Energy recovery strategies as a sustainable solutions for municipal solid waste in Egypt

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Abstract. Plastic is highly durable, strong, elastic, and less expensive to produce, and widely used globally. The result of excessive use causes a high accumulation of plastic waste for communities in developing countries like Egypt. Egypt is one of the largest countries in population in Africa and the middle east. According to Environments Affairs Agency (EEAA), Egypt produces over 22 million tons of municipal waste per year, and waste plastic represents 13% of the total waste. Therefore, plastic recycling is critical in our life. But mechanical recycling is unable to recycle all plastic, as it is an expansive and challenging process. It exhibits a series of degenerated properties like lowering the impact resistance characterizers of polymers. The second recycling process is chemical methods and thermochemical recycling. Thermochemical degradation has a promising substitutional for recycling polymers. For example, pyrolysis can deal with high molar mass organic molecules since the plastic owns a calorific value comparable to fuel. Energy Recovery from waste Plastic using the thermal treatment for plastics as incineration, gasification, and pyrolysis represents a suitable process as discussed. So, the fuel production from pyrolysis polymer would be a better and more promising alternative for a country like Egypt.

1. Introduction

The significant increase in the world's population and changing lifestyle and consumption patterns, such as rapid civilization and manufacturing, are causing an increase in the generation and accumulation of municipal solid waste at a rate that exceeds the natural environment's capacity to absorb and manage the wastes—the risk represented in developing countries such as Egypt. Egypt is one of the most populous countries with a population of more than 100 million, which means increased demand for traditional energy sources, resulting in accumulating municipal solid waste, affecting the global environment like the greenhouse effect and global warming. The economic benefits of modernization, industrialization, population growth, and technology transfer have always been attractive to increase municipal solid waste [1]—Egypt one of the most significant waste plastic sources in the Mediterranean and the Middle East. Indeed, According to the Egyptian Environments Affairs Agency (EEAA), Egypt produces over 22 million tons of waste per year. The composition of municipal waste depends mainly on the population's affluence, contributing to the MSW amount. For example, Cairo-capital city-alone leads the highest percentage, with a waste volume of about 6 million tons annually, representing 45% of the total municipal solid waste, according to the Ministry of the Environment[2–5]. The Municipal solid waste composition in Egypt shown in Fig. 1, according to the Egyptian Environmental Affairs Agency 2015 [3]

The problem of municipal solid waste in Egypt is represented in the lack of possibilities. The increase in its quantity annually is expected to increase at a rate of 3.4% per year. The municipal solid waste grows at a high rate because less than 20 percent of this is appropriately disposed of or recycled. This waste is exposed to uncontrolled incinerators, which negatively affects Egypt and can hazard soil, air, and water source, the same for waste. Therefore, it is necessary to find appropriate and economical ways to solve it and be based on
sustainable development. An effort must be made to conserve non-renewable resources to the maximum extent possible.

Figure 1. Typical composition of solid waste in Egypt according to EEAA 2015 [3]

The increase of solid waste accumulations everywhere in Egypt can hazard soil, air, and water source. This increase in the solid waste leads to a negative impression of public health and the environment [5]. Uncontrolled plastic incineration cause emissions, toxic gases, and ash containing lead and cadmium [6]. The treatment and recycling of solid municipal waste in Egypt are estimated at 12%. About 81% of the waste is disposed of in public and random landfills, while 7% is disposed of in safe landfills. This causes more difficulties on the road to reducing GHG emissions and combating climate change regarding the management of the waste MSW resources in Egypt [4]. As shown in Fig. 1.1, plastic represents 13% of solid waste in Egypt, this means there are approximately million of a ton of waste plastic is generated in Egypt every year [3].

As known, plastic has become a big problem due to the difficulty of dealing with its wastes, and what exacerbates the issue even more, is the significant increase in the daily use of plastic. Also, there is an increase in disposable materials (packaging and packing of food), difficult to recycle. So, getting rid of plastic is difficult because of the variety of uses and materials. And this matter becomes more difficult because of mixing many types of plastic, which may cause great difficulty in sorting and recycling the types. Now, about 9% of plastic can be recycled, and the remaining causes many problems for the environment. The rapid growth of Egypt's population led to an increase in the demand for plastic until it became the first in Africa and the Middle East to consume plastic. This increase has turned into a significant challenge for the local authorities responsible for solid waste management. Egypt as a country, produce and use different types of plastic. The percentage of Egypt's consumption of plastics is shown in Fig. 2 [8].

Figure 2. Percentage of Egypt consumption of plastics by polymer type [8]

Plastic recycling includes four categories. The first is mechanical reprocessing, which is the return to a product that has comparable properties, which is called closed-loop recycling. The secondary mechanical recycling is treated mechanically to obtain products with fewer characteristics, and the third is the return to the
essential chemical components, which is known as chemical recycling. The fourth case is energy recovery from plastic waste, which is done through several effective value processes to obtain fuel or energy from plastic waste [9]. In general, it found that mechanical and chemical recycling is uneconomic without significant subsidy due to the lower price of petrochemical feedstocks than recycled materials due to the process costs of producing monomers from waste plastics.

Plastic waste is characterized as one of the useful materials for the production of recycling fuel, energy from it, due to the high combustion temperature and heating value as shown in table 1, and due to the increasing availability in local communities. Methods for converting waste plastic into fuel depend on the types of plastic to be targeted and the other characteristics of the waste used in the process. Besides, efficient conversion requires selecting appropriate technologies according to local economic, environmental, social, and technical aspects.

2. Material and method of recovery energy

**Plastic**

Plastic, or polymer, consists of a high molecular mass chain and often contains many materials such as carbon, hydrogen, oxygen, nitrogen, chlorine, and sulphur. Today's plastics have become an essential ingredient in our life since Alexander Parkes unveiled Parkesine in 1862. Plastics are utilized in our day by day lives in various applications. This is because plastics are versatile and affordable and useful for manufacturers to use from nurseries, mulches, covering and wiring, bundling, films, spreads, packs, and holders. Food waste and paper squander. These materials' peculiarities, which have lightness, manufacturability, low thermal conductivity, and high chemical resistance [6,10].

3. Energy Recovery as recycling methods

The polymer recycling process is divided into three main classes: First, the mechanical recycling (direct) process, but it exhibits a series of degenerated properties like lowering the impact resistance. The second recycling process is chemical methods and thermochemical recycling.

Chemical recycle such as hydrolysis, ammonolysis, and alcoholics can yield a high percentage of the monomer; nevertheless, these processes required a particular separation material, expansive and complex, had harmful series effects of environmental and safety problems, and toxic organic solvents [11,12]. For example, Hydrolysis required critical condition water [13–15].

Fig 3 shows the alternative thermal treatment of waste plastics (incineration, gasification, pyrolysis) technologies and their products. Plastic has a rapid development production and can be considered an alternative energy resource for substituting fossil fuels. So, using these methods able to produce a significant amount of energy. [16].

![Figure 3. Thermal treatments of waste plastics](image-url)
4. Incineration
Incineration as a method to get energy from waste plastic can reduce the CO₂. Plastic is a material derived from petroleum and contains a hydrocarbon material and minimal moisture content, so plastic calorific values are similar to those of LPG, petrol, and diesel as given in Table 1. On the other hand, Direct combustion/ incineration of polymers may be detrimental to the environment. The incinerate polymers/plastics results in residues of noxious substances such as light hydrocarbons, NOx, sulfur oxides, and dioxins. [17–21].

5. Gasification or Partial oxidation
As known as partial oxidation, using oxygen or steam could generate a mixture of hydrocarbons and synthesis gas (CO and H₂) and produce bulk chemicals, such as acetic acid, from polyolefins via oxidation NO, which is also possible. This method had developed to produce high calorific value purified gas. With efficiency, reach 70% in hydrogen production from polymer waste. Co-gasification of biomass with waste plastic showed increased hydrogen produced while the CO content reduced [22].

| Material                  | Calorific value, MJ/kg |
|---------------------------|------------------------|
| Polyethylene              | 46.3                   |
| Polypropylene             | 46.4                   |
| Polystyrene               | 41.4                   |
| Polyvinyl chloride        | 18.0                   |
| Coal                      | 24.3                   |
| Liquefied petroleum gas   | 46.1                   |
| Petrol                    | 44.0                   |
| Kerosene                  | 43.4                   |
| Diesel                    | 43.0                   |
| Heavy fuel oil            | 41.1                   |

6. Pyrolysis
Pyrolysis is known as thermal cracking, which is defined as controlled thermal degradation of materials in the absence of an oxygen environment. The process is to feed material decomposed into char and volatiles, and volatiles gas is condensed to oil. The non-condensable fraction can collect as a high calorific value gas at the reactor's exit [22–25].

In plastics pyrolysis, polymer macromolecular structures are cleaved into smaller molecules, oligomers, or sometimes monomeric units. Subsequent decomposition of these to low molar mass molecules is dependent on several process conditions and the chemistry of depolymerization. These include but are not limited to temperature, heating rate, the sample's residence time, and released volatiles in the reactor, particle size, inherent or added catalysts, reactor type, and feed composition. Generally, plastic polymers reactivity is influenced by the substituent's size in the side chain [9].

In degradation processes, part of the species generated directly from the initial degradation reaction is transformed into secondary products due to inter and intramolecular reactions. The extent and nature of these reactions depend on the reaction temperature and the residence of the products in the reaction zone, which is primarily affected by the reactor design [16,17,22–24,26].

Pyrolysis has many advantages as an emerging technology that can help reduce fossil fuel resource consumption by recycling plastics for fuel and valuable chemical recovery. It is a suitable method to recycle mixed plastic waste, which cannot be effectively recycled by other means, such as mechanical recycling. Also, pyrolysis can process plastic films and multi-layer packaging films that are not recycled using conventional reprocessing techniques. It is characterized by reducing waste and reducing pollutant emissions since the process is carried out without air [9,24,25,27].

7. Conclusion
Plastic is highly durable, strong, elastic, and less expensive to produce, and widely used globally. The result of excessive use causes a high accumulation of plastic waste for communities in developing countries like Egypt. According to Environments Affairs Agency (EEAA), Egypt produces over 22 million tons of municipal waste per year, and waste plastic represents 13% of the total waste. Therefore, plastic recycling is essential in our life. But mechanical recycling is unable to recycle all plastic, as it is an expansive and challenging process. It exhibits a series of degenerated properties like lowering the impact resistance characterizers of polymers. The second recycling process is chemical methods and thermochemical recycling. Thermochemical degradation (pyrolysis) has a promising substitutional for recycling polymers, as pyrolysis can deal with high molar mass organic molecules since the plastic owns a caloric value comparable to fuel. Therefore, Energy Recovery from waste Plastic using the thermal treatment for plastics as incineration, gasification, and pyrolysis represents a suitable process as discussed. So, the fuel production from pyrolysis polymer would be a better and more promising alternative for countries like Egypt.

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