CPP uses coal with calories of 4200 kcal/kg according to the plant's design, as much as 1056 tons per day. The
composition of 5% biomass in the co-firing target will require 52.8 tons of biomass per day at the same heating value. Table 5 shows the results of the proximate and ultimate tests of coal used in Amurang CPP. Table 5 shows that coal has a higher calorific value than Eichhornia Crassipes because it has a higher fixed carbon value and lower water content. Amurang CPP design specifications need 72.28 tons of biomass per day in dry conditions with a moisture content of about 10%. Based on Table 2, the availability of wet Eichhornia Crassipes is 45,350 tons, and it will decrease to 4,535 tons when dried to 10% moisture content so that it can only supply the 5% co-firing for 62 days. The implementation of co-firing using Eichhornia Crassipes needs a drying process to get the moisture content to be 10%. The use of other biomass such as municipal waste to cover the lack of Eichhornia Crassipes will ensure the sustainability of the supply of biomass raw materials in the co-firing program at the Amurang CPP.

Table 5. Proximate and Ultimate Analysis of Coal in Amurang CPP

| Parameter           | Unit | Value   |
|---------------------|------|---------|
| Total Moisture      | % ar | 24.71   |
| Proximate Analysis  |      |         |
| Moisture            | % ad | 7.53    |
| Volatile Matter     | % ad | 46.38   |
| Ash Content         | % ad | 3.26    |
| Fixed Carbon        | % ad | 42.8    |
| Gross Caloric Value | kcal/kg | 4753.38 |
| Ultimate Analysis   |      |         |
| Carbon (C)          | %    | 51      |
| Hydrogen (H)        | %    | 6.47    |
| Nitrogen (N)        | %    | 0.76    |
| Sulphur (S)         | %    | 0.31    |
| Oxygen (O)          | %    | 38.19   |

Table 6. MSW Feedstock Potential

| Parameter               | Organic Waste | Combustible Waste | Fresh Waste |
|-------------------------|---------------|-------------------|-------------|
| Daily Tonase (tons/day) | 176.45        | 75.95             | 287         |
| Moisture (%)            | 87.1          | 31.7              | 60.27       |
| Tonase in 10% moisture (tons/day) | 25.04 | 57.06 | 125.43 |
| Calorific Value (kcal/kg) | 4095          | 4194              | 3766        |
| Co-firing Biomass Needs (tons/day) | 54.15 | 52.87 | 58.88 |

Alternative biomass from municipal waste can be obtained from the Sumompo landfill, especially from combustible waste and fresh waste. Theoretically, the calorific value for each type of waste with a moisture content of 10% is as shown in Table 6. However, municipal waste utilization to cover the shortage of Eichhornia Crassipes biomass needs to pay attention to the ratio of organic matter according to the National Standard of Indonesia regarding RDF specifications for CPP. CPP cannot fully utilize fresh waste because the organic composition is only 62%. It is necessary to add organic materials with low moisture content and high calorific value, such as garden waste and other agricultural waste. The use of additional market waste and food waste is not recommended because this type of waste has very high moisture and low calorific value.

4. Summary
Eichhornia Crassipes biomass and municipal waste have high moisture in a range 60-93%, so it needs initial processing to meet a heating value close to the specifications of coal in power plant. RDF biomass from Eichhornia Crassipes can be used as raw material for co-firing coal power plants but only supplies
the power plant for 62 days. The use of MSW to cover the lack of Eichhornia Crassipes will ensure the sustainability of the supply of biomass raw materials in the co-firing program at CPP.

References
[1] MOEMR 2021 Handbook of Energy and Economic Statistics of Indonesia 2020 (Jakarta: Center for Data and Information Technology) p 11
[2] MOEMR 2020 National Electricity Statistics 2019 edition 33 (Jakarta: Secretariat General of Electricity) p 7
[3] Mirjana L Milos B Milica J Dejan M 2015 Coal-Fired Power Plants Energy Efficiency and Climate Change Facta Universitatis Series: Working and Living Environmental Protection. 12 217
[4] Yan X Kun Y Jiahu Z Guohao Z 2020 Coal-Biomass Co-Firing Power Generation Technology Sustainability 12 3692 doi: 10.3390/su12093692
[5] First Nationally Determined Contribution (1st NDC) Republic of Indonesia, 2016
[6] Hongting M Yang C Xinyu L Zequn D Weiyi Z 2016 Review of Typical Municipal Solid Waste Disposal Status and Energy Technology Energy Procedia 88 589 doi: 10.1016/j.egypro.2016.06.083
[7] Habtamu Y Fenta A 2019 Impact of the Invasive Water Hyacinth (Eichhornia crassipes) on Socio-Economic J. Agric. Environ. Sci. 4 45-55
[8] Paul N Robert K Purity M Yusuyuki N 2015 Biogas Production Using Water Hyacinth (Eichhornia crassipes) for Electricity Generation in Kenya Energy and Power Engineering 7 209-216
[9] Putra A 2021 Indonesia’s Biomass Cofiring Bet “Beware of the Implementation Risks, Institute of Energy Economics and Financial Analysis, download: http://ieefa.org/wp-content/uploads/2021/02/Indonesias-Biomass-Cofiring-Bet_February-2021.pdf
[10] Hamid R Fahimeh Y P C Jim L Shahab S 2020 Pelletization of Refuse-Derived Fuel with Varying Compositions of Plastic, Paper, Organic and Wood sustainability 12 4645 http://dx.doi.org/10.3390/su12114645
[11] Isabel B Maria E S Germana L Ana C Miguel F 2017 Refuse Derived Fuel from Municipal Solid Waste rejected fractions Energy Procedia 120 349
[12] Ganesh T Vignesh P Arun K G 2013 Refuse Derived Fuel to Electricity International Journal of Engineering Research and Technology (IJERT) 2 2930
[13] Obianuju P Ilo Mulala D Simatele S’phumelele L Nkomo 2020 The Benefits of Water Hyacinth (Eichhornia crassipes) for Southern Africa: A Review Sustainability 12 9222
[14] Retno D Herni K 2018 Carbon Dioxide Emission Factor Estimation from Indonesian Coal Indonesian Mining Journal 21 45-58
[15] Mutiara F R I Gede E L Eka M 2019 SINTEK JOURNAL 13 51
[16] Leopold A Darmawan R 2020 Municipal Solid Waste Characteristic and Energy Potential in Piyungan Landfill Applied Mechanics and Materials 898 58-63
[17] Olisa Y P Ajoko T J 2018 Gross Calorific Value of Combustible Solid Waste in a Mass Burn Incineration Plant J. Appl. Sci. Environ. Manage. 221377-1380
[18] Eleni I John H Innes D Costas V Phil P 2017 Journal waste management 73 pp.535-545 http://dx.doi.org/10.1016/j.wasman.2017.07.001
[19] Sukarni S Yahya Z Sumarli S Retno W Avita A P Suhermanto M 2018 Physical and Chemical Properties of Water Hyacinth (Eichhornia crassipes) as a Sustainable Biofuel Feedstock IOP Conf. Series: Materials Science and Engineering 515 012070

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