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Circular Economy Advancements in Additive Manufacturing and Polymer Waste Recycling: Reshaping Sustainability

Vijay Krishna Banerjee[1], Pulak Adhikary[2], Uddipan Pahari[3]
[1, 2]Mechanical Department, FIEM
[3]Mechanical Department, Dr. Sudhir Chandra Sur Institute of Technology & Sports Complex

***Abstract:** Additive manufacturing is an exponentially growing sector that utilizes a lesser number of materials to create numerous products with the aid of Computer-Aided Design (CAD). Over the years, the adoption rate of polymer filaments in 3D printing has radically increased due to their user-friendliness and molecular properties. However, there are still different ways in which waste can be generated from 3D printing. This paper explores different aspects of ongoing studies to discuss efficacious solutions for closed-loop recycling systems in Distributed Recycling and Additive Manufacturing (DRAM). Concurrently, it probes for different additives that can reinforce the molecular structure of polymers, promoting repeated recycling. On the contrary, the existing papers have only explored the basic phases of the DRAM process. The implementation of closed-loop recycling can revolutionize the manufacturing sector by reducing overall Bourne costs and labor. Moreover, the proposal of compatibility of the DRAM process with different printing technologies, along with the effective implementation of additives, can provide integral benefits. Furthermore, the comparison of pure filaments and recycled filaments used for AM has helped us analyze the economic feasibility and energy recycling elements deployed for polymer wastes. Hence, the contemplation of the pyrolysis process has pontificated the necessity of various catalysts to increase the gasoline and diesel percentage in polymer waste recycling.*

***Keywords:** Additive Manufacturing, Waste Recycling, DRAM, PLA, ABS*

Abbreviations—

AM	- ADDITIVE MANUFACTURING
3D	- 3 DIMENSIONAL
CAD	- COMPUTER-AIDED DESIGN
DRAM	- DISTRIBUTED RECYCLING AND ADDITIVE MANUFACTURING
FDM	- FUSED DEPOSITION MODELING
SLS	- SELECTIVE LASER SINTERING
SLA	- STEREOLITHOGRAPHY
CFR	- CONTINUOUS FIBER REINFORCEMENT
ABS	- ACRYLONITRILE BUTADIENE STYRENE
PLA	- POLYLACTIC ACID
PET	- POLYETHYLENE TEREPHTHALATE
LDPE	- LOW-DENSITY POLYETHYLENE
PVC	- POLYVINYL CHLORIDE
PP	- POLYPROPYLENE
PS	- POLYSTYRENE
HIPS	- HIGH IMPACT POLYSTYRENE
ZSM-5	- ZEOLITE SOCONY MOBIL-5
FCC	- FLUID CATALYTIC CRACKING
AT	- ACETYLATED TANIN
OG	- GRAPHENE OXIDE
DIOP	-DI-ISO-OCTYL PHTHALATE
DOP	- DIOCTYL PHTHALATE

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PETG - POLYETHYLENE TEREPHTHALATE GLYCOL
HDPE - HIGH-DENSITY POLYETHYLENE

I. INTRODUCTION

A. Problem Statement

Plastic is a versatile material that finds use in numerous industries, such as packaging, automobiles, transportation, building materials, electrical and electronic components, and consumer goods. Due to their short usage and discarding cycles, they are always in high demand. The Manufacture of polymer goods has witnessed a significant rise in 2019, amounting to whopping 359 million tons, as per PEMRG (Plastics Europe Market Research Group). Out of this major amount, 51% is in Asian countries, and Europe accounts for 17% [6]. Current predictions have shown that if the demand for polymer-based products remains high until 2050, it can lead to the production of 26 billion metric tons of plastic waste [3]. In recent years, the swift propagation of additive manufacturing, mainly 3D printing, has transfigured the industry. It has also initiated a critical ecological crisis with the prevalent spawning of polymer waste [1]. The lack of efficient waste management policies and tactics poses an imminent threat to the viability of this innovation-driven technology [4]. Even though polymer waste constitutes about 10% of total waste, at a substantial magnitude, it is too time-consuming for collection, classification, and reuse. This results in the recycling of only about 9% of the polymer waste generated [2].

Acrylonitrile Butadiene Styrene (ABS) is one of the most commonly used materials for 3D printing, along with another very common electronic waste polymer. And these wastes are not usually taken care of by government programs. Hence, these polymer wastes can be recycled using the DRAM method, thus increasing their recyclability and reducing the harm done to the Ecosystem [5]. Extrusion is the process through which Filaments for 3D Printers are drawn by recycling the waste from previous prints or polymer waste from other industries. During the extrusion process, the shear stress, high temperature, and contact with oxygen degenerate the polymer, resulting in changes in its physical properties [6].

B. Aim

The study aims to extensively scrutinize polymer waste production across multiple stages of 3D printing, propose structured waste handling tactics, and incorporate Circular Economy principles. The study seeks to dive deep into the prospects of the metamorphosis of polymer waste across industries or its conversion into Value-added Products. The conclusive goal is to encourage sustainable development along with ecological consciousness and promote resource homogeneity across diverse sectors, thus reshaping 3D Printing in an intricate and environment-friendly way.

C. Objectives

1) To understand different stages of the DRAM process for more efficient waste management in additive manufacturing.
2) To study the effect of repeated recycling on the mechanical properties of the polymer and counter-measures adapted for it.
3) To look for ways to convert polymer waste into value-added goods if recycling is not at all possible.

D. Research Questions

1) How can DRAM principles be productively assimilated into the waste management tactics of 3D Printing?
2) What are the possible additives that can be added to homogenized resources across industries to promote enhancements to their mechanical properties?
3) What are the limitations to keep in mind while adding additives?
4) In cases where further recycling is not possible, what indigenous perspectives can be implemented to transform polymer waste into Value added products?

E. Rationale

The rapid advancement of AM in the mass production of polymer products has been seen in the last decade. The AM materials market is expected to grow at a CAGR of 25.6%. This will increase the global market from $2.5 billion in 2022 to $7.1 billion by 2027 [7]. The mainstream plastic waste is huge as compared to the AM-produced polymer waste (379,000kg). However, as the adoption of 3D printing increases, it is evident that it will become a growing issue for global sustainable development. The lack of an End of life (EOL) processing system in AM has resulted in the rare recycling of polymer waste generated from 3D printing. Thus, circular economy solutions, including DRAM, are essential to facilitate the EOL system in AM manufacturing.

It has been recorded that the extrusion process for recycling the polymer can substantially alter the physical characteristics of polymers, including their molecular weight, viscosity, and breaking strength [6]. Many authors have suggested the utilization of various additives such as Acetylated tannin (AT) and Graphene Oxide (G0) for manufacturing the polymer filaments in 3D printing. These can help increase the molecular weight of recycled polymers.

F. Research Gap

The closed-loop system of DRAM in Additive Manufacturing is still an ongoing research topic. Researchers believe that there is a lack of information regarding the compatibility of DRAM recycling methods with different printing technologies (SLS, FDM, and SLA). Similarly, it has been observed that repeated recycling can damage the molecular structure of polymers, which directly reduces product quality and strength. We have identified that there are a few papers that have discussed the usefulness of different additives (Craft Lignin, CFR, and Maleated Polypropylene) to improve the molecular strength of polymer waste.

G. Significance of the study

The essence of this study is to integrally analyze the types of waste generated during different stages of 3D Printing. Also, to propose an improvised waste management method for noteworthy and cost-effective implementation of resources and diminishing environmental consequences, Furthermore, the study aims to go beyond the domain of traditional waste management systems and incorporate the concepts of the Circular Economy. A good initiative to address the problematic situation of polymer waste is to explore the feasibility of converting the polymer debris from one industry into raw components for another. Moreover, explore the possibilities of introducing additives to the polymer waste, imparting greater mechanical strength to the recycled materials. Also, if salvaging the material is inconceivable, then there are possible methods of transfiguring the waste into value-added goods [3].
The result of the study is to venture into potential attempts to reform the topography of Additive Manufacturing by taking into consideration a multifaceted viewpoint. Also, incorporate the idea of homogenization of resources across various industries to steer towards sustainable development and an ecologically meticulous approach. The study elaborates on the strengthening of polymers, augmented by the incorporation of polymeric matrices with fillers or additives like fibers, carbon, particle flakes, and laminate. This imparts exceptional mechanical properties and remarkable utility to the polymer [9].

II. LITERATURE REVIEW

A. The Concept of 3D Printing

The term 3D printing is also referred to as Digital Fabrication Technologies. The process of making three-dimensional solid objects of desired shape and size from a digital model is known as 3D printing or additive manufacturing [11]. The production of 3D-printed objects takes place in several steps. The 3D model of the desired shape and size of the object is created with the help of computer-aided design (CAD). According to the given design and processing, the 3D model is sliced into thin horizontal layers by using slicing software [13]. The 3D printer starts printing the object from the computerized 3D model according to the given prerequisite; thus, by adding successive layers of 3D material in the form of polymer filament, liquid resin, metal powder, or other materials, the material is deposited, melted, cured, or sintered to create each layer, and these layers need to be cooled or solidified and gradually built up to form the final given cross-section. The removal of the support structure takes place after the completion of the process. A support structure requires to prevent overhangs or complex geometries from collapsing during the process. The computer-aided design software (CAD) is used to design the component, which is later sent out to the 3D printer.

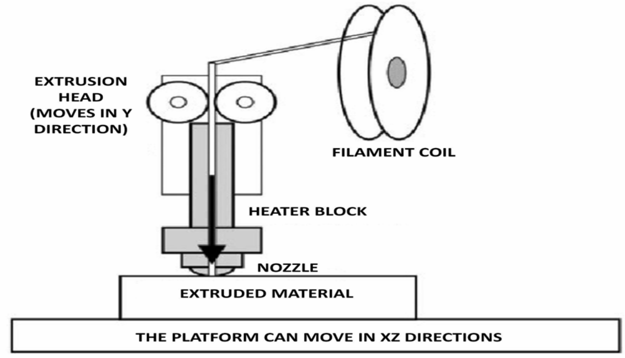

Fig. 1: Working principle of 3D printing

B. Compatibility of the DRAM process with different printing technologies, including FDM, SLS, and SLA

Over the years, the use of High-resolution 3D printers for manufacturing polymer products has increased unprecedentedly. Due to its speed and lower cost characteristics, more businesses are using this technology to produce their desired products. Hence, the need for recycling plastic waste generated in AM is highly essential to reducing environmental impacts. DRAM is an effective process that allows the recycling of different filaments, including ABS (Acrylonitrile Butadiene Styrene), PLA (Polylactic Acid), Nylon, and PETG (Polyethylene Terephthalate Glycol). However, the DRAM (distributed recycling and additive manufacturing) method requires six phases [8].

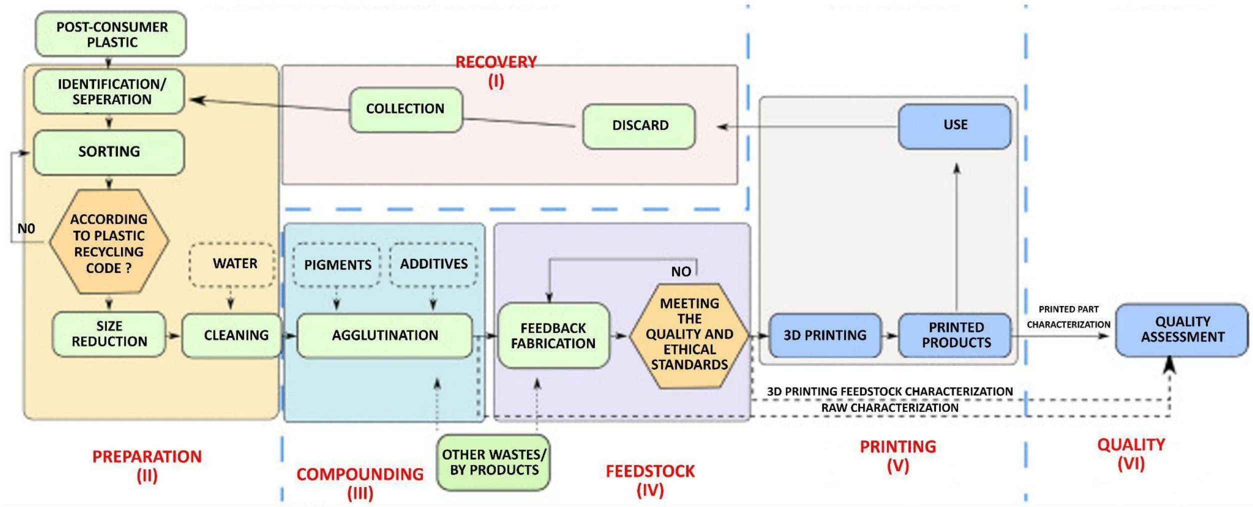

Fig. 2: Closed-loop (DRAM) recycling

In the recovery (1) phase, polymer wastes generated from filaments are collected. Next in the preparation phase (2) identification, sorting, sizing, cleaning, and reduction of polymers are executed to ensure optimum quality of DRAM [8]. In the compounding (3) level, wastes are shredded into smaller microparts, which leads to the feedstock (4) and printing (5) stages, where the composite material is melted and extruded to create filaments for 3D printers. This closed-loop process is a brand-new technology that can help mitigate the environmental impacts caused by polymers in AM [9] DRAM recycling can also be used in FDM, as it helps reduce the requirement for virgin materials. Many authors have suggested the DRAM process as a cost-effective technique to produce high-quality filaments for Fusion deposition modeling printers that use melting and extruding to create prototyping parts. However, the compatibility of DRAM with SLS is an ongoing study that has the power to revolutionize the polymer waste recycling industry [10]. Nonetheless, the compatibility of DRAM is highest with stereolithography, as the closed-loop system easily works with the process called photopolymerization.

C. Adverse effects of repeated recycling on polymers

Recycling polymer waste is a necessity to reduce adverse environmental impacts, but repeated recycling can lead to a major problem of brittleness and shrinkage in the products [6]. Due to repeated closed-loop recycling of polymers, the tensile strength, torsional strength, and shear strength of the material keep degrading with each consecutive recycle. Studies have shown that even commonly used filaments like ABS, PLA, Nylon, and PET in 3D printing can exhibit lower thermal stability. As the polymer chain gets broken down during the recycling process, it makes it highly susceptible to stress.

D. Counter-measures adapted

Due to the continuous recycling of the polymer waste, the mechanical properties of the printed part are drastically reduced. And to maintain repeated recycling and attain a circular economy, mechanical properties such as tensile strength, yield strength, and flexural strength are imparted with the help of additives [14]. These Additives are a type of agent that reinforces the mechanical properties that suffer due to closed-loop recycling.

A frequently utilized material in Additive Manufacturing is Polylactide acids (PLA), which are made up of lactic acid monomers and are easily recyclable [12]. Various additives, such as silica-sand are amalgamated with PLA to enhance its mechanical properties to withstand closed-loop recycling and also solve the problem of environmental pollution.

The combination of PLA and silica mixtures resulted in a considerable increase in tensile strength to 121.03 MPa (10 wt.%) [13]. Whereas lignin as an additive is economical and a biodegradability enhancer, it reduces the adverse environmental impacts of 3D printing and promotes the circular economy.

E. Value Added Goods

After going through the recycling and administration of additives, the polymer becomes incapable of further recycling and will not yield the desired efficiency and structural firmness. At this stage, the conversion of polymer waste into value-added goods is an ergonomic as well as an economic concept [15]. Products such as toys, decorative showpieces, jewelry, garments, and more can be mediums to utilize these polymers [3]. Through this process, a considerable amount of revenue can be generated, which can aid in further enhancement in the field and also lead to the recovery of the material's value.

F. Energy Recycling

Pyrolysis, also known as thermal cracking, is a procedure that requires the absence of oxygen and high temperatures > 400 °C. This process can also be divided into three elements, such as flash, fast, and slow pyrolysis. Generally, slow pyrolysis requires less temperature than the other two. The procurement of pyrolysis oil from low and fast categories is a great source of diesel and gasoline [21]. However, the utilization of catalysts is required in the slow pyrolysis process that helps in the isomerization and cracking of wastes. For example, Zeolite-Y and ZSM-5 catalysts are used to promote the development of branched hydrocarbons and aromatics. In addition, these can greatly improve the proportion of gaseous hydrocarbons in the conversion of Polyethylene and High-density polyethylene [25].

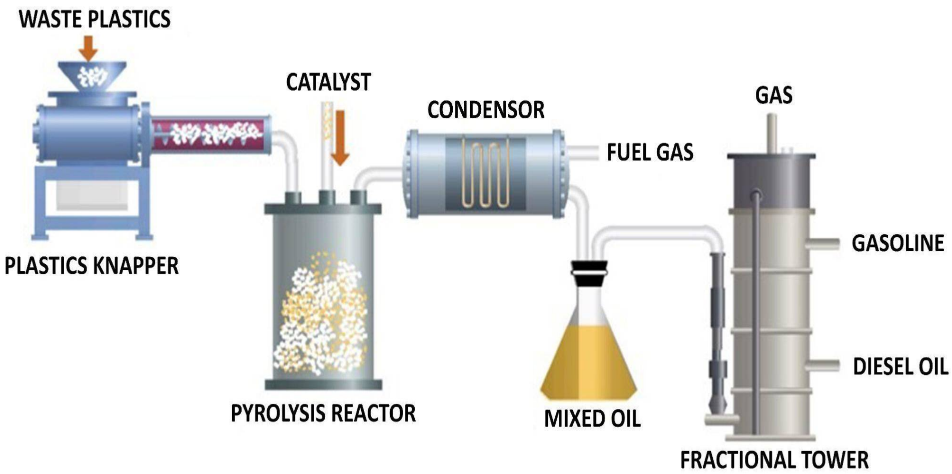

Fig. 3: Pyrolysis of non-recyclable polymer wastes [27]

At the End of Life, energy from polymers (excluding PET and PVC) can be recovered from the polymers through the process of pyrolysis [16]. After pyrolysis, products such as oils, gasses, and Tar are obtained, which can be further utilized for various purposes. Industries such as Automotive, Agriculture, and Power generation can utilize oils obtained after pyrolysis as an alternative fuel [17]. Furthermore, the production of carbon-based solar power can be approached on a large scale by converting polymer waste into carbon-based materials with well-controlled porous structures [18].

III. LITERATURE GAP

The Literature review has provided pivotal knowledge and information about the various prospects of polymer waste management in the context of additive manufacturing, i.e., 3D printing. Also, the review focuses on the importance of closed-loop recycling and the circular economy in addressing the burgeoning global polymer waste issue. However, after an extensive review of numerous journals, it was observed that there are very few journals that comprehensively address the affinity of the DRAM process with different printing technologies. Also, the opportunities, challenges, and interactions of recycled filaments with 3D printers. Furthermore, there have been journal articles stating the potential of using additives to facilitate closed-loop recycling, but there is a lack of extensively detailed analysis of a particular additive on various polymer matrices.

IV. METHODOLOGY

The researchers have used *the interpretivism philosophy* to collect secondary data from different international journals. A mixed research approach (qualitative and quantitative) has been taken for this particular paper to build up casual relationships between different variables of waste management in AM. This has helped the researchers generalize the findings to a specific extent.

At the same time, the researchers have used an *exploratory research design* for the current study, which has enabled them to investigate the research questions by analyzing different theories. The exploratory design is cheaper and provides flexibility and adaptability to change the outcomes. Similarly, for secondary data collection, *Boolean techniques* have also been used, which has resulted in the discovery of the latest information related to waste management in AM. Lastly, for sampling techniques, *inclusion and exclusion criteria* have been utilized to find out precise information based on DRAM and innovative waste management processes in 3D printing.

V. RESULTS AND DISCUSSION

By analyzing the qualitative and quantitative data, we have discovered that the ongoing research on DRAM can be beneficial to creating a circular economy, which leads to sustainability. The feasibility and efficiency of the process are compatible with small- and large-scale manufacturing facilities.

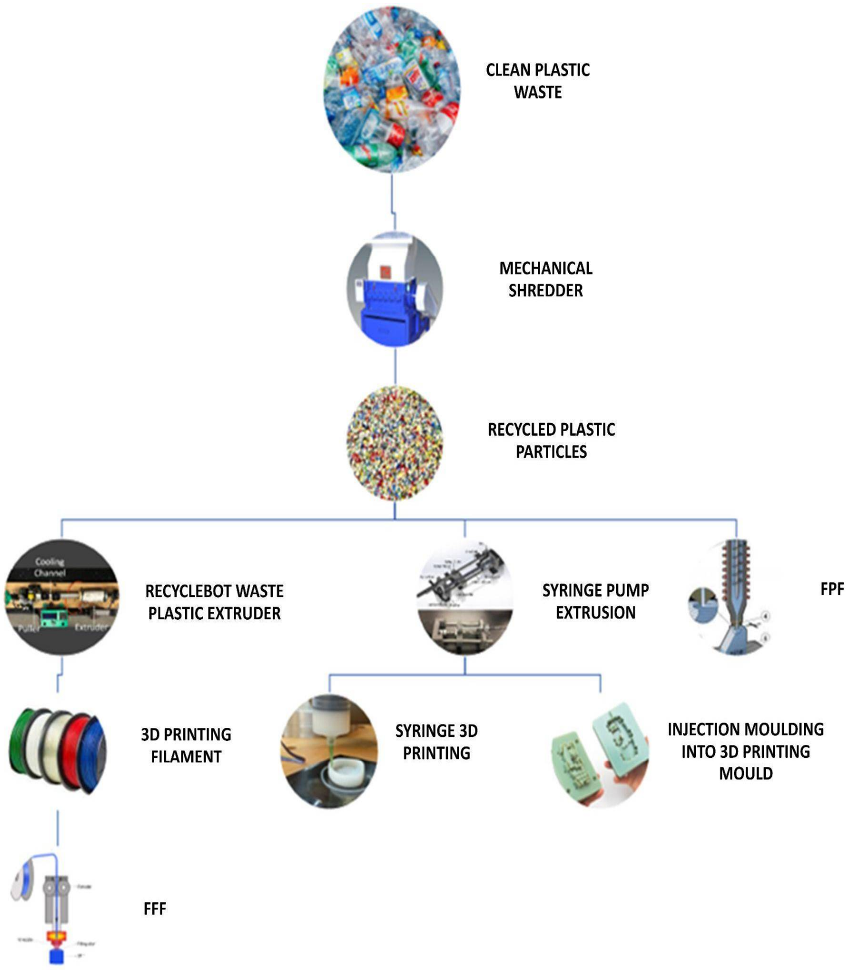

Fig. 4: Block diagram of advanced DRAM process

The above figure illustrates the usability of the DRAM process, as it is a very cost-effective process. This type of technology can help reduce the need for transportation and storage facilities for plastic waste [17]. The 3D-printed parts from DRAM can be of high quality, but their overall standard depends upon the type of polymer waste used.

Table 1: *A Price list for pure thermoplastic filaments* [24]

Material	PLA	PEI	PEEK	ABS	HIPS	PC	Nylon
Price/Kg	$15-25	$140-220	$400-700	$17-25	$20-60	$30-70	$30-70

The foremost reason for recycling waste polymers into filaments for 3D printing is the exorbitant cost of pure thermoplastic filament [24]. If considering the recycling cost in contrast to the cost of pure thermoplastic filaments, a considerable amount of difference in pricing can be observed. Although recycling leads to a lessening of the mechanical strength of the drawn filament, that is an issue that is easily overcome by introducing additives to the polymer.

During a study, it was found that the energy consumption ratio between in-house processed filaments and commercially produced filaments is about 2.5 MJ/Kg: 79.67 MJ/Kg (embodied energy). This indicates that self-processed filaments for 3D printing are approximately 80% more economical as compared to commercial production [25]. In addition to that, it can be observed that the cost per kg of the recycled filaments was reduced to $1/Kg in contrast to more than $20/Kg for commercially recycled filaments [26].

Table 2: Economical aspects of using recycled materials

Printed Parts	Cost using Virgin materials	Cost of using recycled materials
	$9.25	$0.03

However, the pyrolysis process to recycle non-biodegradable material can produce emissions that have negative environmental impacts. On the contrary, the energy consumption rate is high in the DRAM process, but this challenge can be minimized using renewable sources such as solar and wind energy [19]. The utilization of the DRAM cycle in Additive manufacturing can help exponentially increase the weight percentage of recycled and reused polymers.

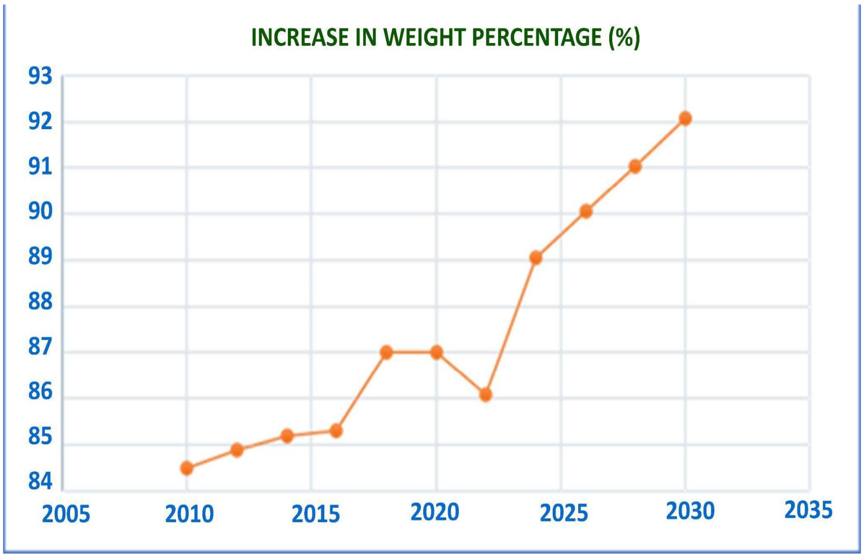

Fig. 5: Weight percentage increase of recycled and reused polymers

The exponential growth of recycling can only be achieved by applying different policies in the global market. To illustrate, developing standardized material standards in AM can help simplify the DRAM cycle. The utilization of pyrolysis in a more efficient way is necessary for the mitigation of energy consumption rates [30]. The development of the recycled filament market is also essential, which can only be achieved by working collaboratively with end users and manufacturers such as RePLAy 3D, GreenGate 3D, and Filamentive. Lastly, an adaptation of the closed-loop system and raising awareness and education can remarkably help the polymer recycling industry make substantial growth in AM.

Table 3: Degradation and printing temperatures for commercial PLA, nylon, ABS, and PET

Filaments	Degradation Temperature	Printing Temperature
PLA	300-400 °C	200–235 °C
Nylon	390–450 °C	240–280 °C
PET	350–480 °C	160–210 °C
ABS	380–430 °C	230–250 °C

The above table has demonstrated the degradation of temperature for different filaments in the 3D printing process. The repeated recycling of PLA can also decrease its thermal properties significantly, as illustrated in the table below:

Table 4: The effect of closed-loop recycling on the variation of PLA thermal properties

Property	After 1st recycling	After 2nd recycling	Virgin PLA
Tc (°C)	104.34	98.32	123.69
Tg (°C)	59.47	59.11	59.86
Tm (°C)	168.39	167.55	165.64

where, Tc = Crystallization temperature, Tg = Glass transition temperature, and Tm = Melting temperature. The molecular weight reduction due to recycling directly reduces the Tc, which makes the PLA filaments more brittle and stiffer [23].

Table 5: Classification of Additives [22]

Sl. No.	Additive type	Additives
01	Reinforcers	Glass fiber, Carbon, Silica-sand
02	Elastomers	Thermoplastic rubber
03	Flame Retardants	Silicon, and phosphorus-based compounds
04	Plasticizers	Dioctyl phthalate (DOP), Di-iso-octyl phthalate (DIOP)
05	Softeners and Extenders	Hydrocarbon oils are "Liquid fillers."
06	Anti-Aging Additives	Thioesters, Phosphite
07	Lubricants	Stearic Acid, Glyceryl Monostearate, and Graphite
08	Colorants	Dyes and Pigments
09	Cross-Linking Additives	Sulfur and peroxides
10	Pure Material	Pure Thermoplastics

The addition of additives imparts strength to the polymer, which makes it able to withstand torsional and shear stress, thus decreasing the breaking probability of the printed parts. As shown above, there are numerous additives used as per the requirements or usage of printed products. Also, the additives are used depending on the placement as well as the working conditions of the part to be manufactured. The usage of additives is not limited to only recycled polymer filaments, it can also be implemented for pure thermoplastics like PLA, HDPE, PET, Nylon, and PE.

Table 6: Successful projects using post-consumer waste [20]

Company	Recycled Polymers (Raw Materials)	Final Product
Audi	Polypropylene, polyurethane, and PVC	Manufacturing tools and Bumper
Ecoalf	Polyvinyl chloride, Polyurethane	Interior Architecture
Philips Lighting	glycidyl methacrylate	Customized Lamp
Tetra Pak and Aectual	75% cardboard and 25% polymer-aluminum mix or	Furniture

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	“PolyAl”	
Azure Printed Homes	Recycled shredded water bottles	Backyard Homes
The New Raw	Recycled fish nets	Chairs
Adidas	Gillnets and polyester	Shoe’s upper part and Midsole

After repeated closed-loop recycling of polymer wastes, eventually, the mechanical strength is reduced to a great extent. At this point, further recycling will not yield any fruitful results that can justify the economic expenditure on the same. So, instead of sending the waste for energy recycling, various value-added goods, such as jewelry and decorative items, facilitate the generation of revenue. Industries such as clothing, jewelry, decoration, polymer tiles, household commodities, furniture, and electrical appliances may very well utilize this unrecyclable plastic waste instead of pure thermoplastic polymers [20]. As a result, this will not only reduce the use of virgin plastics but also generate revenue. Furthermore, this will also reduce the overall waste polluting the environment.

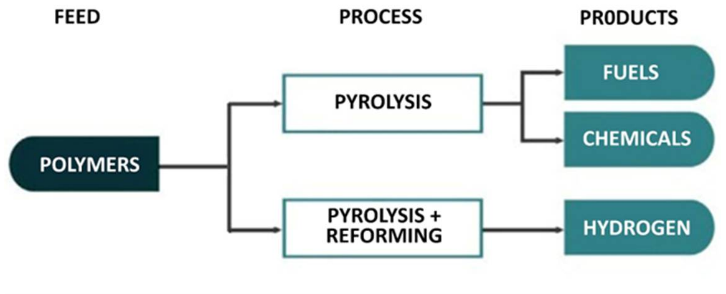

Fig. 6: Polymer Pyrolysis

At the end of the life of plastic waste, it can be further utilized by energy conversion methods. Products such as Oils, tar, and gasses can be obtained from the energy conversion process, thus maximizing the utility of polymer wastes. As shown above, in Fig. 6, a combination of pyrolysis with the reforming process yields Hydrogen.

Table 7: Slow pyrolysis for energy conversion of different plastics [21]

Type of Plastic	Temp (°C), Cat.	Catalyst Ratio	Solid residue yield (wt.%)	Liquid/wax yield (wt.%)	Gas yield (wt.%)	Diesel (C13-C20) (wt.%)	Gasoline (C6-C12) (wt.%)	Monomer recovery (wt.%)	Wax (C20+) (wt.%)
HDPE	450-ZSM	20	2	35	63	0	35	-	0
LDPE [31]	450-None	10	10	74	16	39	34	7	1
PET	550-None	-	2	90	9	37	42	3	11
HDPE	450-MCM	34	15	78	6	60	15	22	25

Table (7) indicates that the influence of catalysts and temperature plays a prominent role in the pyrolysis process [29]. The weaker acid and large pore dimensions of the MCM catalyst significantly contribute to its low impact on the gas generation and the production of gasoline by converting HDPE. It can also be observed that PET in slow pyrolysis produces the highest weight percentage of gasoline compared to other types of plastics.

Table 8: Fast pyrolysis for energy conversion of different plastics [32]

Type of Plastic	Temp (°C)	Solid residue yield (wt.%)	Liquid/wax yield (wt.%)	Gas yield (wt.%)	Diesel (C13-C20) (wt.%)	Gasoline (C6-C12) (wt.%)	Monomer recovery (wt.%)	Wax (C20+) (wt.%)
PVC	740	49	28	15	-	-	-	-
PE	728	2	38	59	-	36	34	-
HDPE [32]	700	-	60	40	17	32	37	11
PP	746	4	29	65	-	29	17	-

This table stipulates that almost 95% of plastic can be converted into liquid or wax products through fast pyrolysis. HDPE produces more liquid or wax as compared to other polymers. Fast pyrolysis offers a higher wax weight percentage (C20+) in comparison with slow pyrolysis processes. Furthermore, a fast pyrolysis process leads to shorter vapor residence times and comparably reduced cracking reactions. The wax produced can be used as a feedstock in fluid catalytic cracking (FCC) units for the production of valuable petrochemical compounds and transport fuels.

VI. CONCLUSION

In Conclusion, this review paper probes into the elaborate relationship between the proliferation of plastic waste worldwide and the procedure of recycling this waste as feed for 3D printers. It illustrates the methodology and role of the DRAM process in maintaining a circular economy. The study also emphasizes the imminent need for ingenious waste-handling tactics to curb the estimated projection of 26 billion metric tons of polymer waste by 2050. During the study, it was observed that Distributed Recycling and Additive Manufacturing (DRAM) appears to be a key contender, exhibiting a closed-loop process, deftly recycling polymer waste, and reducing too much dependency on virgin polymers. However, repeated reuse of plastic waste compromises the mechanical properties, causing anomalies like brittleness and strength reduction. To mitigate this problem, the addition of additives such as silica-sand, lignin, and graphene oxide has shown promise in enhancing strength, life expectancy, and usability. Furthermore, this study introduces the notion of converting non-recyclable waste materials into value-added goods and processing End-of-life wastes for energy recovery through pyrolysis. In totality, this review not only elucidates the crucial problems of the exponential increment of polymer waste worldwide but also how to utilize 3D printing technology to tackle these problems. The amalgamation of waste handling, recycling, additive manufacturing, value addition, and energy recycling of polymer wastes is assured to exemplify the inclination towards a sustainable future in 3D printing.

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