

1 Article

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# Open Source Waste Plastic Granulator

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16  
17 Abstract: In order to accelerate deployment of distributed recycling by providing low-cost feed  
18 stocks of granulated post-consumer waste plastic, this study analyzes an open source waste plastic  
19 granulator system. It is designed, built and tested for its ability to convert post-consumer waste, 3-D  
20 printed products and waste into polymer feedstock for recyclebots of fused particle/granule printers.  
21 The technical specifications of the device are quantified in terms of power consumption (380 to 404W  
22 for PET and PLA, respectively) and particle size distribution. The open source device can be  
23 fabricated for less than USD\$2000 in materials. The experimentally-measured power use is only a  
24 minor contribution to the overall embodied energy of distributed recycling of waste plastic. The  
25 resultant plastic particle size distributions were found to be appropriate for use in both recyclebots  
26 and direct material extrusion 3-D printers. Simple retrofits are shown to reduce sound levels during  
27 operation by 4dB-5dB for the vacuum. These results indicate that the open source waste plastic  
28 granulator is an appropriate technology for community, library, makespace, fab lab or small  
29 business-based distributed recycling.30 **Keywords:** 3-D printing; additive manufacturing; distributed manufacturing; distributed recycling;  
31 granulator; shredder; open hardware; fab lab; open-source; polymers; recycling; waste plastic;  
32 extruder; upcycle; circular economy  
3334 

## 1. Introduction

35 The open-source release of the self-replicating rapid prototyper (RepRap) 3-D printer [1-3]  
36 greatly expanded access to additive manufacturing (AM) because of several orders of magnitude  
37 reduction in costs [4]. As open-source RepRap 3-D printers spawned hundreds of clones, fused  
38 filament fabrication (FFF) enabled a shift in the trend from centralized to consumer (or prosumer)  
39 distributed manufacturing [4-8]. Consumers now use RepRaps or pre-built desktop 3-D printers to  
40 manufacture all manner of products from toys to household items less expensively than purchasing  
41 them from conventional brick and mortar or online retailers [9-11]. The peer-reviewed business  
42 literature now recognizes this potential shift in manufacturing [12-14], which is brought on not only  
43 by the open source sharing of 3-D printer designs, but now more importantly because of millions of  
44 freely shared digital designs of other products that are 3-D printable [9]. Any level of consumer from  
45 scientific research funders to arthritis patients [15] can earn a high return on investment (ROI) [16]  
46 for distributed manufacturing with commercial polymer 3-D printing filament based on downloaded

47 substitution values [17]. However, commercial 3-D printing filament is still sold for roughly an order  
48 of magnitude more than the cost of the raw materials of virgin plastic pellets. This has reduced  
49 adoption of AM at the prosumer level [18]. There are two methods to overcome this artificial cost  
50 barrier for wider spread distributed manufacturing: 1) use distributed recycling to make filament and  
51 2) skip the entire process of fusing filament into a 3-D printed object by printing directly from  
52 polymer granules, shards or particles.

53 3-D printing filament can be manufactured economically using distributed means with an open  
54 source waste plastic extruder (often called a recyclebot) [19]). Recycling is a well-known  
55 environmental benefit and performing distributed recycling of plastic waste into filament decreases  
56 the embodied energy of filament by 90% compared to traditional centralized filament manufacturing  
57 using fossil fuels as inputs [20-22]. Using distributed recycling fits into the circular economy  
58 paradigm [23-26] as it eliminates most embodied energy and pollution from transportation between  
59 processing steps. Many open source commercial and non-commercial recyclebots have been  
60 developed [27] including a 3-D printable version [28]. Many research groups and companies have  
61 demonstrated that pre-consumer and post-consumer waste polymers can be recycled into 3-D  
62 printing filaments, including:

- 63 • polylactic acid (PLA) [28-32]
- 64 • acrylonitrile butadiene styrene (ABS) [24,33-36],
- 65 • high-density polyethylene (HDPE) [19,37,38],
- 66 • polypropylene (PP) [38],
- 67 • polystyrene (PS) [38],
- 68 • polyethylene terephthalate (PET) [39],
- 69 • linear low density polyethylene (LLDPE) and low density polyethylene (LDPE) [40],
- 70 • elastomers [8],

71 In addition, filaments can be made from polymer composites using carbon reinforced plastic [41] and  
72 various types of waste wood [42,43]. Unfortunately, each melt-solidification degrades the mechanical  
73 properties of the resultant 3-D print [44,45] recycling is limited to about five cycles [46,47] without  
74 use some means of reinforcement or blending with virgin materials. The potential for such distributed  
75 recycling could be either completely distributed (where the consumer recycles their own plastic in  
76 their home or business) or part of a local closed-loop supply chain [48].

77 The second method, however, eliminates the need for filament entirely as 3-D printers have been  
78 developed that can print directly from particles, pellets, flakes, regrind, or shreds of recycled plastic.  
79 These fused particle fabrication (FPF) or fused granular fabrication (FGF) 3-D printers and are  
80 becoming established in the academic [49-54], maker [55-57], and commercial venues (e.g. GigabotX,  
81 PartDaddy, Cheetah Pro, David, Erecto-Struder, etc.). FPF/FGF printing is possible with recycled  
82 materials [58-60] as is using FGF printing of molds for distributed injection molding of larger replicate  
83 products [60].

84 Both the widespread deployment of distributed recycling with recyclebots and FPF/FGF are  
85 being restricted because of the lack of accessibility of low-cost pelletizers and choppers to turn post-  
86 consumer plastic products into polymer feedstock. In general, these are large industrial machines not  
87 conducive for makerspaces, fab labs, research or consumer use because of their high throughputs,  
88 noise and capital costs. In order to provide a low-cost tool for making polymer feedstock from post-  
89 consumer waste this study follows the open-source hardware design paradigm [61,62], which has  
90 proven so successful for 3-D printing in general. An open source waste plastic granulator system is  
91 designed, built and tested for its ability to convert post-consumer waste, 3-D printed products and 3-  
92 D printer waste into polymer feedstock for recyclebots of FGF/FPF printers. Then the technical  
93 specifications of the device are quantified in terms of power consumption and particle size of the  
94 output. In order for the device to operate in a fab lab (or similar environment) a noise reduction  
95 system is added and analyzed. The results are presented and discussed.

## 96 2. Design Concept

97 The design of the open source waste plastic granulator system is divided into four separate sub-  
98 systems, each responsible for parts of the machine that serve a specific function:

99 1. Power Transmission: This system encompasses all machine parts needed to convert the electrical  
100 energy being input to the system into mechanical energy, as well as transmit that mechanical  
101 energy to the plastic cutting/granulation system.

102 2. Plastic Cutting/Granulation: This system is the one that directly interacts with the plastic in order  
103 to cut it into small chunks. It is responsible for cutting plastic as well as ejecting granules after  
104 they have reached a uniform size.

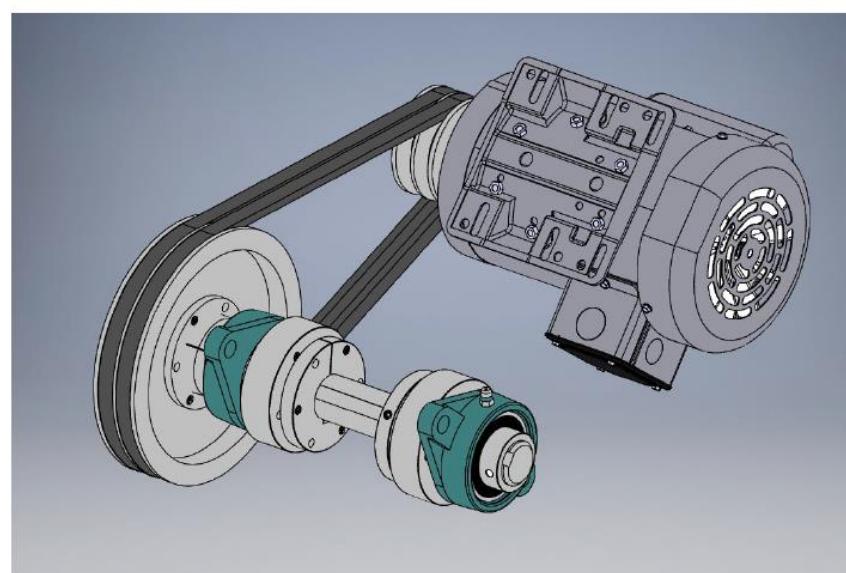
105 3. Material Guidance/Structural: This system involves any parts that keep the plastic feedstock  
106 inside of the proper cutting area during operation or guide the feedstock during its journey. It  
107 includes the hopper chute, the hopper lip, the granulation chamber lip, any mechanism used to  
108 hold the hopper to the granulation chamber, and the upper surfaces of the granulation chamber.

109 4. Electrical: This system encompasses all of the components required to convert electrical energy  
110 from mains power into rotational energy, as well as any other electrical peripherals present on  
111 the machine. This includes the electrical box, safety switches, circuit board, motor, and a  
112 microcontroller.

113 Together, these systems operate all with the end goal of transforming plastic recyclables into  
114 usable 3-D printing feedstock in the form of granules (or particles). The main concepts and parts in  
115 each sub-system will be described but the full open hardware details including the bill of materials  
116 (BOM), drawings for custom parts, CAD files, build instructions and design reports of previous  
117 versions are housed at the Open Science Framework [63].

### 118 2.1. Power Transmission System

119 The power transmission system transfers rotational mechanical energy from the motor spindle  
120 to the cutting rotor shaft. As a first step towards designing this subsystem of the machine the design  
121 team made the decision that a one-phase AC motor would be used to supply mechanical power to  
122 the machine. This method of mechanical power delivery is the most reliable and easiest way for an  
123 individual to drive a machine from their home circuitry. Pulleys and belts are used to convey power  
124 to the cutting rotor; belts are not only inexpensive when compared to a gearbox, but are also more  
125 user friendly since they are easy to install, maintain and adjust once assembled. An isolated view of  
126 the 3-D model for the power transmission subsystem and all of its components can be seen in Figure  
127 1.



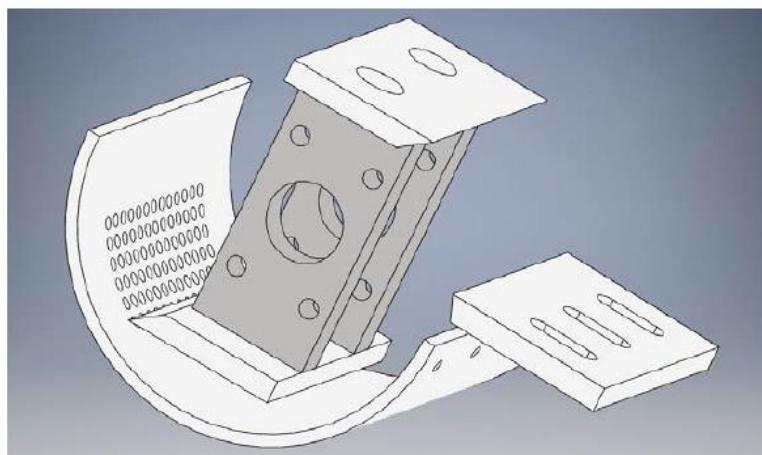
128  
129 *Figure 1: Power transmission system design of the open source waste plastic granulator.*

130 As seen in the Figure 1, the parts of the power transmission system are as follows: AC Motor,  
131 pulleys, belts, flange-mount bearings, rotor shaft, quick-disconnect (QD) bushings, and weld-on hubs

132 (plus mounting hardware). The motor selected to drive the granulator is a 1.5 HP motor with a  
 133 spindle speed of ~1800 RPM. On a previous version of the open source waste plastic granulator, the  
 134 optimal rotor speed for cutting was found to be around 750 RPM [62]; this speed was also used for  
 135 this design as well, leading to a set ratio of pulley diameters of about 1:2.4. A 3.95" (100.33 mm)  
 136 diameter pulley was chosen to connect to the motor spindle using a quick-disconnect style bushing.  
 137 An 8.75" (222.25 mm) diameter pulley was used to attach to the cutting rotor shaft, also with a quick-  
 138 disconnect bushing. Both pulleys have two channels for v-belts to ensure there is no slippage during  
 139 operation. In order to keep the cutting rotor shaft spinning about its major axis two large flange-  
 140 mount bearings were used. In order to connect the shaft to the cutting rotor, QD bushings were used  
 141 in conjunction with weld-on hubs to clamp to the shaft. These components were then bolted to the  
 142 cutting rotor so that the blades would spin with the shaft (see Figure 2).

143 *2.2. Plastic Cutting System*

144 The plastic cutting subsystem is, out of all of the subsystems, the most directly related to the  
 145 overall function of the machine as it is responsible for transforming plastic waste/recyclables into  
 146 granules of a specific size. In order to do this, the design team picked out many different forms that  
 147 would satisfy the subsystem's purpose, and compared them using a decision matrix (details of which  
 148 are found in the OSF database [62]). From the decision matrix, the best option was found to be the fly  
 149 knife design, consisting of two large rotating blades (fly knives) that pass close to a fixed blade during  
 150 operation (Figure 2). Shear force on the plastic between the blades is the main cutting method.



151  
 152 *Figure 2: Plastic cutting system design of the open source waste plastic granulator.*

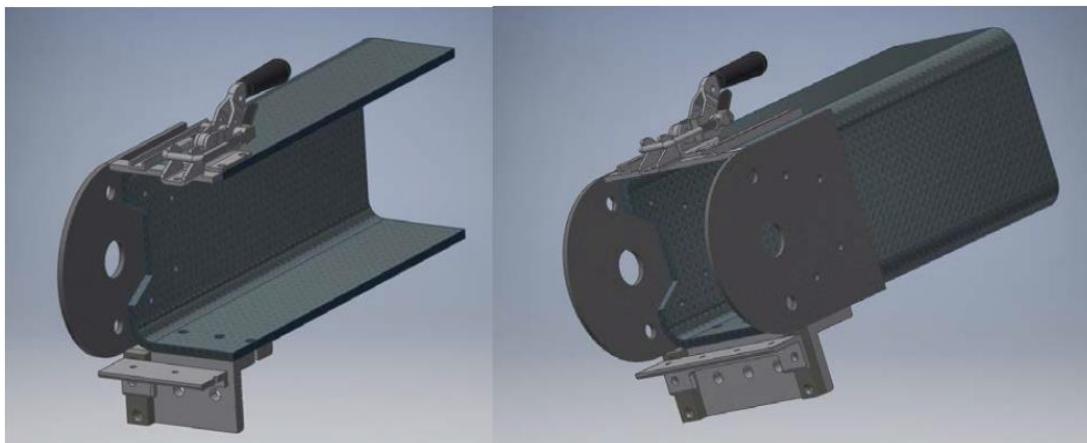
153 The plastic cutting system, consists of four separate components (plus mounting hardware).  
 154 Two blade arms will connect to the cutting rotor shaft (shown in Figure 2) and will spin with the  
 155 shaft. Connected to either end of each blade arm in the configuration shown below are two fly knives,  
 156 which will contact the plastic within the cutting chamber and shear through it. To help with the  
 157 cutting of the plastic granules, there are two more pieces in this system that both interact with the  
 158 rotating fly knives, the granulation screen and the bed blade. As the fly knives rotate in the  
 159 granulation chamber they will pass very close to the fixed bed blade on the right side of Figure 2.

160 This is where the large pieces entering the cutting chamber will be sheared for the first time. In  
 161 our design, all stress-bearing components related to this large cutting force were designed to be able  
 162 to cut  $\frac{7}{8}$ " (22.2 mm) cubes of nylon mill stock. Once large pieces have been cut for the first time by  
 163 the bed blade, they will accumulate on the surface of the granulation screen. The clearance between  
 164 the tip of the fly knives during rotation and the inside of the screen is  $\sim\frac{1}{8}$ " (3 mm), which means that  
 165 any larger granules will get pinched between the screen and the blade and be sheared to a smaller  
 166 size. Once the granules are smaller than  $\sim\frac{1}{4}$ " (6 mm) in all dimensions they are pulled through the  
 167 holes located in the granulation screen and into a collection chamber by a vacuum. In order to make

168 the blade arms rotate, as described in Section 2.1, weld-on hubs attached to the shaft were bolted onto  
169 the blade arms.

170 *2.3. Material Guidance*

171 The material guidance system is responsible for containing the waste plastic both before and  
172 after the cutting operation. In addition to guiding materials, this system also serves as the structure  
173 upon which all other subsystems are constructed. The feedstock is guided using a sloped tube as  
174 shown in Figure 3.



175  
176 *Figure 3 Material guidance system (cut section and completed) for the open source waste plastic granulator.*

177 Overall, the main component used for material guidance is a large steel square tube that not only  
178 provides a smooth, enclosed surface for the waste plastic to slide on while it is on its way to be cut,  
179 but also a very strong and rigid structure that can be built upon. Attached to this large (8" (203 mm)  
180 width) square tube are several other components that support the plastic cutting and power  
181 transmission systems. The two large rounded plates attached to the vertical faces of the tube are what  
182 hold the bearings from the power transmission system in place. The angle iron on the bottom part of  
183 the tube serves two purposes. The larger piece holds the fixed bed blade in place during operation,  
184 as well as clamping to the second piece of angle iron shown, which secures the granulation screen in  
185 place for cutting. The materials on the top of the tube are all responsible for holding the opposite side  
186 of the granulation screen in place and allows the user to disconnect the granulation screen quickly  
187 from one side. This system also includes a secondary tube acting as a hopper for funnelling material  
188 directly from the user's hand into the machine as well as a server rack cart that is used to house the  
189 main cutting mechanism, however, these components are not shown above for clarity.

190 *2.4. Electrical*

191 The electrical system in the machine serves three purposes, powering the motor, powering the  
192 granule extraction vacuum, and monitoring the power consumption of the machine. These functions  
193 are accomplished simply since both the vacuum and the motor require no more than a simple on/off  
194 control scheme. Both the vacuum and the motor are connected directly to 120VAC mains power and  
195 use simple switches to control them. In addition, an emergency-stop switch is included in the  
196 circuitry to cut power to the whole machine if necessary. The final accessory included in the electronic  
197 circuit for this machine is a multimeter that provides a digital readout with information on the power  
198 consumption of the machine. All of the components in the electrical system were designed to operate  
199 using less than 15 Amps during steady-state conditions so that the machine could be run off of a  
200 standard in-home wall outlet. A circuit diagram for the electrical system is included in Figure 4.

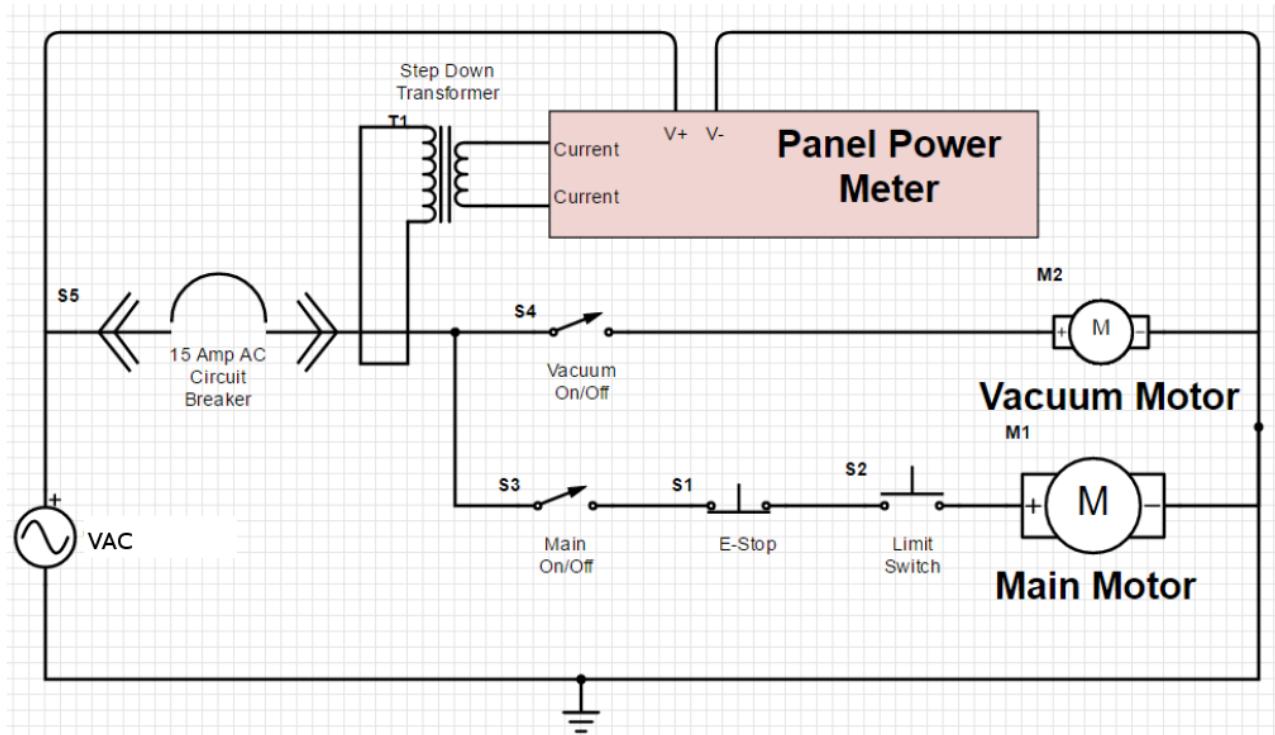
201  
202

Figure 4: Circuit Diagram for electrical control system of the open source waste plastic granulator.

## 203 2.5. Peripheral Parts Assembly

204 Together, the four systems described in Section 2.1-2.4 work together to achieve the overall  
 205 objective of the design of the open source waste plastic granulator. Other than getting the material  
 206 from place to place, all of the actual manipulation of the plastic to transform it from stock material  
 207 into feedstock occurs due to the cutting and power transmission systems. An overall view of the  
 208 machine's core systems are shown in Figure 5.

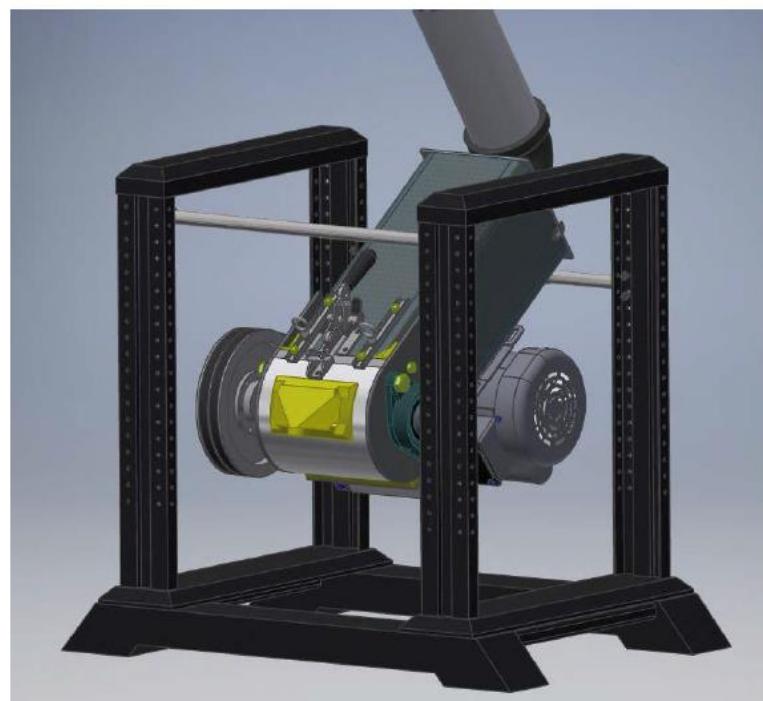
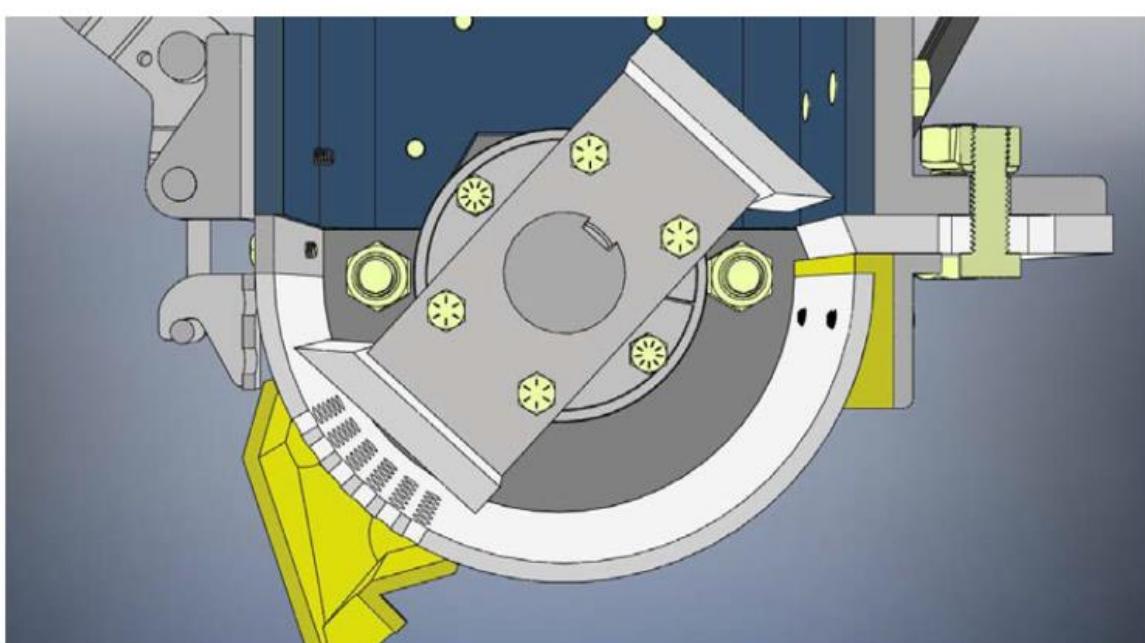
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210

Figure 5: Overall design setup of the open source waste plastic granulator.

211 Figure 5 shows the assembly of the three mechanical design systems, including all of the parts  
 212 explained earlier as well some 3-D printed parts and several parts not shown before. As can be seen  
 213 in the above picture the server rack cart that was mentioned in the material guidance system is  
 214 housing the main systems of the granulator. It holds the machine components so that the major axis  
 215 of the large square tube is angled to allow plastic pieces to slide into the cutting mechanism. To  
 216 accomplish this, several standard size  $\frac{1}{2}$ " (12.7 mm) steel pipes are attached to the server rack using  
 217 u-bolts. The pipe in the rear (as shown in Figure 5) is attached directly to the bottom of the steel tube  
 218 using pipe straps, while the pipe in the front is attached via nylon strapping to the eye-bolts shown  
 219 on the top of the steel tube in the above figure. This is done to allow the builder of the machine to  
 220 easily add a vibration-dampening spring at the front attachment point to mitigate any rotational  
 221 imbalance that may be present in the machine. The hopper consists of the large tube sticking out of  
 222 the top of the server rack as well as a plate that allows it to attach to the back of the square steel  
 223 tube/main machine body. This allows users to safely place materials into the machine for cutting. The  
 224 bend that materials will have to pass through in order to get from the machine's opening to the  
 225 cutting mechanism ensures that a user cannot accidentally place their hands/arms inside the machine  
 226 while it is cutting as well as stops granules from flying out of the machine during operation. To  
 227 highlight the interaction between all three main mechanical systems a cutaway view showing the  
 228 assembled granulation chamber in Figure 6.  
 229



230  
 231 *Figure 6: Cutaway of mechanical systems in the open source waste plastic granulator.*

232 **2.4 Cutting Force Design Analysis**

233 The cutting operation that takes place during the operation of the granulator is unpredictable so  
 234 a simulation was run of the cutting forces that occur during the operation of the granulator [62]. These  
 235 forces are important because they allow for the calculation of the stresses that occur inside the key  
 236 stress-bearing elements of the design. The method and findings are in the OSF database [62].

237 The stress levels inside the blade arm as well as the fly knife bolts are well below the acceptable  
 238 level for steel materials. In order to achieve this, it was determined that the blade arms must be made  
 239 out of  $\frac{3}{4}$ " (19 mm)  $\times$  2.5" (63.5 mm) steel flat stock, and that the bolts must be  $\frac{3}{8}$ " - 16 UNC ( 9.525  
 240 mm) grade 8 hex cap screws. Previous simulations found that a 1/2" (12.7 mm) thick piece of angle  
 241 iron with side lengths of 3" (76.2 mm) would be suitably strong for this piece.  $\frac{1}{4}$ " (6.35 mm) - 20 UNC  
 242 bolts were selected despite being over engineered because they proved inexpensive for this  
 243 application. After iterating the simulation to find the optimal size for the bed blade mounting bolts,  
 244 both locations were considered and  $\frac{1}{2}$ " (912.7 mm) -12 UNC grade 8 hex cap bolts were chosen.

245 Standard fatigue analysis [64] was performed and it was found that the Grade 9 bolts responsible for  
246 attaching the fly knife blades to the blade arms are predicted to fail due to fatigue before infinite life.  
247 That being said however, the analysis done assumes that a  $\frac{3}{4}$  " (19 mm) nylon block will enter the  
248 machine once every time one knife rotates, which, for normal operation is very unlikely. For normal  
249 use the stresses present will never reach the values used for analysis. However, users planning on  
250 using this machine for nylon recycling should replace these bolts every month in order to avoid  
251 failure due to fatigue. The maximum torque acting on the cutting rotor during operation is slightly  
252 less than 1500 N-m, or about 13000 in-lbs. In order to attach the cutting rotor to the shaft two SK type  
253 QD bushings were chosen, since each bushing can support a torque of 7000 in-lbs. Together, these  
254 two bushings can support a maximum torque of 14000 in-lbs, a torque which should never be  
255 exceeded during the normal operation of the machine. In conclusion, the design simulation indicated  
256 that the technology as designed would be able to cut a maximum thickness of nylon stock of  $\frac{3}{4}$ "  
257 (19 mm), i.e. a cube measuring  $\frac{3}{4}$ " (19 mm) on each side is the largest piece of plastic stock that  
258 should be inserted into the machine.

### 259 3. Material and methods

#### 260 3.1 Technical specifications: Power consumption and particle size

261 The power consumption operating the granulator as measured with an open-source printed  
262 circuit board and Arduino Nano attached to the power supply to measure the power output of the  
263 while it was processing different materials. During each of the power recording sessions,  
264 thermoplastic was inserted at a rate the granulator could handle. This rate is not measured, as it  
265 highly depends on the geometry and density of the inserted plastic.  
266

267 The AC power measurement board collects data from both input legs of the 220 VAC power  
268 input to the control electronics. Each leg's corresponding voltage is measured by direct connection,  
269 and current is measured using 100A non-invasive current transformers. Each leg's measurements are  
270 hooked into a channel of the board where the measurements are made using a dedicated Analog  
271 Devices ADE7757 energy metering integrated circuit (IC). The IC meets the IEC61036 accuracy  
272 requirements for power measurements. The ADE7757 transmits the wattage signal through its CF  
273 pin, and is captured by the on-board Arduino Nano. The values are operated on by a linear calibration,  
274 and then written to a microSD card, with time stamps generated by the on-board real time clock.

275 The size characteristics of the particles for the resultant granulated material were quantified  
276 using digital imaging and the open source Fiji/ImageJ using techniques discussed previously [60].

#### 277 3.2. Noise reduction

278 Sound pressure levels were measured using a free field array microphone positioned in front of  
279 the vacuum inlet of the machine. The measurements were logged using a National Instruments  
280 compact DAQ data acquisition system in conjunction with custom LabVIEW software. Multiple  
281 positions were considered before finalizing on the position in Figure 7 due to repeatability and high  
282 signal-to-noise ratio. All trials were performed using this microphone position Sources of sound in  
283 the machine includes the shear cutting mechanism in the granulator and the shop vacuum. Although  
284 the microphone location was not in the operator ear position, it was appropriately placed for  
285 before/after insertion loss measurements.



286

287

Figure 7: Sound measurement test setup depicting the microphone in one of the test locations

288 Tests were performed to find the sound pressure levels of the open source waste plastic  
289 granulator system including the auxiliary devices such as the vacuum pump and the individual  
290 contributions as well. It was determined that the vacuum pump was the loudest source with a distinct  
291 peak in the 250 Hz one third octave band. Panel gaps in the enclosure for the granulator provides  
292 leakage paths for the sound and hence it was decided to seal these gaps appropriately. The inner  
293 lining of the walls were packed with open-celled foam to increase sound absorption and transmission  
294 loss as shown in Figure 8.  
295



296

297

Figure 8: Granulator panel gaps filled with sound proofing material

298 Using the initial acoustic measurements, an expansion chamber was designed (Figure 9) that  
299 could be attached to the 5-gallon bucket shop vacuum, and a 3-D model was produced to utilize PVC  
300 and a 3-D printable components to reduce noise from the operation of the device. As 250Hz was the  
301 chosen frequency one third octave band for attenuation, the double tuned expansion chamber design  
302 was chosen as it provides good transmission loss around the frequency of interest while having good  
303 attenuation around the octave bands as well [65]. However, the muffler aids in higher frequency  
304 attenuation and by lining the inner walls of the muffler with fiberglass foam.



305

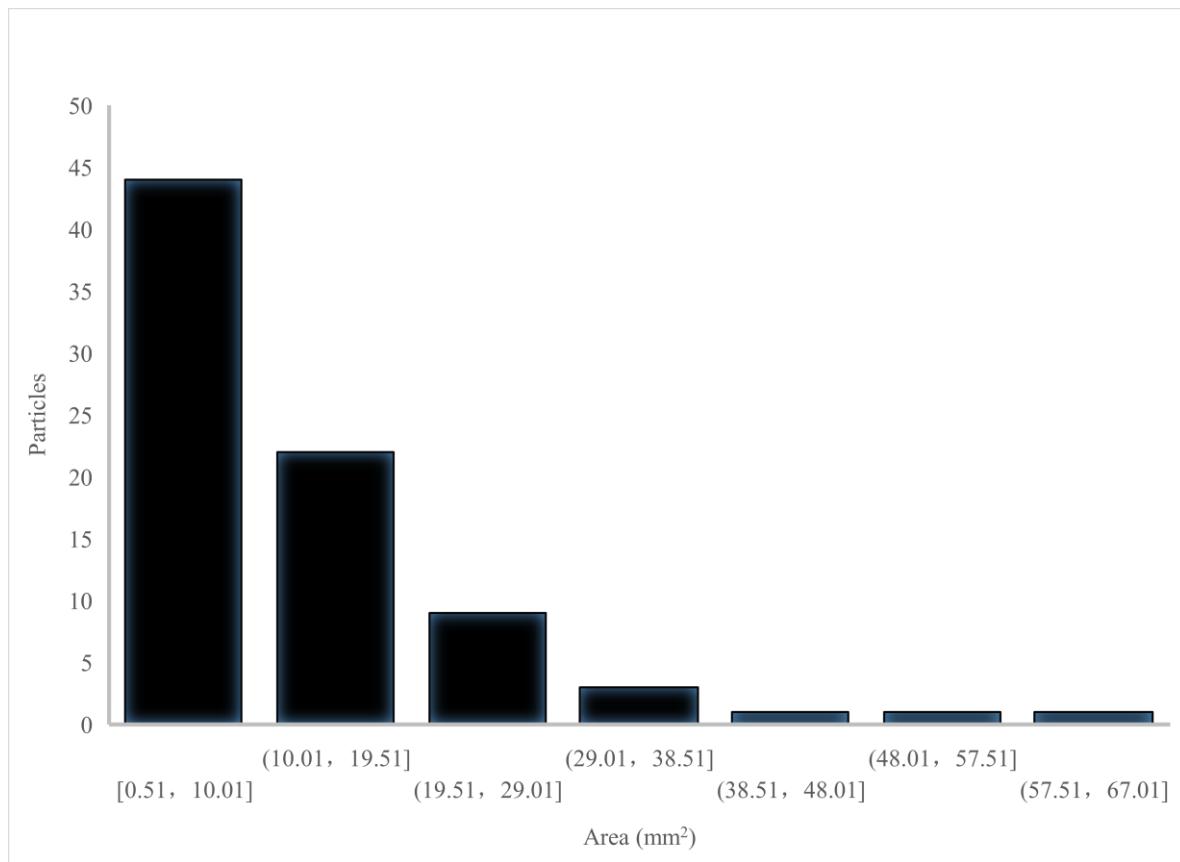
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Figure 9: Comparison between CAD of chamber and finished expansion chamber.

307 **4. Results**

308 **4.1 Technical specifications for particle size and energy use**

309 Figure 10 shows the resultant particles and particle size distribution, where it is clear that the majority  
 310 of particles are fines with total areas under  $10 \text{ mm}^2$ . These particle sizes are appropriate for the  
 311 majority of recyclebots as well as direct material extruder based 3-D printers such as the Gigabot X  
 312 [58-60].



313

314 *Figure 10. Resultant particle size distribution in  $\text{mm}^2$  after shredding in the open source granulator.*

315 This power draw of the open source waste plastic granulator was processed and its results appear  
 316 below in a Table 1. The average power varied depending on the type of plastic and would be expected  
 317 to change based on the type of feedstock (e.g. large solid blocks vs flakes).  
 318

319 *Table 1: Power consumption details*

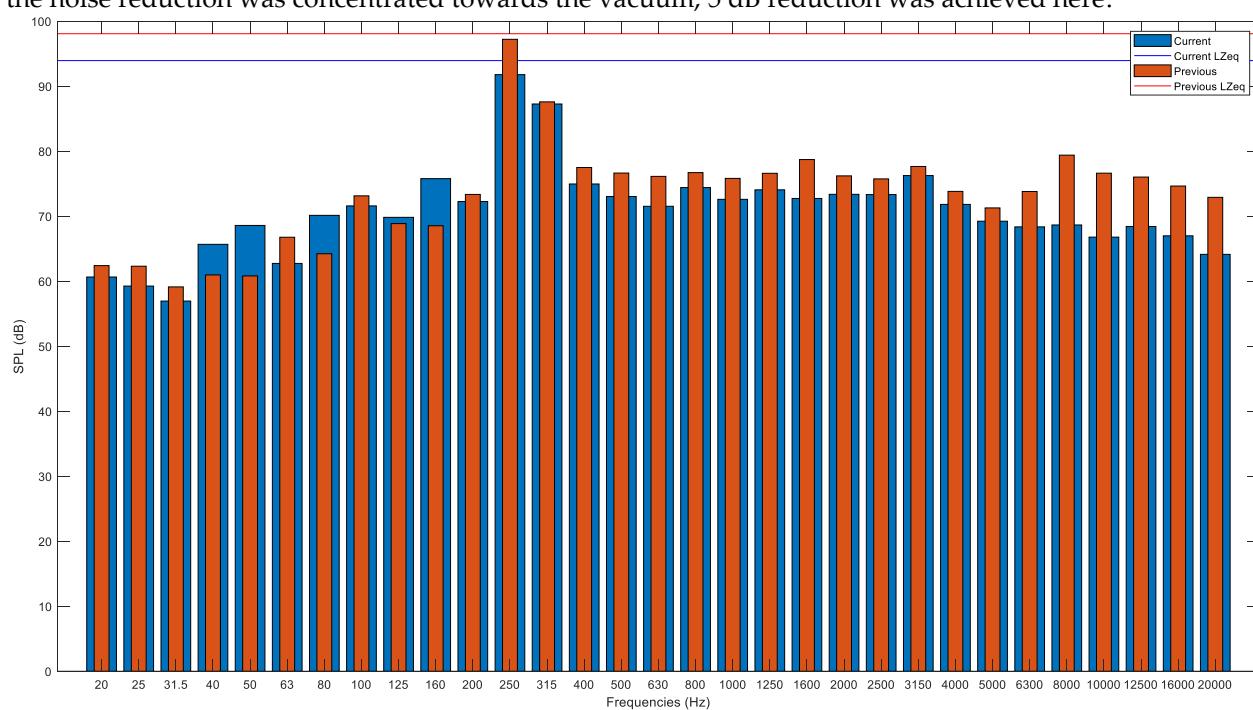
|               | PLA<br>(Polylactic acid) | PET<br>(Polyethylene terephthalate) |
|---------------|--------------------------|-------------------------------------|
| Average power | 403.6 W                  | 383.9 W                             |

320

321 

#### 4.2 Noise reduction results

322 The noise reduction modifications to the granulator were verified with sound level measurements  
 323 and are as shown in Figure 11. Compared to the earlier design, a 4dB overall reduction in sound  
 324 levels was achieved with attenuation at the 250Hz one third octave band particularly. As the focus of  
 325 the noise reduction was concentrated towards the vacuum, 5 dB reduction was achieved here.



326

327 *Figure 11: Results of the sound reduction redesign showing a bar plot of 1/3 octave noise measurements.*328 

## 5. Discussion

329 

### 5.1 Technical specifications for particle size, through put, and energy use

330 The particle sizes demonstrated in Figure 18 are small enough to use in a wide array of recyclebots  
 331 (both commerical and homemade) as well as for direct printing via FPF/FGF as demonstrated in [58-  
 332 60].

333 The volumes that the device can process are appropriate for small businesses [13], community  
 334 centers, libraries, makespaces, and fab labs [59,66] that could potentially become community  
 335 distributed recycling centers. There are challenges with this approach throughout the world. So  
 336 although, libraries in Finland for example routinely offer their patrons free 3-D printing services,  
 337 many countries do not. In addition, the actual recycling process can be challenging due to lack of  
 338 appropriate information in specific countries. For example, China has a sophisticated recycling  
 339 symbol system [67] that covers a wide range of waste plastics, the U.S. groups most of its polymers  
 340 together in only 1 of 7 categories (7- “other”) [68]. In order to have low-cost distributed recycling

341 waste plastics need to be appropriately labeled. The open source 3-D printer community has already  
 342 devised a voluntary recycling code based on China's comprehensive system [68]. To have a more  
 343 widespread impact and reach a cradle-to-cradle material cycle [69] regulations that demand that  
 344 manufacturers identify the materials in their products appears necessary [70].

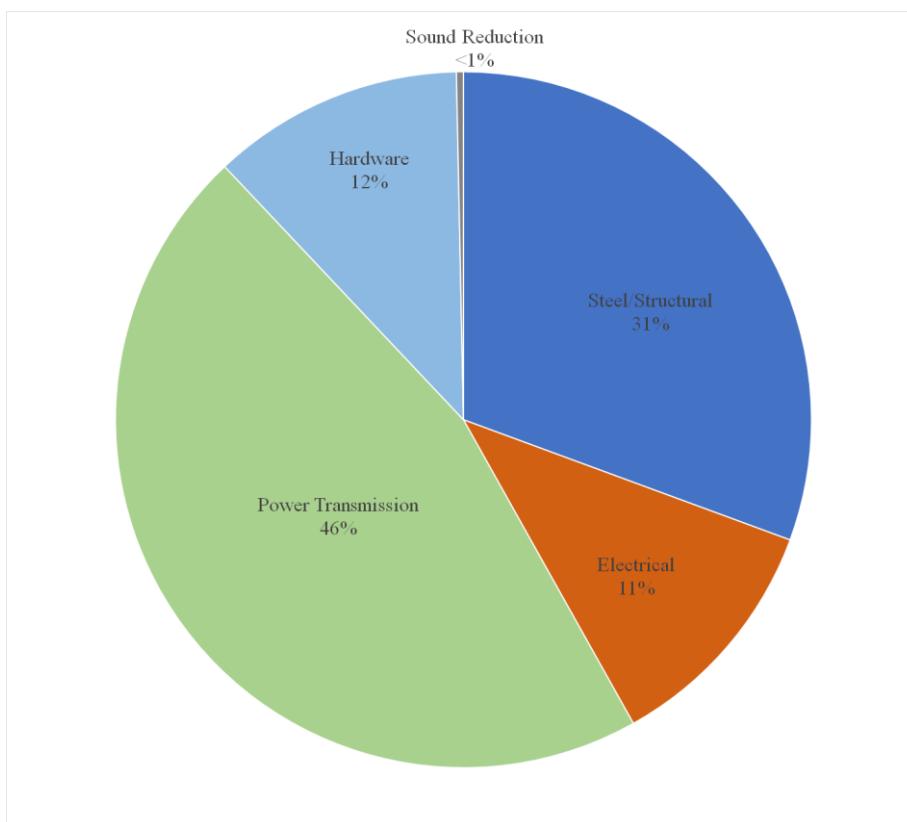
345 The power draw for the open source waste plastic granulator is relatively mild, drawing as much  
 346 power as 3-4 conventional incandescent light bulbs. Coupling this low power use to the rapid  
 347 throughput of the technology results in a relatively low embodied energy of electricity for grinding  
 348 plastic with this machine. This is close to values that have been reported for commercial devices used  
 349 in previous studies of distributed recycling using additive manufacturing [20,21].

350 *5.2 Noise reduction*

351 Sealing the exhaust port of the suction vacuum with the muffler did reduce the noise levels  
 352 experienced, which make the system more amenable to non-production facility based applications  
 353 like mixed-use fab labs. As stated in the results, a 4 dB overall reduction from the granulator and the  
 354 suction vacuum combined was obtained and hence the muffler served the intended purpose.  
 355 However, efforts to control granulator noise were not as successful and this was possibly due to  
 356 existing panel gaps in the enclosure. They were not sealed off due to need for ease of access. Future  
 357 work is needed to explore other methods of sound reduction.

358  
 359 *5.3 Future work*

360 This technology is an open source technology built on prior designs [71] and will continue to evolve  
 361 in the traditional open source fashion. There are thus several areas of future work to improve on the  
 362 design of the open source waste plastic granulator. First, the cost of the materials for the device is  
 363 US\$1,943.11, which limits its accessibility throughout many applications. The breakdown in the cost  
 364 of the materials can be seen in Figure 12.



365  
 366 *Figure 12. Cost breakdown of the bill of materials for the open source granulator.*

367 To further drive down costs, additional components should be redesigned to use digital  
368 manufacturing technologies, the mass of parts should be minimized to maintain the necessary  
369 mechanical integrity (which is most easily done in the reduction of structural steel that makes up  
370 nearly a third of the cost), and the volume footprint of the device should be reduced. These costs were  
371 for retail purchased materials and would be expected to drop significantly if an open hardware  
372 company built the devices at even modest scale.

373

374 **6. Conclusions**

375 This study successfully demonstrate the designs, build and testing of an open source waste plastic  
376 granulator for its ability to convert post-consumer waste, 3-D printed products and 3-D printer waste  
377 into polymer feedstock for recyclebots of fused particle/granule printers. The device can be built from  
378 open source plans using materials that cost less than US\$2000. The device has a power consumption  
379 (380 to 404W for PET and PLA, the most common post-consumer plastic waste and most popular 3-  
380 D printer plastic, respectively). With this device, granules can be produced with a particle size  
381 distribution consistent with distributed recycling and manufacturing using open source recyclebots  
382 and 3-D printers. Simple retrofits for the open source waste plastic granulator are shown to reduce  
383 sound levels during operation by 4dB and 5dB for the vacuum. It can be concluded that the open  
384 source waste plastic granulator is an appropriate technology for community, library, makespace, fab  
385 lab or small business-based distributed recycling

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392 Supervision, Joshua M. Pearce; Validation, Arvind Ravindran, Sean Scsavnicki, Walker Nelson, Peter Gorecki,  
393 Shane Oberloier and Theresa K. Meyer; Visualization, Arvind Ravindran, Walker Nelson and Peter Gorecki;  
394 Writing – original draft, Arvind Ravindran and Joshua M. Pearce; Writing – review & editing, Arvind Ravindran,  
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