Recycled Plastic Filament Pultrusion Machine

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Project Overview

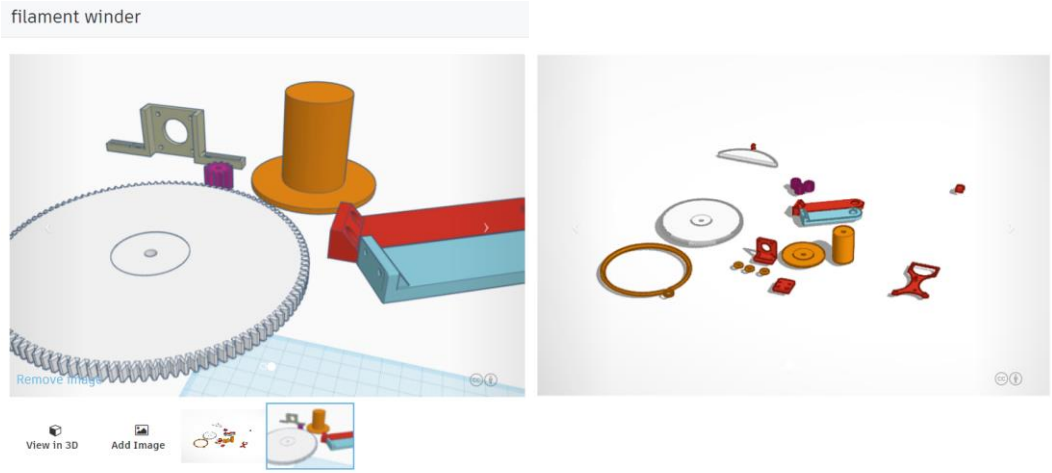
I’d been working with 3D printing for almost 3 years – building, custom modifying, and printing – when I decided to build a filament recycling machine. While filament isn't prohibitively expensive, I was spending a fair amount of money on it and thought it might be more environmentally responsible and cost effective to create filament, myself, through recycling.

I learned about two main methods: (1) melting and extruding virgin plastic pellets; and, (2) pulling plastic strips through a heated nozzle. I chose to focus on the latter as I could recycle empty bottles, making it both cost-effective and environmentally friendly. One drawback of this method is that the recycled plastic may not have the same consistency and properties as virgin plastic and so it could affect the performance of the filament. Even if of lower quality, the filament could prove useful for a variety of purposes.

The device I designed and built uses soda, water, or other bottles of similar quality plastic and recycles them into usable 3D filament. It comprises a cutter mechanism to slice the plastic bottle into long, contiguous strips of plastic ribbon which is then fed through a heated nozzle. The nozzle softens and reshapes the plastic into 1.75mm cylindrical strings of filament which are then rolled onto a spool. This spool can then be placed onto and fed into a 3D printer to print new objects.

It is assembled from a mixture of recycled/repurposed components, salvaged scrap, and several custom parts I designed and printed using my 3D printer. The primary components include:

- Plastic cutter
- Power supply, Raspberry Pi, motherboard
- Motor, gears, and spool
- Heating element/nozzle



Rough CAD: https://www.tinkercad.com/things/fYdagpJhUuR

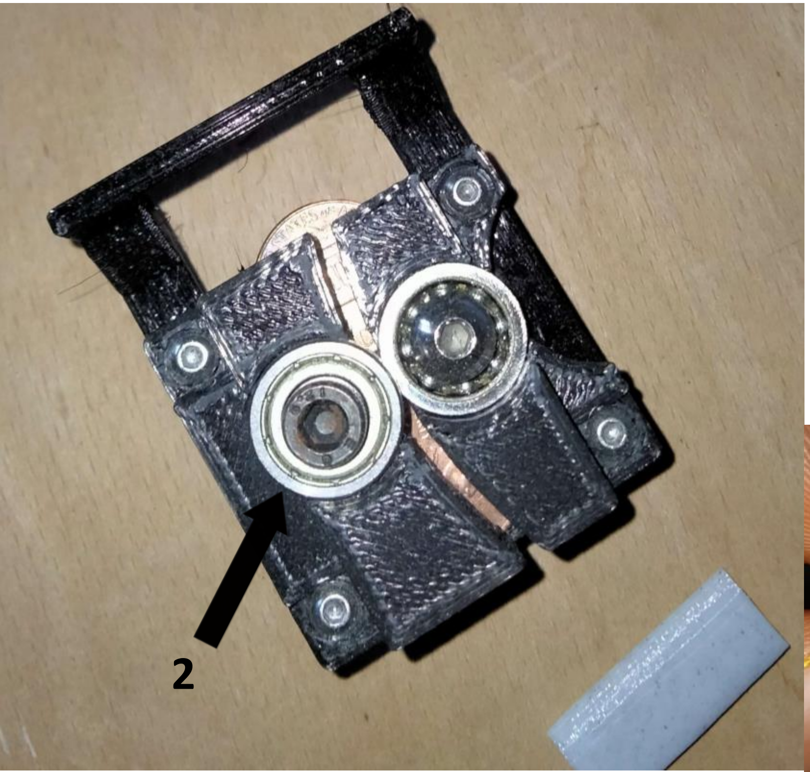
Stage 1: Plastic bottle cutter

The cutter is mounted on the main board. To use it, I first slice the bottom off the bottle and place it onto a supporting rod. The bottle is then pushed between the bearings and rotated (similarly to a can opener), slicing it into a thin ribbon, approximately 5mm wide. Once a short section of the ribbon has been started, it is then pulled through until it can be fed into the nozzle apparatus.

The original bottle cutter (see arrow 1) featured 6203zz bearings with a bevelled edge; the large bearings offered a stable edge that, initially, seemed to work well. However, the dust shield needed to be removed during bevelling, leading to debris entering the bearing and ultimately causing it to seize up.

The second version of the cutter used smaller bearings (arrow 2) that are easier to sharpen but which tend to wear faster (as they're made of a softer metal). This iteration is smaller and easier to assemble. While it lacks the rigidity of the first model, attaching it directly to the wooden base from the top and bottom improved its performance. Adjusting the height of the ribbon can be achieved by adding 3D-printed shims under the bearings.

I found that these bottle cutters can also be used on polypropylene shipping straps, which are inexpensive and are included in packaging larger items such as appliances. Polypropylene is easy to print with and is a chemically resistant plastic. I've included an image of the first layer from a polypropylene print (arrow 3).



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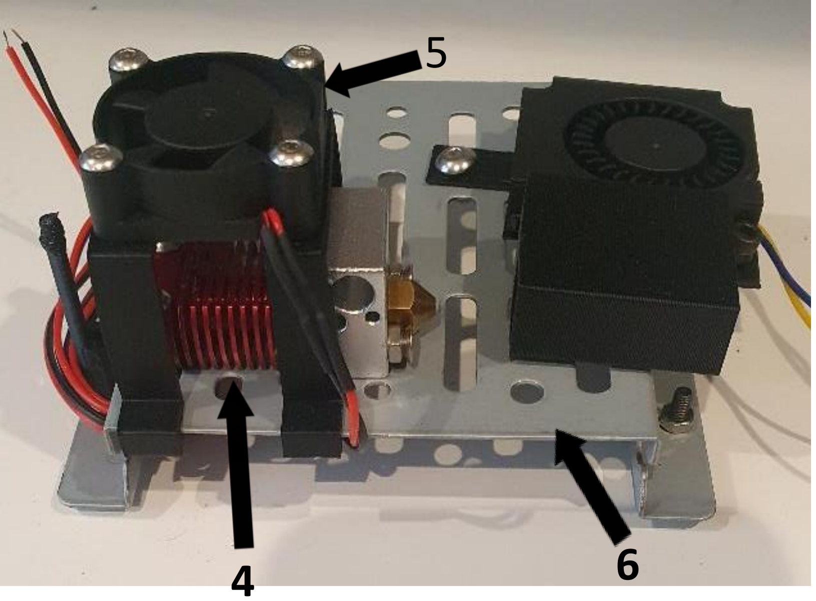
Arrow 1: salvaged roller bearings from and old commercial laser MFP
Arrow 2: recycled from Ender 3 v-slot rollers
Arrow 3: first layer from a polypropylene print

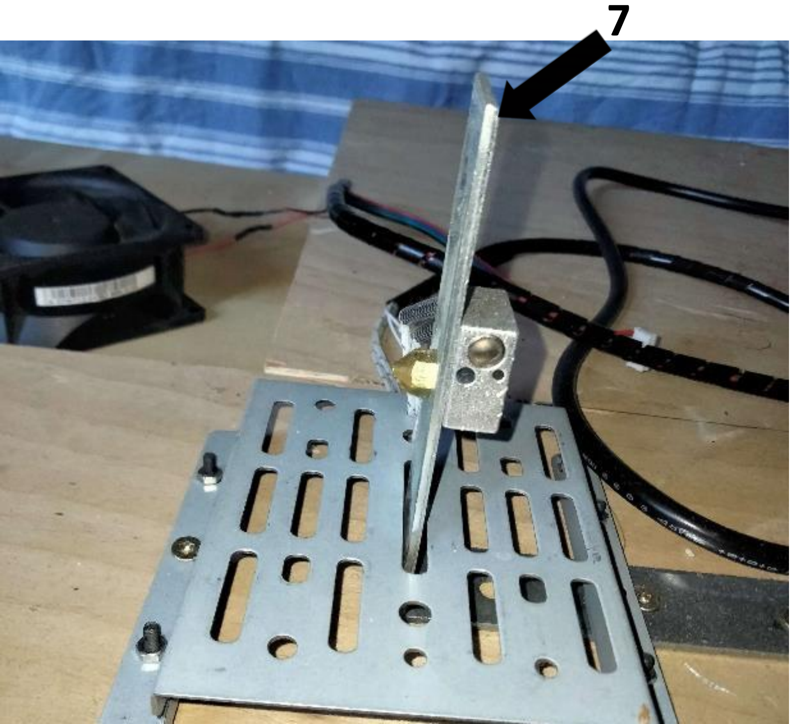


Stage 2: Heating nozzle

As mentioned previously, the plastic ribbon must first be manually fed into the nozzle apparatus from the slicer until the motor can take over and pull it the rest of the way through.

The first nozzle build utilized old parts from an Ender 3 printer and included a red heatsink (see arrow 4) that I drilled-out to an 11mm diameter, using a stepped drill, to facilitate the passage of the ribbon through the nozzle. The nozzle itself was designed to be 1.8mm wide, allowing the filament to stretch and reach the target diameter of 1.75mm. A fan was also mounted above the heatsink (arrow 5) to prevent overheating and premature melting of the ribbon. The entire assembly was then mounted onto a metal computer hard drive caddy (arrow 6) because a 3D-printed mount would not be able to withstand the working temperature (~150C).

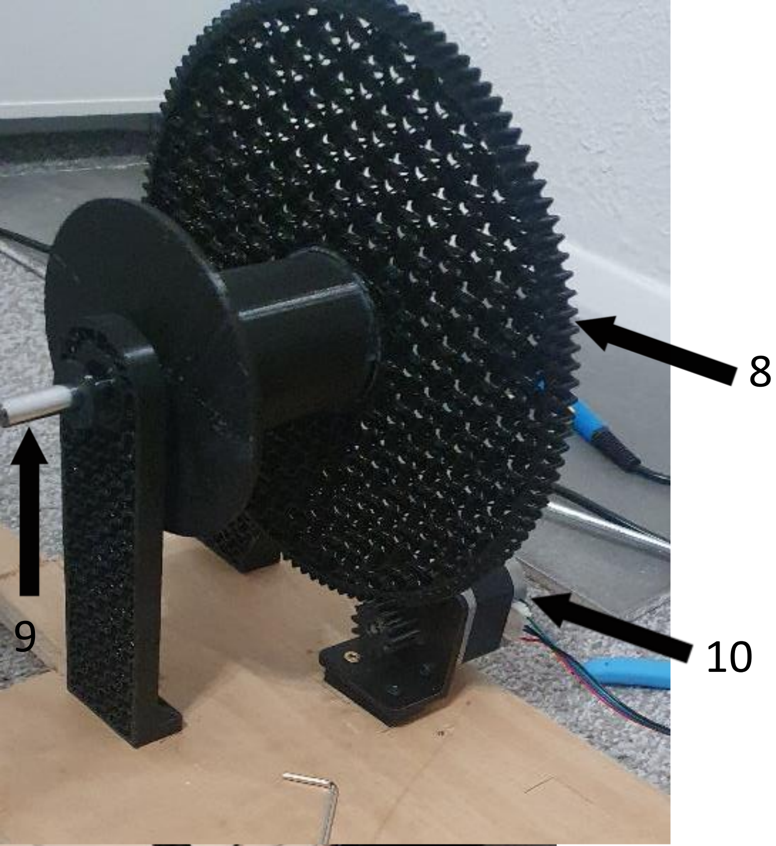
Unfortunately, my design was flawed as the 30W heater struggled to adequately heat the nozzle given the added thermal mass of the hard drive caddy. In the second iteration, the hard drive caddy was retained for wire routing and mounting purposes, but a stainless steel shelf bracket (arrow 7) was used instead to hold the nozzle and block. This reduced the amount of heat transferred, which solved that issue, but then the bracket was too high, causing some misalignment with the other components.

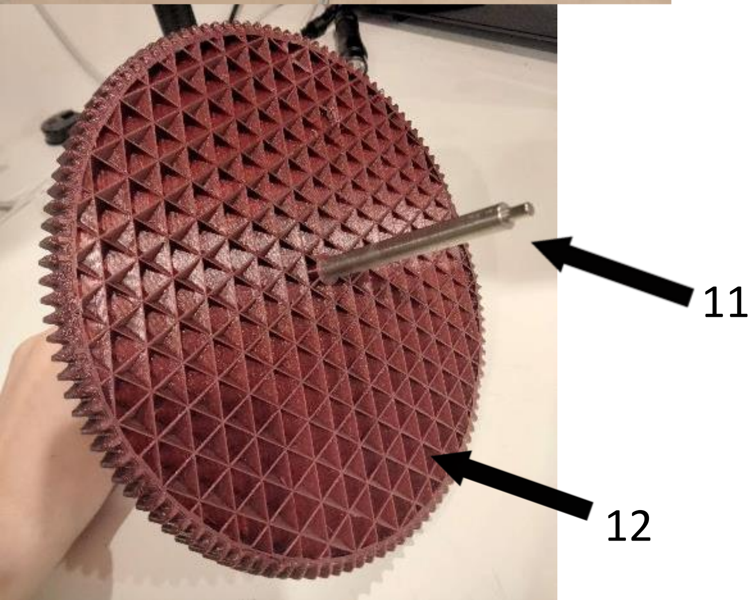


A potential third iteration of the nozzle build could utilise metal tubes (similar to Slice Engineering's Mosquito Hotend) to suspend the block, reducing heat transfer and improving performance. However, these parts would need to be purchased, which is contrary to one of my project aims. Other design changes or modifications could be implemented to address the issues with the previous iterations, such as using a more powerful heater or a different material for the mount.

Despite the challenges and imperfections of the design, it performed adequately for a few closely monitored tests.

Arrows 4 and 5: from an Ender 3 Hotend assembly
Arrow 6: recycled hard drive cage
Arrow 7: from a discarded desktop PC left in a skip on the side of the road





Stage 3: Motorised spool

Next, the extruded plastic filament is attached to a spool in order to be pulled through by the motor during the filament production process.

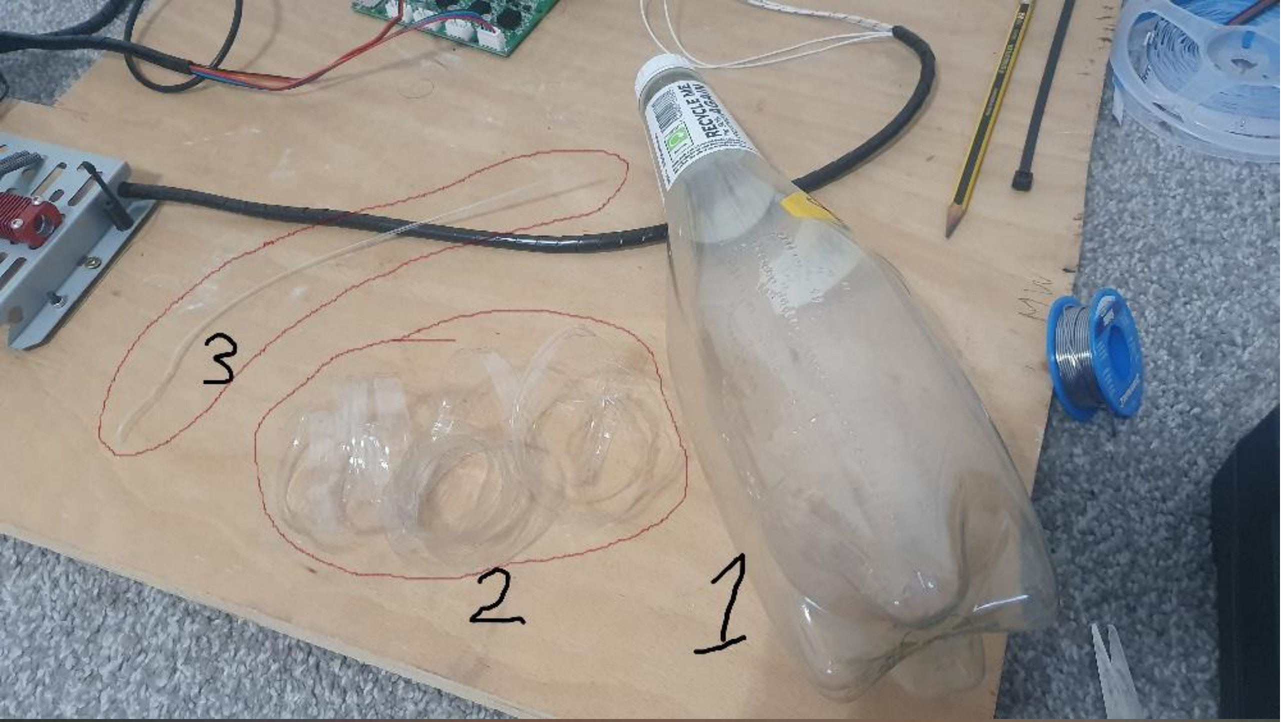
This main spool (arrow 8) is designed to rotate around a smooth chrome rod (arrow 9) and is driven by a 10:1 gear ratio using a Nema17 stepper motor which was salvaged from a decommissioned commercial laser printer (arrow 10) and is controlled by an A4988 driver, which is sufficient for the low speeds at which the spool operates. The driver is a bit noisy, but a quieter driver such as the TMC2209 could be used, though was not necessary in this case.

During operation, the spool rotates and pulls the plastic ribbon through the heated nozzle. It requires high torque and low speed to pull the filament through at an appropriate rate to ensure it's formed properly and does not snap.

I designed and 3D printed the entire spool in PLA (polylactic acid); using ABS (acrylonitrile butadiene styrene) for the gear would have been difficult and potentially resulted in warping during printing. To avoid the need for including supports during the printing process, the spool was designed to be printed in three separate parts – a geared side, smooth side, and connecting tube – and then glued together. In this first prototype (arrow 8), a gyroid infill was used to provide equal strength in all directions. Due to its shape, the gyroid infill did not provide sufficient rigidity; a simpler grid infill would be needed to provide improved performance and so was incorporated into my second design.

In a later iteration, the design was modified to include a notched rod (arrow 11) that is press-fit into the spool. This rod rides on two bearings instead of relying on the chrome rod's low friction; these bearings were added to prevent the gear from jamming during operation. The new gear also has a cubic infill (arrow 12) for added rigidity. This change was made to improve the performance and reliability of the spool.

Arrows 8 and 12: 3D printed spools using Polymaker's recycled PLA filament
Arrows 9 and 11: recycled steel rod from a scrap commercial laser printer
Arrow 10: recycled motor from the same scrap commercial printer



Plastic

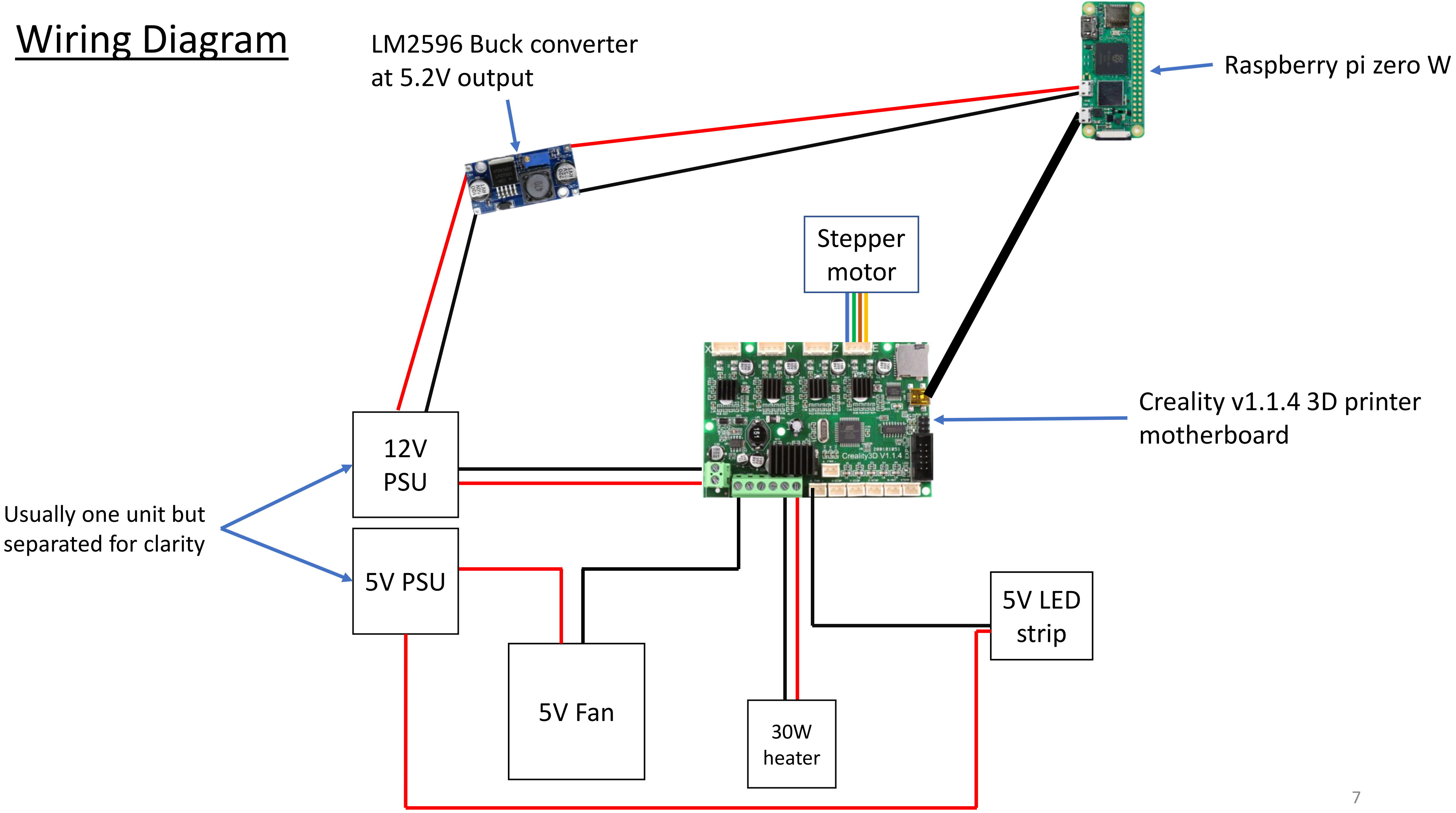
This image shows the three stages of the plastic:

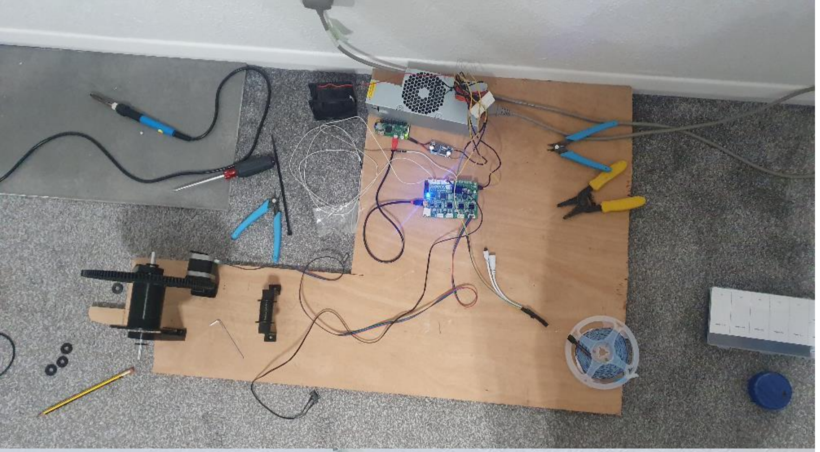
1. The used soda bottle;
2. A contiguous strip of plastic ribbon produced by running the bottle through the machine's slicing mechanism; and,
3. A short section of the usable filament that was formed via pultrusion through the machine.

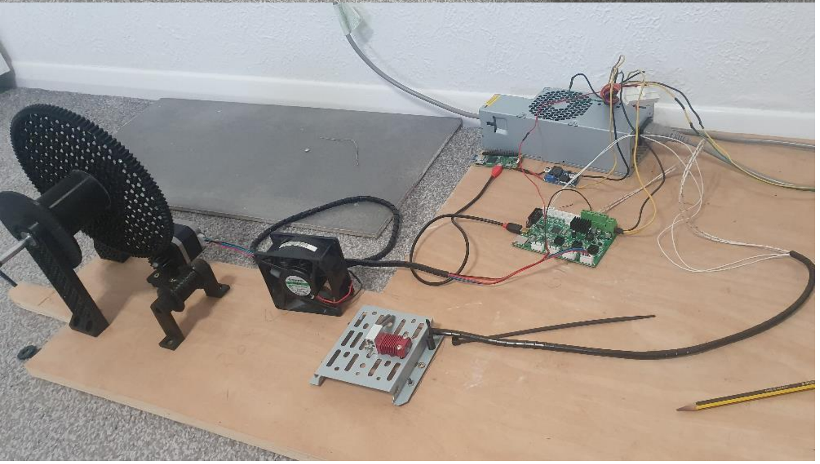
Cover and lid

I built a cover for the machine to protect the electrical components and help maintain a constant temperature. I used wooden boards from a broken dresser and a glass panel from a broken minifridge; I used 3D printed hinges to attach the lid, providing easier access to the controls. Purely for aesthetics, I added an RGB LED strip removed from the back of a broken TV and connected it to the Raspberry Pi for remote control.

Wiring Diagram







These are two photos showing the rough layout of the machine while I tested it.
The lower image shows the first prototype nozzle and the top image shows a rough mock-up before fitting the second nozzle revision

To improve the project further, assuming it does not rely only on recycled parts:

- A GT2 belt could be used instead of gears to ensure a better transfer of torque
- Two sets of grooved bearings after the nozzle could be used to support and shape the filament as it cools
- A 12v air pump could be used to direct air at the tip of the nozzle and prevent the plastic from stretching OR a water pump could be used to pump water through a trough and cool the filament
- A few short lengths of 2020 aluminium extrusions could be used for easier mounting and more rigidity; the wooden board makes changing the distance between parts difficult as new holes have to be drilled each time

These were some of the challenges I encountered and would address in future iterations

- Due to inconsistencies in the plastic bottles, some sections of filament came out with a larger diameter than would be considered acceptable; this can cause clogs and jams during printing as the filament may no longer fit through the PTFE tube. To address this, it likely means limiting the specific bottle types that can be used or finding an alternative mechanism for ensuring consistency.
- The heat block’s temperature occasionally fluctuates; a large enough temperature fluctuation can cause the pultruded filament to melt and shear, interrupting the pulling process.
- The stepper motor used would be more appropriately suited to something requiring precise control, not continuous rotation. Something such as a brushed or brushless DC motor would be better suited as it offers speed control by simply supplying a power source and setting its speed rather than requiring the constant pulses needed by a stepper motor.