Energy Consumption Analysis for 3D Printing FDM materials: PLA vs. PETG vs. PHA.

FDM 3D Printing: The Evolution and Challenges of Printed Materials

Fused Deposition Modeling (FDM) 3D printing is rapidly becoming a household staple, much like the introduction of personal computers in the early 1980s. This widespread adoption has been largely driven by the open-source community that initially pioneered the technology. Today, lower cost, user-friendly 3D printers simplify the process, incorporating RFID-tagged materials that automatically adjust settings for optimal printing. This innovation moves us closer to the seamless, one-touch printing solutions often depicted in science fiction, though we are still far from replicating Captain Picard's tea, we can at least print the cup sitting on a saucer with a spoon all at once.

The most widely used material for FDM 3D printing has long been PLA (Polylactic Acid), a bio-based polymer derived from fermented corn or sugarcane. Through external polymerization with metal catalysts, PLA is processed into pellets for filament production.

While PLA is sourced from renewable materials, its end-of-life (EOL) options remain poorly defined. Terms such as "compostable" and "recyclable" are often used ambiguously, despite the lack of infrastructure necessary for proper disposal. Without dedicated industrial composting facilities or an effective recycling system, PLA's environmental benefits remain largely theoretical.

The question remains: who will fund the infrastructure needed to handle PLA waste properly? Thirty years after its introduction as a functional resin, the industry has yet to provide a definitive answer.

The Challenges of PETG in 3D Printing and Recycling

The second most used material in FDM 3D printing is PETG (Polyethylene Terephthalate Glycol), a modified form of PET, one of the world's most widely recycled plastics. However, despite its shared origins, PETG is chemically distinct enough to be incompatible with existing PET recycling infrastructure. The addition of glycol to the polymer chain enhances impact resistance and printability but renders the material impractical for large-scale recycling.

This incompatibility is particularly concerning given PET's status as one of the most mismanaged plastics. PET bottles are the top discarded plastic item found on beaches, shorelines, and in lakes, contributing significantly to global plastic pollution. If improperly disposed of, PETG poses a similar environmental threat. As it degrades under UV exposure and physical abrasion, it slowly releases microplastics, contaminating ecosystems. The degradation timeline for PET-based materials in natural environments is estimated to be up to 600 years.

Given these limitations, the most responsible disposal method for PETG prints is landfill or incineration—a reality that contradicts the sustainability claims often associated with 3D printing. Without a viable end-of-life solution, PETG remains a single-use plastic in the context of 3D printing, further highlighting the need for alternative materials and improved waste management strategies.

PHA Filament: A Truly Biodegradable Alternative

Enter PHA (Polyhydroxyalkanoates), a naturally occurring polymer produced by bacteria as an energy storage mechanism. Unlike PLA, PETG, and nearly all conventional plastics, which are synthetically engineered, PHA was discovered rather than invented. First identified in the 1920s by French biologist Maurice Lemoigne, PHA is synthesized when bacteria metabolize various biomass sources, including agricultural byproducts and biogases such as methane and CO_2.

This biological origin makes PHA fundamentally different from conventional plastics. Instead of requiring complex polymerization processes with chemical catalysts, PHA is naturally produced and extracted directly from bacteria. As a result, when exposed to microbial activity in soil, freshwater, or marine environments, PHA readily biodegrades without leaving behind persistent microplastics or toxic residues. It is not only biodegradable but also biocompatible and non-ecotoxic, making it one of the most promising materials for sustainable manufacturing.

PHA: A True Circular Material, but Not a Free Pass

Despite its inherent biodegradability, PHA still faces the same end-of-life challenges as PLA and PETG due to the lack of dedicated processing infrastructure. While technically recyclable and compostable, industrial composting facilities are not equipped to distinguish PHA from other biopolymers, meaning that in most cases, it will be diverted to landfills alongside conventional plastics.

However, unlike PLA and PETG, PHA naturally degrades in unmanaged environments, providing a crucial safety net against the growing accumulation of microplastics. This does not mean PHA waste should be carelessly discarded—it is not an excuse to toss failed prints out of a moving car window. Instead, this biological advantage helps mitigate environmental contamination when plastics inevitably escape waste management systems. Or if the intended use exposes the material directly into the environment with no chance of recovery.

For responsible disposal, the best option for failed PHA prints is a home composting system where bacterial activity will efficiently break them down. If home composting is not available, the next best solution is landfill disposal, where microbial activity may still contribute to degradation. Placing PHA prints in municipal composting bins is ineffective, as these facilities lack the ability to process different biopolymers and will ultimately send them to a landfill anyway—so it's better to skip the middleman and use the garbage bin directly.

Now that we've covered PHA's true End-Of-Life reality and skipped the greenwashing, let's explore its energy consumption and processing efficiency.

Setting the Stage: Evaluating Energy Consumption in 3D Printing

This report will not delve into the Life Cycle Analysis (LCA) of the tested materials, as we are not covering the manufacturing, transportation, or raw material processing stages. There are numerous third-party reports on this topic—though they should be read with a critical eye. Most LCAs from petrol-chemical base polymers conveniently halt their analysis at the point of purchase (when the material reaches the consumer), automatically assuming all materials are successfully recycled or industrially composted. Whether this reflects reality is left to imagination, wishcycling and fairy tales.

Instead, our focus is on home energy consumption during 3D printing. We will examine identical object printed on the same platform using three different FDM materials to provide a direct comparison of energy use.

The test object is the Pine Cone Table Lamp, a large beautifully designed lampshade model by Lieselotte Llg (Aka: @Blue Hazel) on Printables. Due to its popularity within my group of friends and colleagues, ten units were made as gifts. The model is available here: 🔗 Pine Cone Table Light on Printables. This print averages 6 hours using 0.6 mm nozzle and 0.2mm layer height in vase mode.

3MF files are linked at the end as well for download.

The 3D printer used is the Prusa Mk4S with a Prusa Enclosure. This marks my sixth Prusa printer, chosen for its dependability, open-source support, and upgradability across generations. More details on their lineup can be found here: 🔗 Prusa 3D Printers

The energy meter is an amazon purchased Spartan Power Electricity Usage Monitor Watt Meter Model SP-PM120.

It provides key data such as Amps (0.001 to 15 amps), voltage, phase balance and W and Kw meter. The unit does have a battery memory backup, therefore moving it to different receptacles or different appliances does not reset the counter inadvertently.

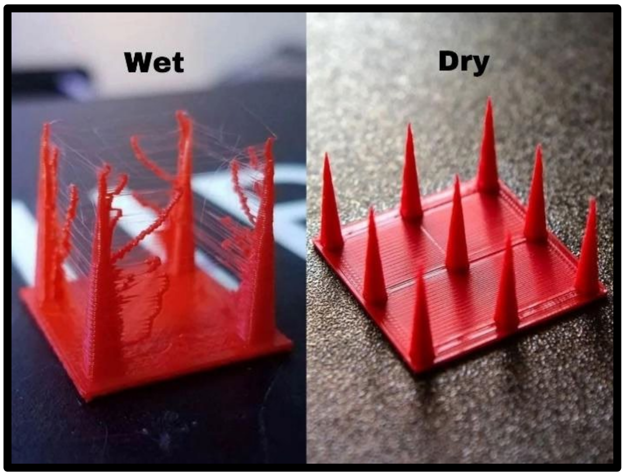
The material dryer is a general-purpose Hot Air Food Dehydrator, a common unit used for its low cost and easy modification needed to convert to a spool material dryer. The unit does have a “temperature” adjusting knob, but the actual temperatures data within the unit were measured using a dual channel J-type handheld thermocouple temperature gauge.

Material Drying:

Nearly all FDM materials are hydrophilic, and while the moisture absorption % is relatively low in the range of 0.3% to 0.5%. The negative impact of moisture on the FDM process cannot be understated. The water particles will in fact bond to the polymer chains, and as they are heated well above their boiling points. The moisture instantly converts into steam and fracture the chain, thus reducing material strength and processability.

This is a common troubleshooting technique for new members of the community when running into printing issues. And simply ensuring the material is in fact dry will facilitate the learning sometime needed to achieve the perfect print.

For both PLA and PETG, moisture saturated filament can be observed by the sound of “popping” steam bubbles upon close inspection at the machine nozzle. Other signs of moisture ingress are “stringing” and poor overall printing performance.



Source: howto3dprint

While the spools of filament do come in sealed bags with small bags of desiccant. It’s important to acknowledge that 3D filament manufacturing does include the use of extended and lengthy water baths to cool the material before it is spooled as a product. It’s also worth noting that any moisture re-absorbed by the material during its processing and potential storage before final packaging also increases the chance of moisture ingress.

Therefore, it should never be assumed that a brand-new spool coming out of a sealed PP bag is in fact dry. And the tiny desiccant bag will do nothing to remove the moisture in the material. It's simply there because people have become accustomed to seeing it and will in fact complain to the manufacturer if they are missing.

There are three methods of removing the moisture from polymers, in industrial conditions. A vacuum hot air system is highly efficient and effective but cost thousands of dollars.

Using recirculating hot air through desiccant beds, where heated air is pumped through the material and then passes through a desiccant matrix for re-absorption of the moisture carried. These are also expensive and have high energy cost.

Last and most coming is simply hot air circulation, where ambient air is pumped and heated then passed through a chamber to collect moisture and is vented out. These are low-cost solutions, and while they are not as effective. For home 3D printing, they are perfectly suited for the job and this is what was used for this report.

There are other options using thin tri-polymer membranes that are energized and attract moisture, but these are not commercially available within the resin processing industry and more suited for high end electronics.

PHA on the other hand is naturally hydrophobic, and while it does absorb a small amount of moisture. The saturated level has little to no impact on the material performance. Therefore, drying PHA is not necessary, neither is the desiccant bag nor the plastic sealed bag. But old habits are hard to break.

Materials Tested: 1kg size

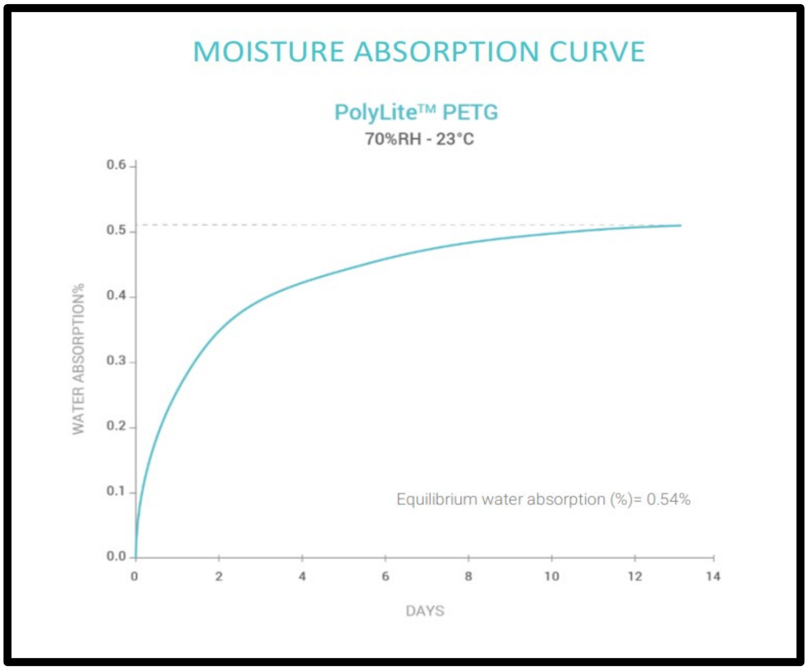
PLA: Generic Bambu Lab White PLA, packaged on a reusable ABS spool in a sealed PP bag with a desiccant, inside a cardboard box.

PETG: Polymaker Poly-Lite White PETG, packaged on a cardboard spool in a sealed PP bag with desiccant, within a cardboard box.

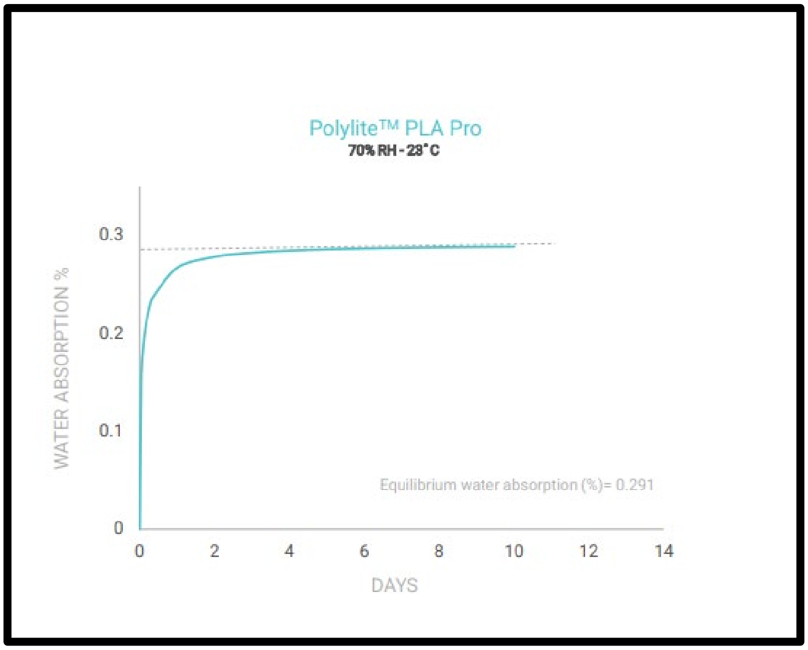
PHA: genPHA™ by ecogenesis biopolymers LLC. (third-generation PHA blend) from our own product line. This mineral and dairy (yes, cows....no there are no bits of cows in our filament) based formulation contains no petrochemical-based or no ecotoxic additives. Packaged in a cardboard box and spool, with a PP liner and desiccant bag.

Polymaker PETG Poli-Lite does offer a Moisture Absorption Curve, using Relative Humidity at 70% ~ 21C.

The graph shown below shows saturation at 0.54% just 14 days after exposing the material out of its protective* PP bag. Thus, re-enforcing the need for proper drying prior to use.



Source: Polymaker US.



PLA shows a saturation of 0.291% after just 48 hours @ 70% RH – 23c

Source: Polymaker US.

Drying Data:

There are specific drying data established by filament providers. I've included two other material vendors per material type.

Type	Brand	SKU	Temp (c)	Hours
PETG	Polymaker US	Polylite™	65	6
	Overture	PETG	65	7
	eSun	PETG	65	4
PLA	Polymaker US	Polylite™	50	6
	eSun	PLA	65	6
	Overture	PLA	65	6
PHA	ecogenesis bio	genPHA™	0	0
	Beyond plastic	EcoPHA™	0	0
	ColorFabb	AllPHA™	0	0

*PP or polypropylene bags are also hydrophilic and will also allow moisture absorption and saturation. Any filament left in a PP bag for longer than 6 months can be saturated with moisture.

Initial Results: Drying

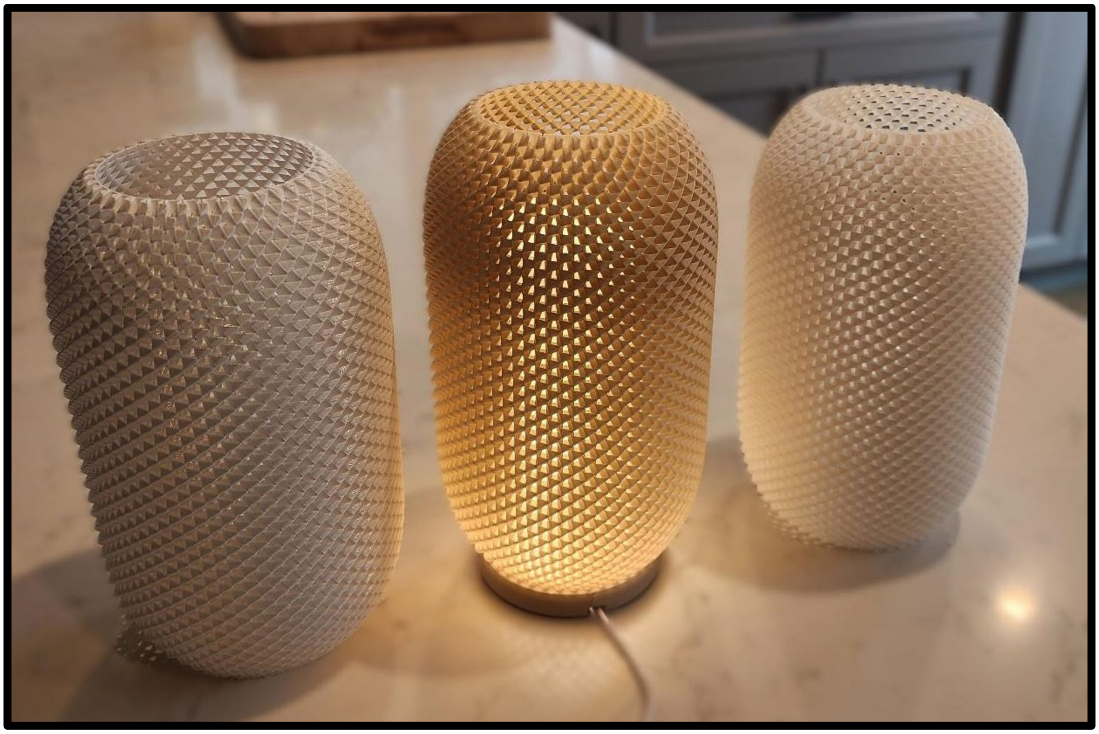
Material	Drying Time	Temp	Kw/hr.	Total Kw
PLA	6	60	0.872	5.232
PETG	6	63	0.930	5.58
PHA	0	0	0	0

Average amperage drawn of 1.884 Amps for the converted food dryer.

Per 1Kg of PETG, we used 5.58 kW. Or roughly $0.908 for a national average cost of 16.26 cents per kw/h.

Initial Results: Printing

Material	Print Time	Temp (Ext/Bed)	Kw/hr.	Total Kw
PLA	6	210/60	0.473	2.838
PETG	6	240/80	0.872	5.232
PHA	6	200	0.231	1.386



Left to Right: PETG - PHA - PLA

On the per print total consumption, PHA is 67% less than PLA and 73% lower than PETG for an identical 6-hour print.

The overall cost impact comparing each material is not significant. $0.23 vs. $0.46 per print is not going to break the bank so to speak.

Material	Total Kw	$/kW (National av. $0.1626)	Compared to PHA
PLA	2.838	$0.46	2X
PETG	5.232	$0.84	3.6X
PHA	1.386	$0.23	

Looking at both activities of Drying + Printing, the delta between each material greatly expands. Especially when comparing PHA.

Results: Assuming Print + Drying

Material	Total Kw	Est Cost	Compared to PHA
PLA	8.07	$1.32	5.7X
PETG	10.812	$1.76	7.7X
PHA	1.386	$0.23	

Drying PLA before printing isn't always necessary, as moisture sensitivity varies between different brands and formulations. Factors such as the material's age and the time elapsed between manufacturing and delivery also play a significant role in its moisture content. Unfortunately, there is no simple way to determine a filament's moisture levels. Accurate measurement requires a moisture analyzer, a destructive testing method that involves cutting a sample, weighing it precisely, and rapidly heating it to high temperatures.

In contrast, PET is highly moisture-sensitive and can introduce significant challenges when troubleshooting print quality. Given its hygroscopic nature, it's generally safe to assume that a PETG spool exposed to a typical indoor environment for any period has absorbed moisture and should be considered "wet."

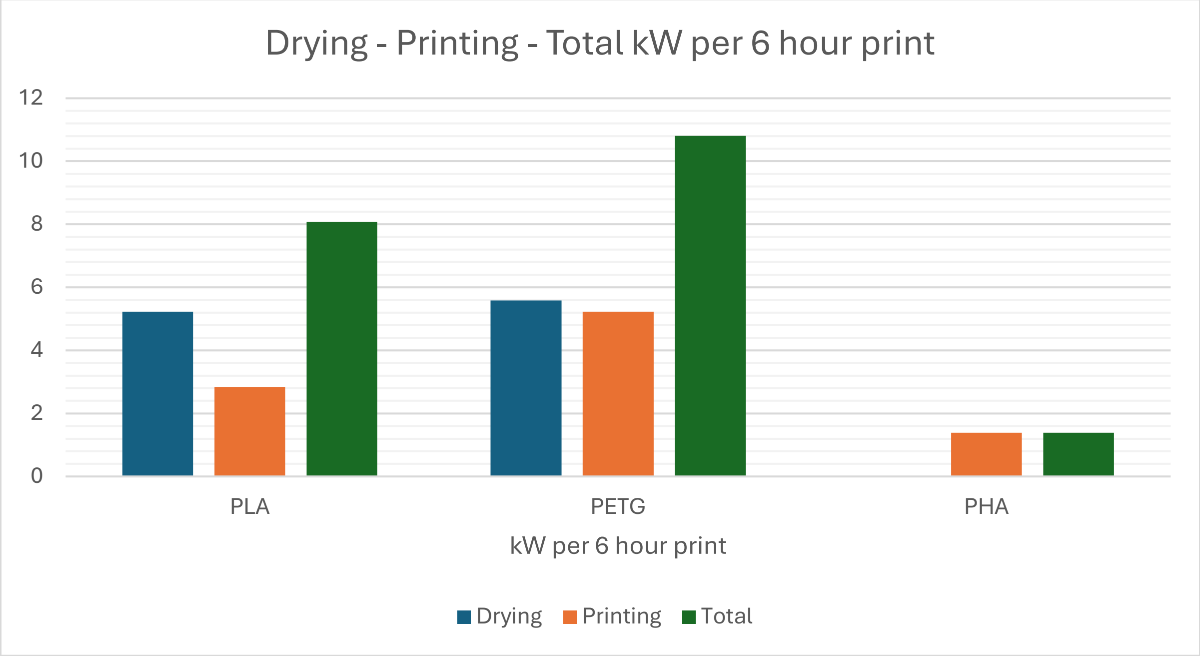
Conclusion

As 3D printing becomes a household staple, it's increasingly finding its place in garages rather than living spaces, especially given concerns over VOC emissions (a topic for another time). With the industry growing at an annual rate of 20–25%, printer manufacturers are making strides toward user-friendly systems. The adoption of RFID-based automation is simplifying the process, allowing users to select an object, choose a material, and print without extensive technical knowledge.

However, on the materials side, little has changed. PLA, PETG, TPU, ABS, and other early 3D printing filaments still face the same end-of-life (EOL) challenges. While PLA has matured in some ways, manufacturers have largely backed away from misleading "compostable" claims—the reality is now widely acknowledged: PLA does not biodegrade meaningfully and can contribute to environmental contamination just like PETG, ABS, and other traditional polymers.

Another major concern is the lack of regulation surrounding 3D printing plastics. Since they are not marketed as food-safe, the pigments, colorants, additives, and modifiers used in filaments remain unregulated and proprietary, making their exact compositions a mystery. As a result, landfill disposal remains the best-case scenario for most of these materials.

PHA filament presents a more sustainable alternative, particularly for those with access to a home composting system and the patience to allow natural degradation. If mismanaged and exposed to the environment, PHA does not contribute to long-term plastic pollution, unlike conventional polymers. This makes it an ideal choice for applications such as garden planters or pet-safe prints—ensuring that even if a PHA object ends up in nature, it won't leach toxins into the soil or water.



Additionally, this report would indicate that PHA printing activities consume **five times less energy** than the more common PLA filament. While this might not make a significant difference for hobbyists, it can become a crucial factor for large-scale printers running multiple printers around the clock.

Energy efficiency, combined with true environmental safety, positions PHA as a smart choice for those looking beyond the current status quo of 3D printing materials.

Just remember, do not expect PHA Carbon Fiber Re-enforced Glow in the Dark Hot Pink filament anytime soon.

3mf files are available here: https://drive.google.com/drive/folders/1f-FlBvuN8J-vlNB75eLXuVfjyu2fn9AK?usp=drive_link

Author: Fred Pinczuk, CTO, ecogenesis biopolymers, LLC. For more information about Fred, https://www.linkedin.com/in/fredpinczuk