Paper Need Not Be Flat: Paper and Biomaterials Industries Need to Converge to Bring about True Innovation

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Biomaterials and new processes (3D printing and flexible hybrid electronics) offer opportunities to break free from a 2D paper world by allowing for the development of smart multi-dimensional structures. While there has been recent progress reported in each of these areas of technology, to date, the merger of these technologies has been very limited. We believe that their merger offers boundless opportunities and an opportunity for the paper industry to innovate a low cost, sustainable housing solution capable of promoting the well-being of its occupants while minimizing the environmental impact of its daily use.

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Introduction

There are over 28,000 uses of paper, most of which are 2D in structure. However, with the global need for low cost, sustainable, and renewable material solutions, this industry has the potential to create product innovations that are multi-dimensional in nature. While today's paper is used for communication, packaging, hygiene, and many other applications, its use has fallen over the years as much of the publication markets have been lost to electronic media, and the use of plastic and foils for packaging have increased. If we use a paper sheet as a 2D reference, we can easily come up with another 2D application, maybe of a different size or color. However, with the advent of digitization, e-commerce, and development in biomaterials, the paper industry no longer needs to be confined to 2D. Instead, the industry must begin to look at what can be done with its resources to create multi-dimensional products utilizing new biomaterials, 3D printing, and printed flexible hybrid electronics to spur new market growth. Can utilizing these technologies enable smart, flexible, stretchable, foldable renewable structures to be created? Are low cost and biodegradable structures possible? The challenges faced in bringing together biomaterials and 3D printing technologies diminish as each technology advances in its own right, but what will bring these technologies together? One possibility is a global need that cannot be answered without new innovation, and can only occur through the merging of these technologies. We believe that one such need is affordable and adaptable housing that is safe and smart enough to contribute to the well-being of its occupants and surroundings. 3D printed houses using biomaterials could be boundless and contain smart sensors, energy storage devices, and other active devices capable of promoting the well-being of its occupants and minimizing the environmental impact of their daily use. Such an undertaking would require the engagement of a multidisciplinary team of industry experts with many public, private, and government sectors of business.

Biomaterials

The development of biomaterials derived from renewable resources has the potential to dramatically impact many commercial markets including construction, medical, automotive, aerospace, and consumer products industries. There is a renewed interest in replacing fossil-derived synthetic plastics with renewable polymeric materials due to increased environmental concerns and end-of-life disposal challenges. This can be achieved through the careful selection of the feedstock, chemical, and physical structures of polymer materials during processing. For example, nanocellulose and nanocellulose reinforced materials are lightweight, ductile, stronger, and stiffer. They can be made transparent and can conduct electricity. They can be produced in relatively large quantities unlike other high-performance materials such as graphene. However, some key challenges exist such as low solids levels of nanocellulose suspensions, slow rate of drying, high cost, and difficulties in achieving immobilization and stable dimensions. We need to make rapid progress by addressing these issues for successful commercial implementation in existing and new markets such as rheology control, packaging, coatings, environmental remediation, energy conversion, and sensing technologies.

3D Printing

A large portion of today's consumer and industrial products are mass produced using a variety of traditional manufacturing processes such as molding, machining, forming, and joining. They are mainly produced from fossil-derived synthetic plastics, ceramics, and metals on a large commercial scale for distribution around the world. This is a proven business model; however, it has drawbacks such as special tooling needs for manufacturing, higher costs for low volume and complex parts production, risk of availability due to limited sourcing and catastrophic events, and increased environmental concerns and end-of-life disposal challenges. In addition to these drawbacks, this business model also has a limited scope for design iteration for exploring new designs and materials due to high upfront tooling costs and lead time. It also has an inefficient supply chain due to a dependence on large-scale centralized manufacturing facility requiring massive support infrastructures. It also has a high cost of shipping, warehousing, and distribution due to raw materials and finished products shipping around the world instead of regional production.

There is a continued thrust to find alternative business models to develop manufacturing technologies, materials, and a supply-chain to conserve the limited reserve of nonrenewable raw materials such as fossil-derived synthetic plastics, ceramics, and metals and to develop renewable biomaterials to support future growth in consumption. 3D printing is a relatively new process to create three-dimensional objects. It is categorized as a layer manufacturing technique, since it has the remarkable characteristic of not only making existing parts, but also making possible the production of new products that weren't even conceivable before by controlled addition, rather than subtraction. It provides the freedom to make complex geometries, customization, and functionalized designs that could lead to the production of light-weight products without sacrificing strength. The continued development of 3D printers and materials could pave the way for the development of high performance light weight, green, and smart machinery. 3D printing has already been demonstrated to be capable of producing customized cars, buildings and other large scale structures, but the emergence of this technology to embrace biomaterials and to build structures capable of interacting with their environment has not yet emerged.

Flexible Hybrid Electronics

Flexible hybrid electronics combines flexible silicon chips with printed electronics substrates to create lightweight, conformable, active electronic devices. Special attention is being given to paper as a substrate for printed electronics due to its excellent properties, such as resilience, low dielectric constant, stiffness, foldability, mechanical strength, disposability, ease of availability, thermal stability (ability to be processed at relatively high temperatures), controlled transparency, scalability, and low cost. However, modifications to paper substrates are required in order for them to be adapted for use in the production of printed flexible electronic devices. The substrate properties needed for printed electronic applications depend upon the type of device to be produced, which dictates the number of layers of functional inks that must be printed, print resolution, registration accuracy between layers, and print quality. Examples of printed electronics on paper demonstrated to be functional are capacitors, batteries RFID antennae, biosensors, and intelligent packing labels.

Paper-based printed electronic devices have also been created by incorporating electronic materials into paper during the papermaking process. Such papers have been used to fabricate energy storage devices, sensors, electric heaters, electric field emitters, and electromagnetic shields. Photoluminescent papers have also been produced in a similar manner by adsorbing a luminescent polymer onto the surfaces of cellulose fibers. Another approach not yet explored would be to utilize the high surface area of nano-fibrillated fibers to create electronic scaffolds that can be formed into sheets or 3D printed to create functional devices. The advantage of incorporating such materials into a paper web is that it could be done over large areas at high throughput. Selective patterning methods could then follow to activate or deactivate parts of the sheet, but would require the development of new paper machines or converting operations that are modular and more flexible to enable seamless changeovers.

Growth Opportunities with Convergence

With the convergence of biomaterial products and novel manufacturing technologies, this industry could go after many markets, including construction, which is forecasted to be $10.3 trillion in 2020 [1], addressing a global need for affordable and adaptable housing that is safe and smart enough to contribute to the well-being of its occupants and surroundings. Transition from flat paper to 3D paper could enable biomaterials printing of functional structures with embedded sensing technologies, *i.e.* nature homes, by being controlled transparently around the clock, folding or stretching when needed, and harvesting energy directly from sun, *etc.*, so as to bring human beings closer to nature even when they are inside their house.

References

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