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Hardware Article

RepRapable Recyclebot: Open source 3-D printable extruder for converting plastic to 3-D printing filament

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ABSTRACT

In order to assist researchers explore the full potential of distributed recycling of post-consumer polymer waste, this article describes a recyclebot, which is a waste plastic extruder capable of making commercial quality 3-D printing filament. The device design takes advantage of both the open source hardware methodology and the paradigm developed by the open source self-replicating rapid prototyper (RepRap) 3-D printer community. Specifically, this paper describes the design, fabrication and operation of a RepRapable Recyclebot, which refers to the Recyclebot's ability to provide the filament needed to largely replicate the parts for the Recyclebot on any type of RepRap 3-D printer. The device costs less than $700 in mate rials and can be fabricated in about 24 h. Filament is produced at 0.4 kg/h using 0.24 kWh/kg with a diameter ±4.6%. Thus, filament can be manufactured from commercial pellets for <22% of commercial filament costs. In addition, it can fabricate recycled waste plastic into filament for 2.5 cents/kg, which is <1000X commercial filament costs. The system can fabricate filament from polymers with extrusion temperatures <250 °C and is thus capable of manufacturing custom filament over a wide range of thermopolymers and composites for material science studies of new materials and recyclability studies, as well as research on novel applications of fused filament based 3-D printing.

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Specifications table

Hardware name	*RepRapable Recyclebot*
Subject area	• Engineering and Material Science • Educational Tools and Open Source Alternatives to Existing Infrastructure
Hardware type	• Mechanical engineering and materials science
Open Source License	*GNU General Public License v. 3*
Cost of Hardware	*$671*
Source File Repository	*https://osf.io/9hsmb/*

1. Hardware in context

In 2015, world-wide plastic production was 322 million tons per year and is growing 3.86%/ year [1]. Both landfilling [2] and incineration [3] of plastic create well-established health and environmental issues [4,5]. Rather than follow a linear model of materials use, a circular economy model can be used to provide sustainability by separating economic growth from resource consumption [6,7]. Thus, recycling, is now established in the circular economy as the optimum treatment of post-consumer plastics [8]. Unfortunately, there can be significant environmental impacts from the collection and transportation of relatively low-density waste plastics to collection centers and reclamation facilities for separation and reconstruction in traditional recycling [9,10]. In addition, in developing regions (and even in some developed economies) the labor for this recycling is provided by waste pickers, which collect post-consumer plastic in landfills, among other places, far below poverty-level wages [11–14]. To reduce the embodied energy of transportation needed for centralized recycling [15], while at the same time potentially improving the financial situation of waste pickers a distributed recycling paradigm has been proposed [14–17].

One method of distributed plastic recycling is to upcycle plastic waste into 3-D printing filament with a recyclebot, which is an open source waste plastic extruder [18]. Previous research on the life cycle analysis (LCA) or the recyclebot process using post-consumer plastics instead of raw materials, showed a 90% decrease in the embodied energy of the filament from the mining, processing of natural resources and synthesizing compared to traditional manufacturing [19,20]. In addition, the recyclebot provides the potential for consumers to recycle plastic in their own homes to save money by offsetting purchased filament [19–21]. Recyclebots are also useful for laboratory and industry prototyping research as failed prototypes can be recycled into filament for future work. Many versions of recyclebots have been developed by both companies (e.g. Filastruder) as well as individuals (e.g. Lyman) [22] including open source versions from the Plastic Bank, Precious Plastic, and Perpetual Plastic. There are also several commercial versions of the recyclebot including the Filastruder, Filafab, Noztek, Filabot, EWE, Extrusionbot, Filamaker (also has shredder) and the Strooder, Felfil (OS), which all could potentially be used for waste plastic. Additionally, there are several examples of commercialized recycled filament (e.g. Filamentive, Fila-cycle and Refil). However, most filament research as well as production is still accomplished with large-scale extruders inappropriate for distributed recycling. These systems range from $6000 to tens of thousands of dollars for manufacturing level extrusion lines that can produce a few kg/h.

The small extruders on the market as well as the freely posted designs suffer from one or more of the following deficiencies: 1) not open source (thus, do not provide adequate control and customizable features needed for laboratory work [23,24], 2) do not have adequate control (e.g. single speed), which is needed for non-uniform feedstocks of waste plastic, 3) are made from components that are not robust enough to handle contamination as well as composite waste, 4) demand machining experience and access to equipment often unavailable for DIY systems, 5) have high costs, 6) have slow extrusion rates, 7) have limited temperature ranges so cannot do some thermopolymers, 8) do not have a reliable form of process observation (e.g. filament diameter monitoring).

Although some polymers have been successfully recycled as single component thermoplastics such as PLA [25–28], HDPE [18,29,30], ABS [21,30,31], elastomers [32] as well as waste wood composites [33] and carbon fiber reinforced composites [34]. This early work, however, hardly begins to scratch the surface of the potential to use distributed methods to recycle a much longer list of polymers as well as composites made up of multiple distributed waste streams [35]. There is a tremendous potential to further improve the feed stocks as well as recycling 3-D printed parts themselves [36].

To assist researchers meet this potential, a recyclebot designed for fused filament-based 3-D printer filament research is described here that takes advantage of both the open source hardware methodology [37,38] and the paradigm developed by the open source self-replicating rapid prototyper (RepRap) 3-D printer community [39–41]. Specifically, this paper describes the design, fabrication and operation of a RepRapable Recyclebot – an open source 3-D printable waste plastic extruder, which can provide the filament to largely replicate the machine that produces it.