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Empowering Sustainable Energy: Pyrolysis Optimization for Transforming LDPE Plastic Waste into Diesel Fuel in Palembang

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Abstract:- Indonesia faces a significant plastic waste problem, with 8 million tonnes ending up in the oceans annually. The COVID-19 pandemic has worsened the situation, adding more waste due to discarded masks and other protective equipment. To combat this, a solution is proposed using pyrolysis, a process of converting waste into energy, to power small-scale diesel generators. This conversion can create alternative fuels, like plastic oil, from widely available plastic waste. However, there are limitations with certain types of plastics and further development is needed. The Pyroenergy Pyrolysis Reactor engine can improve fuel production efficiency by controlling combustion temperature and optimizing the condensation process with two condensers. There are plans to add a shredder for better combustion. However, this is still simple technology. Meanwhile, plastic waste in Palembang has hit 1,200 tons per day, with Low-Density Polyethylene (LDPE) being dominant. The rising population is set to increase this volume. To counter this, the government has initiated actions, like the Presidential Regulation Number 35 of 2018 for developing environmentally friendly tech-based electrical installations. The Pyrolysis power plant complex, a proposed solution, can be a model for small islands, improve living standards, and support Indonesia's goal of 23% green energy by 2030 while reducing plastic waste.

Keywords:- *Pyrolysis, Sustainable Energy, LDPE usage, Palembang*

I. INTRODUCTION

As the largest archipelago in the world, composed of nearly 18,000 islands, Indonesia hosts a population close to 280 million people, including an expanding middle class, which collectively creates a substantial need for energy, particularly electricity [1-3]. The sole provider of the nation's electric power, the Indonesian State Electric Company (PLN), predicts that by 2050, the demand for electricity will escalate to 430 GW [4,5]. Given that almost 80% of the current power is generated from non-renewable sources, Indonesia faces a considerable challenge: how to boost renewable energy's contribution to 23% by 2030 to achieve regional emissions reduction targets [4].

These challenges are further compounded by Indonesia's geography. As the largest archipelagic country in the world with a significant population spread over thousands of islands, electrification is still a problem in this country. People who already have access to electricity also often face reliability problems. According to Tempo, 60 villages in South Sumatra do not have access to electricity. In response to this, PLN, as the only national electricity provider, seeks to increase the electrification ratio and supply electrical energy to remote areas. However, in 2020, there are still 433 villages in Indonesia. The eastern part is not yet electrified, with anelectrification ratio of 40% [5]. The government continues to boost the construction of 35,000 MW power plants to improve the quality of electricity access throughout Indonesia later [6]. The local government plans to supply electricity to the village by building a Solar Power Plant next year. However, in the 60 villages electrification project, the Governor of South Sumatra, Herman Deru, said there were regulatory obstacles. This is because part of the village area is in a protected forest [7]. This solar power plant itself requires a very large area of 20,000 m2 for an installed capacity of 1 MW of solar power. Alternative energy is needed to obtain social justice in South Sumatra, especially in Palembang.

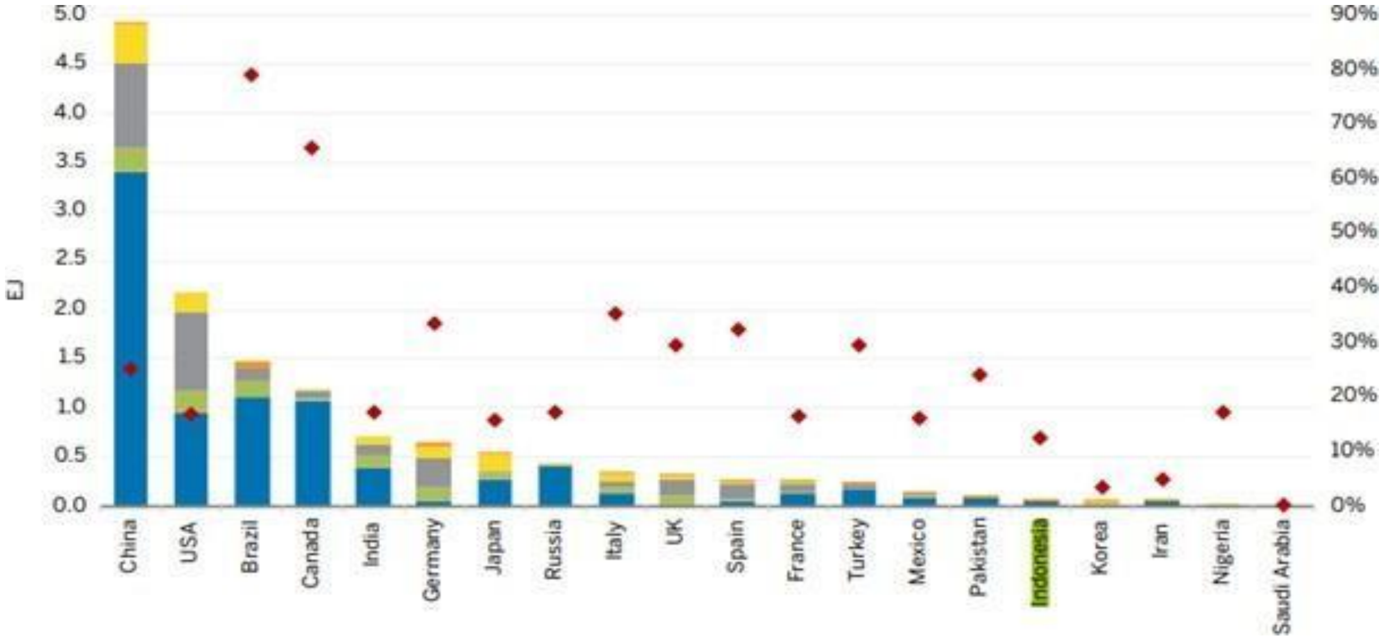

Fig 1 Global use of Renewable Energy

Besides alternative energy problem, the abundance of waste has become one of the biggest environmental problems currently faced by Indonesia. Palembang, South Sumatra, is one of the places that have problems with waste management. In 2021, waste in the Palembang area is recorded at 1,200 tonsper day where the producers of waste are in Ilir Barat 1 and IlirTimur Districts. According to the Palembang City Environmentand Hygiene Service, waste is dominated by plastic. Along with the increasing population of Palembang every year, the volume of waste also has the potential to continue increasing. The President of Indonesia saw these two main problems in Palembang and issued a Presidential Regulation Number 35 of 2018 concerning the Acceleration of Development of Environmentally Friendly Technology-Based Electrical Installations and considering that the city of Palembang isincluded in 12 cities that will implement the Presidential Regulation. Pyrolysis is here to answer these problems. The process of pyrolysis (or devolatilization) is the thermal decomposition of materials at high temperatures in an inert atmosphere. This involves changing the chemical composition. The word was coined from elements derived from the Greek pyro "fire" and lysis "to separate". Pyrolysis requires plastic waste to be burned and produces a liquid that can start a dieselengine. That can make an electric generator that uses diesel fuel ignite. Pyroenergy Pyrolysis itself can help people to have a better life because it makes the environment clean and produces valuable resources that can be used for multiple purposes.

In this paper, the proposed design of the Pyrolysis Machine as a waste-to-energy conversion system will be thoroughly analyzed by performing simulation, peer-review of reputable publication, and cost analysis. This paper also proposed furtherresearch areas and further development into reliable electricitygeneration from plastic wastes that could eventually help solve environmental problems in Indonesia and encourage Indonesiato move away from non-renewable electricity sources.

II. DEFINITION OF PROBLEM

This paper primarily explores three focal points. Firstly, it scrutinizes the development of enhanced waste management systems capable of energy recovery. Secondly, it investigates the proliferation of green electricity in smaller communities, particularly in Palembang, South Sumatra, under the purview of Presidential Regulation Number 35 of 2018. Finally, the paper assesses the practicality, affordability, and supply chain integration of pyrolysis machines, instruments capable of converting waste into energy, within these small communities.

III. SOLUTION OFFERED

A pyrolysis machine is a machine that will degrade plastic waste through a heating process that will turn into an oilproduct which can be utilized for multiple purposes. The design of the Pyrolysis Machine is presented in the figure below.

Fig 2 Illustration of Pyroenergy Pyrolysis Machine

Pyrolysis is chosen because of the bad plastic waste management in Palembang as stated above. Eco-friendly and financially improved, Pyrolysis is the viable method and technique for the treatment of plastic issues nowadays. In this paper, focusing on utilizing Low-Density Polyethylene (LDPE) plastic as the source because it is one that contributes the most to environmental pollution. The consideration of using LDPE is explained in the following table.

Table 1 LDPE Properties and Characteristics

	LDPE	**PP**	**PVC**
Proximate analysis (wt %)			
Moisture	0.1 ± 0.01	0.2 ± 0.07	0.1 ± 0.07
Volatile matter	99.9 ± 0.02	99.7 ± 0.24	66.6 ± 0.72
Fixed matter	N. D	0.08 ± 0.01	29.0 ± 0.72
Ash	N. D	N. D	4.3 ± 0.47
Ultimate analysis (wt %)			
Carbon	85.2 ± 0.16	85.1 ± 0.06	50.1 ± 0.17
Hydrogen	14.5 ± 0.07	14.5 ± 0.07	6.2 ± 0.01
Oxygen	N. D	N. D	18.3 ± 0.11
Chlorine (ppm)	457 ± 11	684 ± 11	253700 ± 17600
Lower heating value (MJ/kg)	40.3	46.2	20.5
N.D = Not Detected			

The components of the pyrolysis machine are Shredder, Reactor, Furnace, Condenser, and Pump. The specifications of each component are explained in the following section:

- *Shredder*

Waste plastic is first sent into a pretreatment process that removes any foreign matter, then sent into a plastic shredder. Ashredder is used to crush the plastic into smaller pieces to help the combustion process become faster and easier so that the quality of oil products will not be interrupted by impure materials. Shredder is made from aluminum as it is light and not easily rusted. The shredder uses a double rack rotary cutterblade to pulverize the plastic that goes in. Then, it will be integrated with a conveyor belt which connects the shredder and reactor to transfer the plastic into the combustion process.

- *Reactor*

A reactor is a place where plastics are burned by indirect heat from combustion in the furnace. The type of reactor used is a fixed bed reactor as it has a simple design and compact structure that can be applied [9]. The reactor is made from chromium alloy steel to withstand high temperatures and not easily wear. From the calculation based on Megyesy PV Handbook, using several assumptions data as stated in the table below, operating temperature and design pressure are 350 C and 1200 kPa, hence the shell thickness selected is 6.35 mm and head thickness is 8 mm. The inside diameter is 500 mm, and the outside diameter is 513 mm. Due to the lower temperature used, it will need a catalyst to accelerate the reaction and it approximately reaches < 30 mins with a heat rate of 10 C/min.

Table 2 Chromium Alloy Steel Characteristics

Chromoly Steel Properties	
Density	7850 kg/m³
UTS	700 Mpa
Yield strength	500 Mpa
Young modulus elasticity	205 Gpa
Thermal Conductivity	41 W/mK
Heat capacity	477 J/gK

Table 3 Reactor Calculation

Design Specification	
Design pressure	1.200 kPa
Operating pressure	800 kPa
Operating temperature	350 (◦C)
Stress	128.000 kPa
Corrosion allowance	3.125 mm
Inside diameter	500 mm

Joint efficiency	0.9
T selected	6.350 mm
Outside diameter	512.700 mm
Head length	100.000 mm
K factor	1.375
Tr head selected	8 mm

- *Furnace*

Furnace is used as the combustion chamber to generate heat sources to burn the plastic inside the reactor. The furnace is made from ceramic fiber and ceramic brackets as the inner layer to maintain the temperature constantly. Moreover, the characteristic of ceramic fiber which has low thermal conductivity has a high efficiency on trapping the heat inside the furnace [10]. For the outer layer, ASTM 516 gr 70 is chosen because of the greater strength and toughness offered. From the calculation, the thickness of each layer is known, ceramic fiber 1 cm, refractory ceramic 2 cm, steel 2 mm. Therefore, the dimension of outside diameter is 613 mm, and the inside diameter is 553 mm.

- *Condenser*

The condenser is utilized to convert gas vapor into liquid via a process of liquefaction facilitated by water circulating within it. Two condensers are integrated into the design, a preference stemming from their ability to refine and purify the quality of oil produced from the liquefaction process. The construction of the condensers from stainless steel provides resistance against corrosion.

Through the first condenser, heavy oil is produced. This heavy oil is then converted into light oil by the second condenser, which holds the potential for use in running generators for electricity generation. The gas residue from the final condenser is cycled back into the furnace, serving as an additional heat source, and thereby minimizing future fuelusage.

- *Pump*

The type of pump used in this design is condenser water pump. This pump is used to circulate condensed water from the water tank into the condenser to liquify the gas vapor into oil. It will pump the water from the top branch of the condenser and circulate below and back to the tank. The specification that will be used is using the 60 W approximately (low power). To reduce the vibration to the main part, the pump is mounted to a steel frame that will be connected by 1 in the pipe.

IV. FEASIBILITY STUDY

- *Sustainability Potential*

Pyrolysis represents a thermochemical decomposition method of substances such as plastic waste at elevated temperatures in an oxygen-free environment [9]. Predominantly, a wide range of plastic types can serve as feed materials. However, the focus is on Low-Density Polyethylene (LDPE), the escalating disposal of used consumer plastics due to increased consumption alongside industrial development [11]. Consequently, LDPE is a prominent contributor to waste in Palembang area.

Decomposition of LDPE is relatively straightforward, regardless of whether catalysis is used or not. The production of pyro oil can occur at relatively lower temperatures, around 400°C [11]. The operation of the Pyrolysis machine developed is depicted in the subsequent figure. Upon the shredding of plastic by the shredder, a conveyor transfers it to the reactor. A furnace enveloping the reactor ignites a heat source derived from organic waste and gas fuel to warm the reactor shell. Subsequently, the plastic transforms into gas vapor and is directed to the catalyzing chamber to expedite the process and enhance the bio-oil structure. the oil yield from LDPE can approach nearly 80% of the total mass, a value that is anticipated to increase further catalysis.

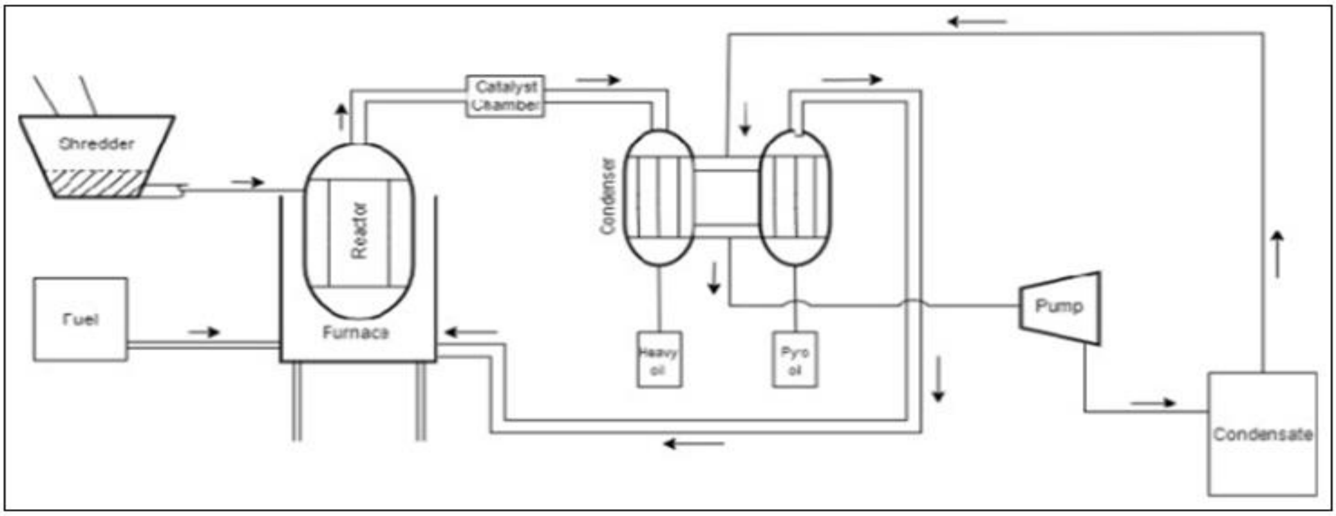

Fig 3 The Process of Pyrolysis Oil Production

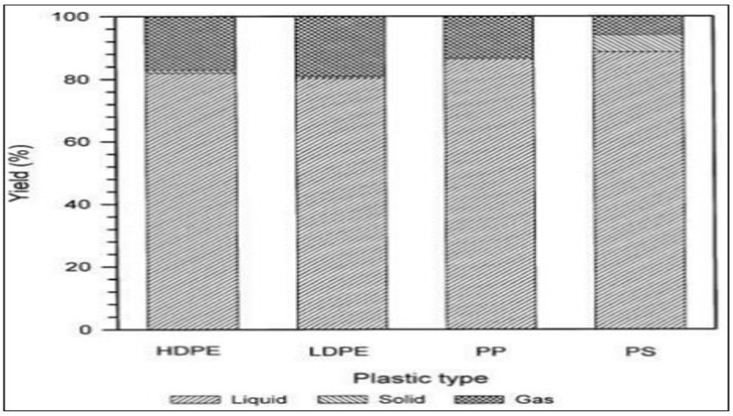

Fig 4 Yield Percentage of Plastic Type

Pyrolysis is a promising innovation to solve the problems of current low recycling rates. Assuming that the machine is assumed will work 24 hours daily, it can reduce 14.4 tons of plastic daily through several points in Palembang with 60 machines operating and will continue increasing every year by adding more machines. It may not be significant to reduce all the plastic waste, but with this strategy to continue improving the system and adding more machines each year, it will continue progressing to create a plastic-free environment.

The consideration of material and dimension was planned maturely as stated in the earlier section. The dimensions of each part are defined by calculation based on Megyesy Pressure Vessel Handbook. The heat transfer between furnace and reactor is calculated through composite wall equality calculation. The furnace's temperature is obtained from the calculation below, but there will be tolerances and factors that make the operating temperature supposed to be higher than that.

$$q\ reactor = q\ furnace$$

$$kr * A1 * \Delta T1/L1 = kf * A2 * \Delta T2/L2$$

$$41 * (51{,}3^2 - 50^2) * (Tf - 623)/100 = 5 * (61{,}3^2 - 55{,}3^2) * (303 - Tf)/60 \quad Tf = 425\ ^\circ C$$

- *Supply Chain Feasibility*

There exists a considerable amount of untapped energy potential in Palembang, stemming from areas that generate plastic waste, including markets in Pasundan, Sultan Syahrir, and Pulau Layang. Utilizing remote sensing and ArcGIS software, supply chains can be integrated starting from the producer, distribution to the waste destination such as landfills, and proceeding to pyrolysis oil production points. The map reveals the communal wastes, landfills, and vacant spaces in Palembang that could potentially house pyrolysis production points. In determining the most suitable location for the pyrolysis production point, factors such as the distance from the neighboring environment and the proximity to TPA or communal trash are taken into consideration.

Given the aforementioned factors, three potential areas have been identified for the construction of a pyrolysis production point. The first is in the northern area of Palembang, near the Sukawinatan landfill. The second is situated in the southern region, near the Karyajaya landfill. The final location is in the vicinity of communal waste points, which include Pasundan Kalidoni, Sultan Syahrir, and Pulau Layang. The strategic placement of these locations will foster a more efficient and economically viable supply chain forpyrolysis production.

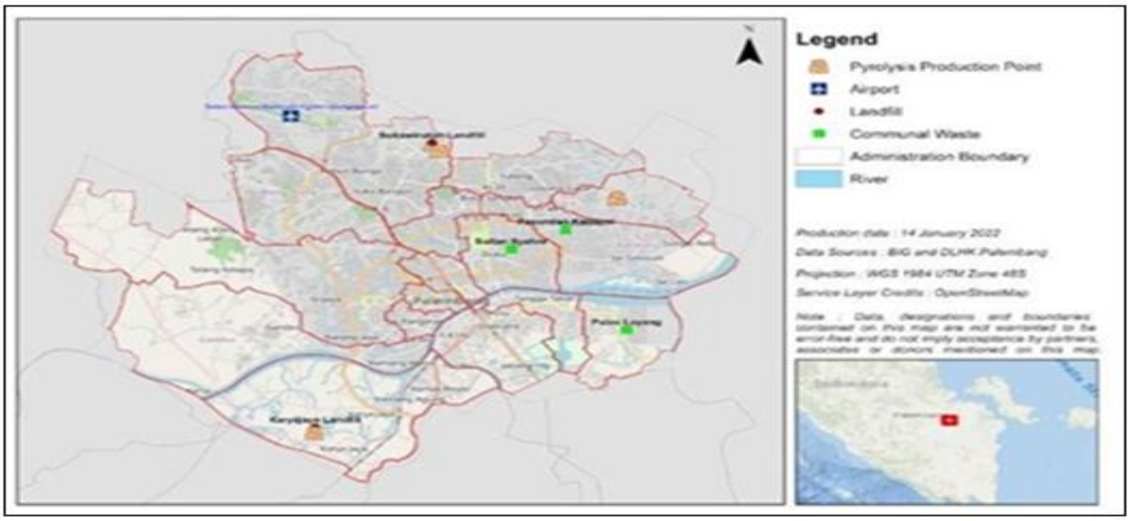

Fig 5 Pyrolysis Production Points Mapping [12]

➢ *Enviromental Impact*

The burgeoning issue of plastic waste accumulation in Palembang has been a source of various problems. Notably, in December 2021, floods struck Palembang as a result of the drainage system being blocked by plastic waste, a disaster that has recurrently been experienced over the past year due to the escalating waste problem [13]. The piling up of plastic waste not only contaminates the environment but also nurtures conditions detrimental to health. An advantageous solution to these issues can be found in Pyroenergy Pyrolysis machines, which convert waste plastics into energy in the form of plastic oil, thereby enhancing waste management. With plastic waste pyrolysis, a significant reduction in the amount of waste deposited into landfills and oceans can be achieved, turning this plastic waste into useful resources. By lowering the volume of plastic waste, this advanced recycling system can mitigate flooding risks and aid in the establishment of a healthier environment.

Additionally, the heavy reliance on fossil fuels has brought about devastating repercussions. From the stages of mining or drilling to transportation, electricity generation, and eventual product disposal, numerous toxic pollutants are unleashed intothe environment. Air quality deterioration due to fossil fuel mining or drilling, land degradation, water contamination and siltation, habitat damage for flora and fauna, noise, and vibration are among the major problems tied to fossil fuel mining and drilling activities. The oil extraction process from the ground alone significantly contributes to global warming, accounting for approximately 1.7 gigatons of carbon dioxide. Plastic oil produced by pyrolysis can serve as an alternative energy source, potentially diminishing the dependence on fossil fuels, consequently leading to reduced greenhouse gas emission rates and lessened environmental damage risk. The pyrolysis technique can lower greenhouse gas emissions by upto 14%, water usage by 58%, and energy derived from fossil fuels by 96% [14].

The proposed initiation of the project with 60 machines working round the clock would facilitate the reduction of up to 14.4 tons of plastic and the production of 4,320 liters of pyro oil daily. Given its ability to improve waste management and provide a more sustainable energy source, the optimism surrounding the continual improvement of the Pyroenergy Pyrolysis complex is palpable. Accordingly, the addition of 10 more pyrolysis machines each year by the government will likely lead to even greater waste reduction and a larger production of pyro oil.

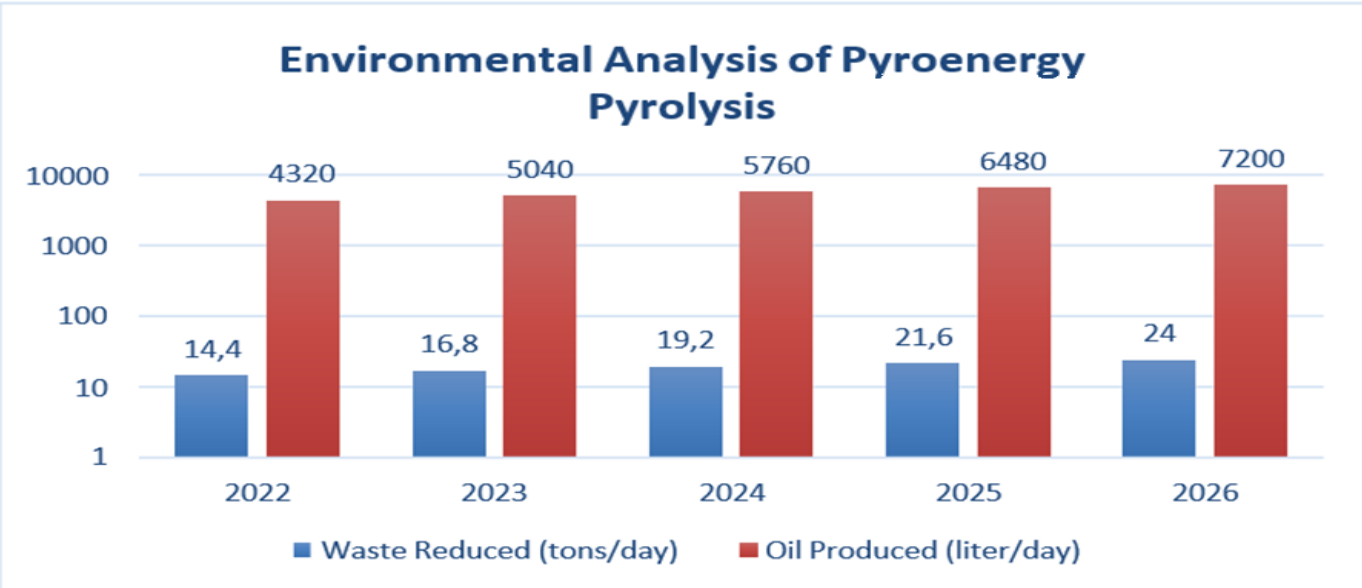

Fig 6 Waste Reduced, and Oil Produced by Pyroenergy Pyrolysis

V. CONCLUSION

It has been demonstrated that the Pyroenergy Pyrolysis system possesses the capacity to address significant challenges in Palembang, specifically by implementing an improved waste management approach and delivering dependable, consistent, and environmentally friendly energy to enhance thequality of life for communities in Palembang, South Sumatra. In a span of merely 30 minutes, the Pyroenergy Pyrolysis machinery can transform 5 kilograms of Low-Density Polyethylene (LDPE) plastic waste into 1.5 liters of plastic oil,provided the inclusion of a shredder, heat controller, and two condensers to produce pyro oil of superior quality.

Furthermore, an increase in efficiency and environmental sustainability is presented by the Pyroenergy Pyrolysis machine, as the ash and gas emissions are recycled within the production process. By harnessing plastic waste from landfills, a significant reduction in plastic waste can be achieved through Pyroenergy Pyrolysis, leading to an environment that is healthier, cleaner, and free of plastic. In addition, the provision of an eco-friendly energy source that enhances the standard of living is also facilitated by the system.

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