Potential Utilization of Plastic River Debris as Electricity Power Plant in Jakarta, Indonesia

Mega Mutiara Sari¹, Takanobu Inoue², Regil Kentaurus Harryes³, Kuriko Yokota², Iva Yenis Septiariva⁴, Sapta Suhardono⁵, Ika Bagus Priyambada⁶, Shigeru Kato², Suprihanto Notodarmojo⁷, I Wayan Koko Suryawan¹

¹Department of Environmental Engineering, Universitas Pertamina, Indonesia
²Department of Architecture and Civil Engineering, Toyohashi University of Technology, Japan
³Faculty of Vocational Studies, Indonesia Defense University, Indonesia
⁴Study Program of Civil Engineering, Universitas Sebelas Maret, Indonesia
⁵Department of Environmental Science, Universitas Sebelas Maret, Indonesia
⁶Department of Environmental Engineering, Universitas Diponegoro, Indonesia
⁷Department of Environmental Engineering, Institut Teknologi Bandung, Indonesia

Corresponding Author: Mega Mutiara Sari; Email: mega.ms@universitaspertamina.ac.id

ARTICLE INFO
Keywords: Energy Recovery; Environmentally Friendly; River Debris; Waste Management.

ABSTRACT
River debris is the main problem from the negative impact of poor waste management. The composition of river debris in Jakarta consists mostly of plastic waste. Plastic waste from river debris has an opportunity for energy recovery. This study aimed to see the potential for utilizing river debris in energy recovery in power plants. This research was conducted at three sampling shelter points in Pesing, Pluit, and Perintis. Waste generation and composition were quantified using the load count method on Indonesian state standards for seven consecutive days. River debris generation in Pesing, Pluit, and Perintis averaged 7.2; 3; and 1.8 tons/day. More than 60% (w/w) of plastic bag waste was found in the Pesing and Pluit shelters, while 67.3% was found in the Perintis shelter. Based on the calorific value of each plastic waste, the energy potential from plastic waste recovery can reach 16,197,109 kWh/year. This is equivalent to an electricity supply of 0.05% of the total electricity demand in Jakarta.

INTRODUCTION
Marine Debris states that marine waste can cause pollution and damage marine life, animals, ecosystems, and human health (Kandziora et al., 2019; van Truong & BeiPing, 2019; Vince & Stoett, 2018). The presence of marine debris is a global environmental problem and is a growing concern (Miladinova et al., 2020). River debris or aquatic solid waste is a persistent solid material produced or processed by humans, directly or indirectly, wasted or left behind in the marine environment (Sulistiawati & Eisma-Osorio, 2021). River debris is goods that have been shaped or used and intentionally dumped into the sea or river by humans. Materials that enter or move into the waters from the land through rivers, drainage systems, or wastewater disposal and wind can be said to be River debris. River debris can be classified into two categories, namely organic and inorganic water waste. For River debris, the organic category consists of wood, leaves, and others (Safira et al., 2021). Meanwhile, the inorganic debris category consists of plastic, metal, glass, paper, cardboard, rubber, clothing, textiles, and others (Nadyanti Ivanie et al., 2020).

Debris is a persistent solid material produced by humans, directly or indirectly, disposed of or even left in the aquatic environment (Richards & Beger, 2011). In addition, river debris can be interpreted as a material that is difficult to
decompose in the form of processed or manufactured solids that is disposed of or left intentionally or not by humans in the waters (Chen et al., 2021).

Plastic debris is also a non-biodegradable waste that harms the environment (Dwivedi et al., 2019). Plastic debris consists of straws, food packaging, drink cups, pet bottles, another packaging, plastic bags, and other plastics (Chitaka & von Blottnitz, 2019; Clayton et al., 2021; Walther et al., 2018). Plastic waste generally has a high calorific value, so it has the potential to be used as fuel (Sawono et al., 2021). The utilization of plastic debris as fuel for Refuse Plastic Fuel (RPF) has several advantages (Murakami et al., 2006). This RPF includes reducing the cost of handling plastic debris that has been transported out of the factory using third-party services, reducing the use of fossil fuels, and making the factory clean from plastic waste. Compared to coal, plastic waste energy recovery is more environmentally friendly, and CO₂ emissions are 33% lower (Kumar et al., 2020). On the other hand, the pyrolysis process in PRF is an effective and environmentally friendly option for solid waste treatment to obtain a liquid fuel called pyrolytic oil or bio-oil (Pawar et al., 2020).

With the possibility of greater use of plastic waste, a more in-depth study of the energy potential that can be recovered is needed. This research was conducted in Jakarta, where the problem of marine plastic waste is still severe and considers the policy direction for energy-based waste management. This study aimed to determine the potential use of marine plastic waste as raw material for PRF to generate electrical energy in Jakarta.

**Materials and Methods**

The collection of generated data will be carried out using the load count analysis method following the measurement and analysis method (Damanhuri & Padmi, 2015). This method is carried out by measuring the volume of garbage collection vehicles that carry marine waste to the Reiver debris TPS for one full day. Then the waste generation and composition data will be carried out following SNI 19-3964 1994 concerning methods for collection and measurement of samples of generation and composition of urban waste and the sampling technique used by the World Bank (Shuker & Cadman, 2018). This method is carried out by dividing the pile of garbage into four quadrants. First, 1 m³ will be taken using an excavator from the four quadrants, then mixing is carried out to make the sample homogeneous. Furthermore, from the 4 m³ of collected waste samples, it will be divided into four quadrants which will then be chosen one of the quadrants.

The maximum heat energy released by a fuel through a complete combustion reaction per unit mass or fuel volume is defined. The calorific value is the heat transferred when the combustion is complete. The heat energy in question is obtained from calculating the calorific value, which is the product of the specific heat and the composition of the waste.

The heat analysis of fuel is intended to obtain data on the heat energy that power can release by the occurrence of a reaction/combustion process (Sutanto, 2021). The calorific value shows the heat transferred when the combustion product is complete. According to the ASTM D 2015 standard, the calorific value is determined in the standard test in Bomb Calorimeter. There are two kinds of determination: high calorific value (gross) (HHV, higher heating value) where it is assumed that all the vapor formed has condensed; so that in this case, it includes the latent heat of vaporization of water vapor in the product; and the lower heating value (LHV) which does not have the latent heat. In this study, the calorific value used is LHV and HHV, where the sample tested is the original sample. Because plastic waste cannot absorb water or penetrate water, LHV and HHV in Reiver debris are assumed to be the same.

**Results and Discussion**

Residents around the riverbanks have carried out the activity of throwing waste into the river for years, so throwing debris and dirt into the river is not a new story (Nugraha et al., 2018; Safira et al., 2021; van Voorst & Hellman, 2015). This habit occurs in the DKI Jakarta area and is almost evenly distributed in all regions in Indonesia. Therefore, it is not uncommon for garbage to accumulate and blockage at several points on rivers in cities in Indonesia. Thus, the waste will flow downstream along with floods during the rainy season. The findings in our study on the average peak condition of waste generation at Pesing, Pluit, and Perintis
monitoring points were 7.2; 3; and 1.8 tons/day (Table1).

Table 1. River Waste Generation in Three Locations Jakarta

| Location | Plastic waste generation |
|----------|--------------------------|
| Pesing   | 7.2                      |
| Pluit    | 3.0                      |
| Perintis | 1.8                      |

Source: Sari, Andarani, et al., 2022

Daily human activities have indirectly increased the amount of waste in the aquatic environment, such as the disposal of household activities such as kitchen waste food or beverage packaging into the waters. The most common inorganic waste dumped into rivers in the Jakarta area is inorganic waste in plastic cups, plastic bags and wrapping materials, fast food wrappers, plastic bottles, and other plastic packaging. River debris collection also usually requires heavy equipment because the amount is very large every day.

River debris samples taken will be sorted according to the type or classification of waste at each TPS for Reiver debris. This sorting results in a category based on the type of plastic waste. The plastic class currently used globally by SPI (Society of the Plastics Industry) is a resin identification code (RIC), which is a plastic classification based on the resin used (Khajuria et al., 2017). Types that can facilitate recycling the plastic waste produced plastics are classified into seven groups (Faraca & Astrup, 2019; Kazemi et al., 2021; Klemeš et al., 2021), namely polyethylene terephthalate or PET/PETE (01), high-density polyethylene or HDPE (02), polyvinyl chloride, or PVC (03), low-density polyethylene or LDPE (4), polypropylene or PP (05), polystyrene or PS (06) and others or Others (07). However, the composition is too complex with the existing conditions; therefore, the distribution of the dominant waste in the study location is carried out (Figure 1).

The plastic collected is domestic waste or a type of household waste in product packaging, plastic bags, household appliances (mats, toys, kitchen utensils), and food packaging (styrofoam). In addition, several objects from shipping activities were also found, for example, the remains of fishing gear and pieces of cooling boxes. The amount of polypropylene and polyethylene plastic waste collected reflects the surrounding community's waste management and consumption patterns (van Emmerik, Loozen, et al., 2019). So, the primary sources of plastic waste come from packaging and consumer goods in households (Schwarz et al., 2019).

A study conducted in the Cimandiri watershed, West Java Province showed a smaller abundance and density of plastic waste than in the Baturusa watershed (Taryono et al., 2020). A higher population will produce more plastic waste (Lebreton & Andrady, 2019; Mongtoeun, 2019). Still, the amount of plastic waste in waters is influenced by various factors, namely the type of waste management, the location of the city, dams and garbage traps, seasons and seasonal river discharges, and flood events (van Emmerik, Tramoy, et al., 2019). These factors show the complexity of the problem of plastic waste in rivers.
Plastic waste in rivers requires serious handling by various parties. One way to manage plastic waste is to recycle waste according to the 3R principles, namely reduce, reuse, and recycle (Kabirifar et al., 2020). The waste bank program is implemented to recycle plastic waste generated from domestic activities. The Waste Bank Program is community-based waste management by integrating the 3R principles and managing as close as possible to the source (Kubota et al., 2020).

The calorific value contained in plastics with other energy sources in this study can be seen in Table 2. Given the high energy content of plastic materials, the potential for its use as an energy source has good prospects in Indonesia. This can get two advantages at once, namely reducing the problem of plastic waste and producing energy that can reduce dependence on conventional energy sources (Gopinath et al., 2020).

Energy recovery is converting plastic waste into a form of electricity (Lombardi et al., 2015; Zahra et al., 2022). This step is the main topic of this study, especially converting plastic waste into electrical energy. Although this process is not well known in Indonesia itself, especially by the public, several theories, studies, and methods are used to study ways to convert plastic waste into electrical energy. In general, plastic waste cannot be converted directly into electrical energy but is first converted into liquid, solid, or gas fuel, then converted into electrical energy using a generator. Several technologies can convert plastic and biomass waste into fuel, including conversion to solid fuel, liquid fuel, and conversion to gas fuel (Cheong et al., 2022; Gasim et al., 2022; Koko et al., 2022; Rakasat et al., 2021; Septiariva et al., 2022; Suryawan et al., 2022). Overall, the use of marine plastic debris in Jakarta can indeed supply 0.05% of Jakarta's total annual energy demand if carried out.

| Plastic Composition | Caloric Value (MJ/kg) | Caloric Value (kWh/kg) | Electricity Generation Potential (kWh/day) |
|---------------------|-----------------------|------------------------|------------------------------------------|
| Straw               | 10.9                  | 3.03                   | 96.50                                    |
| Food packaging      | 5.63                  | 1.56                   | 1,261.89                                 |
| Drink cup           | 12.2                  | 3.39                   | 911.48                                   |
| PET bottle          | 16.6                  | 4.61                   | 2,170.41                                 |
| Another packaging   | 18.1                  | 5.03                   | 1,352.27                                 |
| Plastic bag         | 14.7                  | 4.08                   | 17,846.84                                |
| Others Plastic      | 8.63                  | 2.40                   | 2,256.67                                 |
| Total Electricity Generation (kWh/day) | 25,896.05 |
| Total Electricity Generation (kWh/year) | 16,197,109 |
| Total Electricity Consumption (kWh/year) | 32,194,867,748 |
| Electricity Supplied from River Plastic Waste Potential (%) | 0.0503 |

Source: Calculated based on (Sari, Andarani, et al., 2022)
Research that examines the construction of a waste power plant in terms of fulfilling electrical energy for the community and in terms of reducing environmental problems due to waste (Qodriyatun, 2021). The construction of a waste power plant is expected to contribute to meeting the electricity needs of the community. This research is interesting because the potential for energy production from fossils is starting to decrease and the global community has committed to reducing Greenhouse Gas (GHG) emissions from marine debris generation. On the other hand, several cities in Indonesia are already in a waste emergency condition, such as Jakarta (Koko et al., 2022; Rahmalia et al., 2022; Sari, Andarani, et al., 2022; Sari, Inoue, et al., 2022).

**CONCLUSION**

River debris generation in Pesing, Pluitm, and Pernting averaged 7.2; 3; and 1.8 tons/day. Plastic bag waste was found in more than 60% (w/w) in the Pesing and Pluit shelters and 67.3% (w/w) in the Perintis shelter. Based on the calorific value of each plastic waste, the energy potential from plastic waste recovery can reach 16,197,109 kWh/year. This potential energy recovery finding is equivalent to an electricity supply of 0.05% of the total electricity demand in Jakarta.

**REFERENCES**

Chen, H. L., Nath, T. K., Chong, S., Foo, V., Gibbins, C., & Lechner, A. M. (2021). The plastic waste problem in Malaysia: management, recycling and disposal of local and global plastic waste. *SN Applied Sciences*, 3(4), 437.

Cheong, W. L., Chan, Y. J., Tiong, T. J., Chong, W. C., Kiatkittipong, W., Kiatkittipong, K., Mohamad, M., Daud, H., Suryawan, I. W., Sari, M. M., & Lim, J. W. (2022). Anaerobic Co-Digestion of Food Waste with Sewage Sludge: Simulation and Optimization for Maximum Biogas Production. In *Water* (Vol. 14, Issue 7).

Chitaka, T. Y., & von Blottnitz, H. (2019). Accumulation and characteristics of plastic debris along five beaches in Cape Town. *Marine Pollution Bulletin*, 138, 451–457.

Clayton, C. A., Walker, T. R., Bezerra, J. C., & Adam, I. (2021). Policy responses to reduce single-use plastic marine pollution in the Caribbean. *Marine Pollution Bulletin*, 162, 111833.

Damanhuri, E., & Padmi, T. (2015). *Pengelolaan Sampah Terpadu Edisi Kedua*. ITB.

Dwivedi, P., Mishra, P. K., Mondal, M. K., & Srivastava, N. (2019). Non-biodegradable polymeric waste pyrolysis for energy recovery. *Heliyon*, 5(8), e02198.

Faraca, G., & Astrup, T. (2019). Plastic waste from recycling centres: Characterisation and evaluation of plastic recyclability. *Waste Management*, 95, 388–398.

Gasim, M. F., Choong, Z.-Y., Koo, P.-L., Low, S.-C., Abdurahman, M.-H., Ho, Y.-C., Mohamad, M., Suryawan, I. W., Lim, J.-W., & Oh, W.-D. (2022). Application of Biochar as Functional Material for Remediation of Organic Pollutants in Water: An Overview. In *Catalysts* (Vol. 12, Issue 2).

Gopinath, K. P., Nagarajan, V. M., Krishnan, A., & Malolan, R. (2020). A critical review on the influence of energy, environmental and economic factors on various processes used to handle and recycle plastic wastes: Development of a comprehensive index. *Journal of Cleaner Production*, 274, 123031.

Kabirifar, K., Mojtahedi, M., Wang, C., & Tam, V. W. Y. (2020). Construction and demolition waste management contributing factors coupled with reduce, reuse, and recycle strategies for effective waste management: A review. *Journal of Cleaner Production*, 263, 121265.

Kandziora, J. H., van Toulon, N., Sobral, P., Taylor, H. L., Ribbink, A. J., Jambeck, J. R., & Werner, S. (2019). The important role of marine debris networks to prevent and reduce ocean plastic pollution. *Marine Pollution Bulletin*, 141(July 2018), 657–662.

Kazemi, M., Faisal Kabir, S., & Fini, E. H. (2021). State of the art in recycling waste thermoplastics and thermosets and their applications in construction. *Resources, Conservation and Recycling*, 174, 105776.

Khajuria, V., Chowdhary, S., Roshi, Gupta, S., & Rani, N. (2017). Evaluation of adherence to RIC standards for plastic packing of liquid pharmaceutical medications. *JK Science*, 18 (4), 252–254.
Klemeš, J. J., Fan, Y. Van, & Jiang, P. (2021). Plastics: friends or foes? The circularity and plastic waste footprint. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 43*(13), 1549–1565.

Koko, I. W., Lim, J., Surya, B., Yenis, I., Sari, N. K., Sari, M. M., Zahra, N. L., Qonitan, F. D., & Sarwono, A. (2022). Effect of sludge sewage quality on heating value: case study in Jakarta, Indonesia. *Desalination and Water Treatment, 28071*, 1–8.

Kubota, R., Horita, M., & Tasaki, T. (2020). Integration of community-based waste bank programs with the municipal solid-waste-management policy in Makassar, Indonesia. *Journal of Material Cycles and Waste Management, 22*(3), 928–937.

Kumar, A., Dash, S. K., Ahamed, M. S., & Lingfa, P. (2020). *Study on Conversion Techniques of Alternative Fuels from Waste Plastics BT - Energy Recovery Processes from Wastes* (S. K. Ghosh (ed.); pp. 213–224). Springer Singapore.

Lebreton, L., & Andrady, A. (2019). Future scenarios of global plastic waste generation and disposal. *Palgrave Communications, 5*(1), 6.

Lombardi, L., Carnevale, E., & Corti, A. (2015). A review of technologies and performances of thermal treatment systems for energy recovery from waste. *Waste Management, 37*, 26–44.

Miladinova, S., Macias, D., Stips, A., & Garcia-Gorriz, E. (2020). Identifying distribution and accumulation patterns of floating marine debris in the Black Sea. *Marine Pollution Bulletin, 153*, 110964.

Mongtoeun, Y. (2019). Household Solid Waste Generation and Socioeconomic Factors in the Capital City of CAMBODIA. *International Journal of Environmental Sciences & Natural Resources, 20*(1), 1–4.

Murakami, S., Terazono, A., Abe, N., Moriguchi, Y., & Miyakawa, H. (2006). Material flows of end-of-life home appliances in Japan. *Journal of Material Cycles and Waste Management, 8*(1), 46–55.

Nadyanti Ivonie, R., Mardiastuti, A., & Aulia Rahman, D. (2020). Proposed classification of waste that landed on small island in Indonesia for the conservation of waterbird. *IOP Conference Series: Earth and Environmental Science, 528*(1), 12012.

Nugraha, A., Sutjahjo, S. H., & Amin, A. A. (2018). Perception and Participation on the Household Waste Management through in South Jakarta. *Journal of Natural Resources and Environmental Management, 8*(1), 7–14.

Pawar, A., Panwar, N. L., & Salvi, B. L. (2020). Comprehensive review on pyrolytic oil production, upgrading and its utilization. *Journal of Material Cycles and Waste Management, 22*(6), 1712–1722.

Qodriyatun, S. N. (2021). Pembangkit Listrik Tenaga Sampah: Antara Permasalahan Lingkungan dan Percepatan Pembangunan Energi Terbarukan. *Aspirasi: Jurnal Masalah-Masalah Sosial, 12*(1), 63–84.

Rahmila, I., Oktivianny, N. Y., Kahalnashiri, F. S., Ulhasanah, N., & Suryawan, I. W. K. (2022). Pengelolaan Limbah Alat Pelindung Diri (APD) di Daerah Jakarta Barat Berbasis Smart Infectious Waste Bank (SIWAB). *Jurnal Ilmu Lingkungan, 20*(1), 91–101.

Raksasat, R., Kiatkittipong, K., Kiatkittipong, W., Wong, C. Y., Lam, M. K., Ho, Y. C., Oh, W. Da, Suryawan, I. W. K., & Lim, J. W. (2021). Blended sewage sludge–palm kernel expeller to enhance the palatability of black soldier fly larvae for biodiesel production. *Processess, 9*(2).

Richards, Z. T., & Beger, M. (2011). A quantification of the standing stock of macro-debris in Majuro lagoon and its effect on hard coral communities. *Marine Pollution Bulletin, 62*(8), 1693–1701.

Safira, R. H., Sari, M. M., Notodarmojo, S., Inoue, T., & Harryes, R. K. (2021). Potential Utilization Analysis of River Waste in Jakarta, Indonesia. *Geosfera Indonesia, 6*(2), 157–172.

Sari, M. M., Andarani, P., Notodarmojo, S., Harryes, R. K., Nguyen, M. N., Yokota, K., & Inoue, T. (2022). Plastic pollution in the surface water in Jakarta, Indonesia. *Marine Pollution Bulletin, 182*, 114023.

Sari, M. M., Inoue, T., Harryes, R. K., Suryawan, I. W. K., & Yokota, K. (2022). Potential of Recycle Marine Debris in Pluit Emplacement
, Jakarta to Achieve Sustainable Reduction of Marine Waste Generation. *International Journal of Sustainable Development and Planning, 17*(1), 119–125.

Sarwono, A., Septiariva, I. Y., Qonitan, F. D., Zahra, N. L., Sari, N. K., Fauziah, E. N., Ummatin, K. K., Amoa, Q., Faria, N., Wei, L. J., & Suryawan, I. W. K. (2021). Refuse Derived Fuel for Energy Recovery by Thermal Processes. A Case Study in Depok City, Indonesia. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, 88*(1), 12–23.

Schwarz, A. E., Ligthart, T. N., Boukris, E., & van Harmelen, T. (2019). Sources, transport, and accumulation of different types of plastic litter in aquatic environments: A review study. *Marine Pollution Bulletin, 143*, 92–100.

Septiariva, I. Y., Suryawan, I. W. K., Zahra, N. L., Nabila, Y., Putri, K., Sarwono, A., Qonitan, F. D., & Lim, J. W. (2022). Characterization Sludge from Drying Area and Sludge Drying Bed in Sludge Treatment Plant Surabaya City for Waste to Energy Approach. *Journal of Ecological Engineering, 23*(4), 268–275.

Shuker, I. G., & Cadman, C. A. (2018). Indonesia - Marine debris hotspot rapid assessment : synthesis report.

Sulistiawati, L. Y., & Eisma-Osorio, R.-L. (2021). *Marine Plastic Pollution and the Rule of Law.*

Suryawan, I. W. K., Septiariva, I. Y., Fauziah, E. N., Ramadan, B. S., Qonitan, F. D., Zahra, N. L., Sarwono, A., Sari, M. M., Ummatin, K. K., & Wei, L. J. (2022). Municipal solid waste to energy : palletization of paper and garden waste into refuse derived fuel. *Journal of Ecological Engineering, 23*(4), 64–74.

Sutanto, R. (2021). *The Influence of Pyrolysis Process Time on the Quality of Horse Feses Bioarang Brickets.* 6(2), 17–19.

Taryono, Pe, E. O. L., Wardiatno, Y., & Mashar, A. (2020). Macroplastic distribution, abundance, and composition which flows to Cimandiri estuary, West Java. *IOP Conference Series: Earth and Environmental Science, 420*(1), 12031.