Green Roof Team
Sustainably Green Solutions

Economic Benefits of 3D Printing and Composite Materials in Small Wind Turbine Blades

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I. Introduction

The increasing prevalence of wind power in recent years, in addition to a societal focus on zero emissions and sustainable energy, leads us to question the potential of small wind turbines and their future improvement. In light of the 14% increase in national wind power ("Wind - IEA"), we will discuss the economic benefits of small wind turbines actualized by recent developments in 3D printing and bio-composite materials.

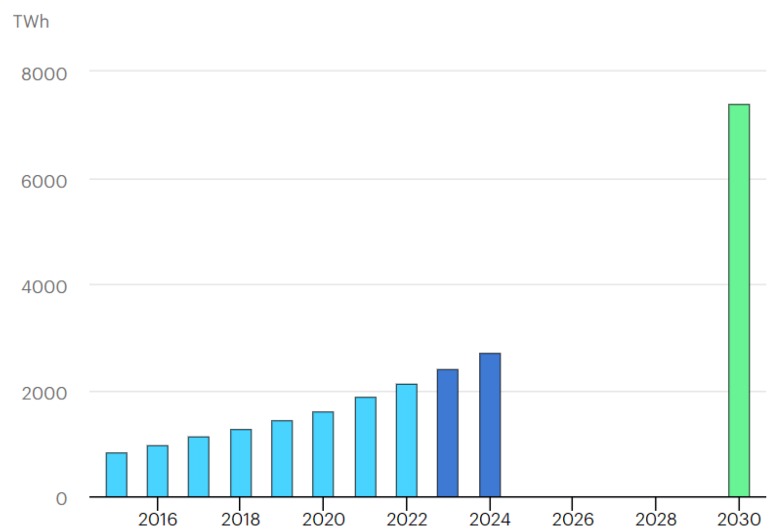


Figure 1. Year vs Global Wind Power Output

In summary, 3D printed wind turbine blades may be cost effective for small turbine manufacturers by providing a cheap and fast manufacturing method capable of creating custom turbine blades. Additionally, the development of bio-composite materials like BioBalsa and hemp composites offer a cost-saving and sustainable material capable of integration into already-existing turbine blade manufacturing processes. Finally, small wind turbines are already profitable to homeowners, and their viability for home use and environmental-impact will only increase as these new technologies are implemented.

II. Traditional Manufacturing vs Additive Manufacturing

Wind turbine blades are often manufactured using a large casting mold. The blade itself is often made from steel, cured resin, carbon fiber, or fiberglass (Mishnaevsky). Large part casting typically requires a large down payment to produce the mold, eventually paid off through mass production reusing the same mold again and again.

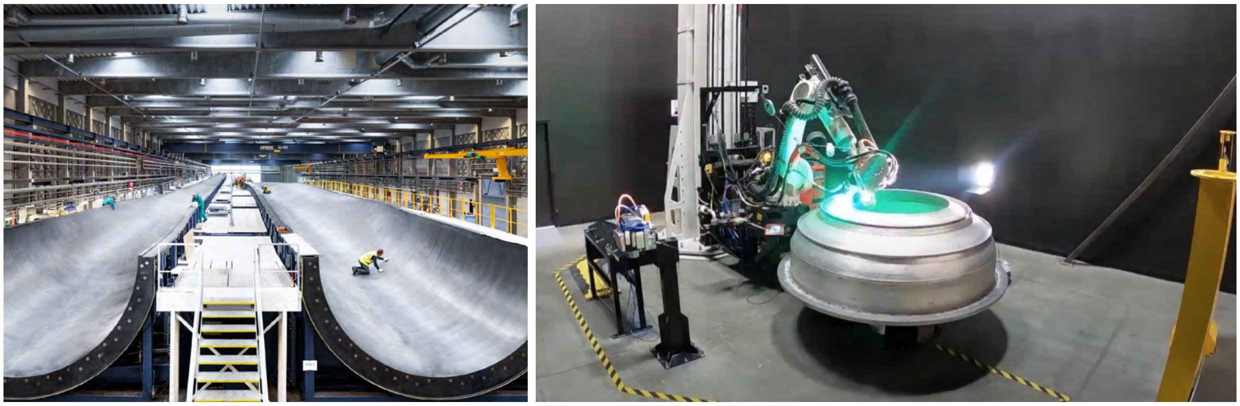


Figure 2. Two halves of a wind turbine blade and a rocket being printed

The use of 3D printed plastic or metal may offer cost and time savings compared to this method, specifically for smaller sized turbine blades. Eric Monson, a former intern for Relativity Space, says that “3D printing allows for quick, cheap, and precise manufacturing.” For this reason, many aerospace companies are adopting metal 3D printing for their engines. Relativity Space, a company responsible for the first 3D printed rocket, is proving that 3D printing is a viable manufacturing method for any industry, according to Monson. “If you can 3D print a working rocket, you can 3D print anything.”

In addition to time and cost savings, 3D printing turbine blades allows for variable blade designs unlike molded parts. Though largely limited by size, 3D printers would allow different size and region-optimized turbine blades to be produced from a single machine without long curing times, a valuable resource for small companies making small wind turbines.

III. Traditional Manufacturing vs Bio-Composite Materials

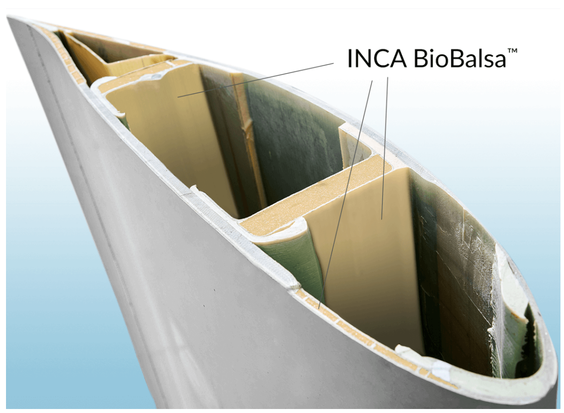
Alternatively to 3D printing, bio-composite materials may help meet typical stiffness targets while remaining lightweight, with natural-based composites like hemp fiber offering a sustainably-minded replacement for carbon fiber.

Carbon fiber and fiberglass, common materials used for turbine blades, are hard to recycle and are produced using complicated chemical processes. Unlike these fibers, hemp fiber can be grown and is biodegradable. While hemp composites are lighter, they often have a considerably smaller Young’s Modulus, indicating more material would need to be used to achieve the same rigidity as carbon fiber (Krigslund-Hansen).

Furthermore, according to a Sandia National Labs paper, textile based heavy-toe composite materials offer a better strength-to-cost ratio. They also have a better tensile vs compressive strength ratio, which is ideal for wind turbine blades. Due largely to these factors, the Sandia National Labs researchers found that the material cost for a textile composite turbine blade was 16% lower than their fiberglass design and 43% lower than their carbon fiber design for a 3MW turbine (Ennis).

Figure 3. A hemp fiber weave

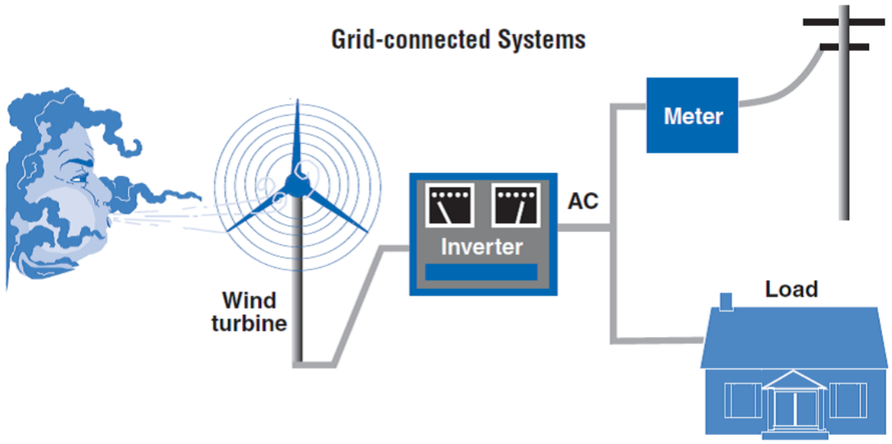
A Canadian-based company INCA RenewTech is already utilizing bio-composites to replace the strengthening foam and balsa wood commonly placed inside wind turbine blades. RenewTech's Chief Marketing and Sales Officer claims that BioBalsa "generates 107% less greenhouse gas emissions and reduces waste generation by 93% compared to the cutting and milling of balsa wood. It generates 164% less carbon emissions than PET and has 99.56% less waste production and 93% less water consumption than foam production" (Jay).



Bio-composites come with drawbacks, however. As previously discussed, hemp composites have a smaller Young's Modulus carbon fiber, requiring more material for the same rigidity. The need for more material can restrict the geometry of the turbine blade to less slender designs, which are less aerodynamic and have worse energy efficiency than carbon fiber blades (Ennis). Additionally, lack of hemp supply poses a serious obstacle; there are not enough large-scale hemp farms dedicated to industry to fully replace the carbon fiber used for wind turbines. (Krigslund-Hansen).

VI. LIFE CYCLE COST ANALYSIS

The cost for a small wind turbine averaged $5120 per kilowatt in 2021, with a 5 to15 kilowatt turbine required to significantly help power a typical home. That translates to between $25,000 and $75,000 dollars to buy a small wind turbine. The payback period depends on the turbine, where the customer lives, and the customer's energy needs ("WINDExchange: Small Wind Guidebook"). Maintenance costs average 1.5-2% of the original cost for modern turbines ("Wind Measurement International"). For a certain wind turbine, take the AIR 40 for example, the payback period is about 15 years, assuming electricity costs $0.10 per kWh. This calculation is linear, so if a region charges $0.20 per kWh, the payback period will be half of 15 years (Shine).



Wind turbines should last at least 20 years. This is generally considered the minimum, especially with small wind turbines that require less repair. Once again assuming a payback period of 15 years and a product lifetime of 20 years, the wind turbine effectively generates a minimum profit of 33% of its original cost over its lifetime. For the $25,000 - $75,000 range, this is an average of $16,500 total profit, or $825 a year. Note that this profit is generated sustainably, and small wind turbines will only become more efficient as the previously discussed technology is further integrated.

V. CONCLUSION

To conclude, 3D printing offers a unique opportunity to produce wind turbine blades, as demonstrated by companies like Relativity Space. Meanwhile, new bio-composite materials provide a cost-saving solution to the negative environmental impacts of typical turbine blade manufacturing. Though both technologies are promising, more research needs to be done into their upscaling. How many and how large hemp farms are needed to fully replace the carbon fiber used by current wind turbine manufacturers? Is there a relationship between 3D printer size and efficiency?

Despite these uncertainties, we can clearly see that the development of 3D printing and bio-composite technologies offer relevant and sustainably-minded improvements to the wind turbine industry.

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