Title: The Influence of Biomimicry on Sustainability

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Table of Contents

I. Abstract

The natural world has been evolving for over three billion years through the process of natural selection. Evolution continues to perfect systems through form, function, pattern, strategy, and enumerable other applications. Looking towards nature can reveal previously overlooked or ignored capabilities and functions. When solving design problems or seeking innovative solutions, billions of years of natural selection can help deliver insight on problems or solutions beyond what was originally conceived. This process is called biomimicry: applying biological solutions to human problems. Growing interest in biomimicry has prompted a reenergized focus on innovation inspired by nature. The possible applications of biomimicry are immense and continue to reveal inspiration in innovation and design beyond what was originally imagined or constructed. This paper will investigate the applications of biomimicry in innovation - emulating form, function, pattern, and strategies. By investigating applications of biomimicry, it can be deduced that advancing this field will greatly influence a renewed focus on sustainable innovation. As sustainability becomes increasingly important, looking towards biomimicry will pave the path towards a sustainable inspired innovation platform. Eco-innovations energy savings, materials optimization and waste reduction display further insight on how biomimicry is influencing sustainable innovation.

II. Introduction

Growing enthusiasm surrounding biomimicry has spawned a reenergized glimpse into how biology can be interpreted and incorporated into innovation through design. The biological systems we observe today are a result of nearly 4 billions of years of natural selection. Further insight into the natural worlds form, function, pattern, and strategy can reveal new avenues for innovation beyond what was originally conceived. As technology continues to advance, it is imperative that the most innovative apparatus on earth, natural biology, is not overlooked. The essence of innovation inspired by nature will pave the path to new designs that promotes greater efficiency and sustainability. Inefficiency is a paradox in nature. The brutality of natural selection dictates that organisms better adapted to their environment survive. Thus, nature can inspire a plethora of solutions to the problems we face currently and looking towards the future.

Biomimicry illuminates the interdisciplinary nature of science and technology. Humans have long looked towards nature to draw inspiration in design. Leonardo da Vinci famously imitated his observations from bird movements to design his flying apparatus in the Renaissance period [1]. This early example of conventionally applying observations from nature reveals its multifaceted applications. Biology can be mimicked, re-interpreted, and re-applied; ranging from energy, architecture, transportation, materials, and communications, it's difficult to completely grasp the full potential of new capabilities and functionality biomimicry can hone. Human curiosity inherently drives new innovation, but there is a renewed paradigm shift towards sustainable innovation. This paradigm shift is representative of the increasing importance to derive innovations that will aid in solving the most pressing problems we collectively face today through sustainable innovation.

In this paper, I intend to investigate the application of biomimicry in sustainable innovation – emulating form, function, pattern, and strategies. Nature has always been a source for inspiration, however, within the last decade it's apparent that this transformative field has a lot more to offer in the

sphere of sustainable innovation. The future of sustainable innovation will predominantly be overshadowed with an increased emphasis on biomimicry to reevaluate our use of energy and materials. Nature continues to reveal surprising revelations on how energy can be honed, how materials can be reimagined, how our processes can more efficient and less toxic. Biomimicry as a sustainable innovation platform is enlightening opportunity areas in energy savings, materials optimization, and waste reduction.

Biomimicry is reinvigorating the sustainable revolution by challenging the way we view nature and reapplying it practically in industries already saturated with innovation. Sustainable value honed from biomimicry-based innovations will show how this field is altering industries spanning from energy, materials, to industrial biotechnology. Sustainability and biomimicry have a wide arching influence - ranging from technology to more benign forms of design. Nature influences biomimicry while sustainability emulates sustainable credentials [2].

Considering the main area of research, biomimicry and sustainability will be defined individually and concurrently. The following passages will include a multifaceted literature review aiming to reveal the applications and influence of biomimicry on sustainability. More specifically, examples will be cited in the realm of energy, materials, and waste reduction.

III. Biomimicry

Biomimicry is an approach to innovation that seeks to promote sustainable solutions by creating products, processes, and policies that emulate nature's patterns and strategies [3]. The term biomimicry first appeared in scientific literature in 1962 and became more widely adopted among biological scientists in the 1980's [4]. Although emulating nature to solve problems was not a novel and unexplored field relative to the act, associating the term "biomimicry" to the concept allowed wider scientific adoption as well as curiosity in the field.

Biomimicry was famously coined by scientists Jenine M. Benyus in her 1997 publication "Biomimicry: Innovation Inspired by Nature" [3]. Beynum defines biomimicry as "the conscious emulation

of life's genius" [4]. Proponents of biomimicry argue that this enables a path towards a more sustainable future. For instance, nature harnesses energy and utilizes materials while not imposing toxins on the surrounding environment. Thus, human can study nature's model and innovate with an ecological lens.

In biomimicry, nature is viewed as a ***model***, ***measure***, and ***mentor*** [3]. Nature as a ***model*** means either the imitation or inspiration from nature's design processes to solve human problems. Nature undoubtedly provides us with a rich source of knowledge that lies beyond the "direct imitation of natural forms" [5]. This means that imitation does not necessarily entail direct mimicking, but rather learning from nature's processes and reapplying it towards human requirements - such as a solar cell inspired by a leaf. Nature as a ***measure*** relies on the ecological standards developed over the 3.8 billion years of natural evolution to determine what does and doesn't work. This standard enables an understanding of what innovations are "right" relative to what's appropriate and will last [3]. Nature as a ***mentor*** is a new way of valuing nature beyond from what we can extract from it, but rather what we can learn from it. The industrial revolution marked the transition to new manufacturing processes which was characterized by the domination and exploitation of nature [6]. Contrary to the industrial revolution, biomimicry is characterized by learning from nature rather than exploiting it.

It's evident that nature holds an all-encompassing slew of information greater than any conceivable library. Biomimicry offers strategic advantages relative to uncovering new observations and discoveries that enable reimagined innovations. Applying natures designs and strategies is challenging the way we capture energy, make materials, and conducts business. The synthesis of biologically inspired innovation is opening "novel insights of biologically-compatible, environmentally-friendly and energetically efficient" innovations spanning from technology, materials, to processes [7].

A. Biomimicry Principals

The principals of biomimicry are fairly straightforward and revolve around the fact that nature created conditions conducive to life (***figure 1***). These conditions are interconnected, interdependent, and

has a set of strategies that has sustained for billions of years. Each condition highlights nature's ability to ensure enduring performance, skillfully take advantage of resources, respond to change, invest optimally, integrate into surroundings, and use chemistry that integrates with life's processes [8]. The process of sustainability is essentially engrained into the building principals of biomimicry.

Figure 1: Life's Principles Biomimicry DesignLens [8]

Benyus further simplifies this into 9 basic principles: "(1) Nature runs on sunlight. (2) Nature uses only the energy it needs. (3) Nature fits form to function. (4) Nature recycles everything. (5) Nature rewards cooperation. (6) Nature banks on diversity. (7) Nature demands local expertise. (8) Nature curbs excesses from within. (9) Nature taps the power of limits [3]." These principals reiterate the dynamic and interconnected functionality of nature. The process of research and development is engrained within evolutionary progressions optimizing form, processes, and strategies. This reiterates how biology and sustainability have interconnected attributes that can offer inspiration to solve human problems.

B. Biomimicry Approaches

Approaches to biomimicry can be divided into problem based (top-down) and solution based

(bottom- up) approaches (***figure 2***). The problem-based approach is problem driven biologically inspired. This approach looks towards biology for inspiration to solve problems. The solution-based approach is solution driven biologically inspired. This bottom-up approach defines a solution then looks towards biology for inspiration. Both methods highlight how biomimicry can drive and inspire innovation while capturing value through problem and solution based approaches.

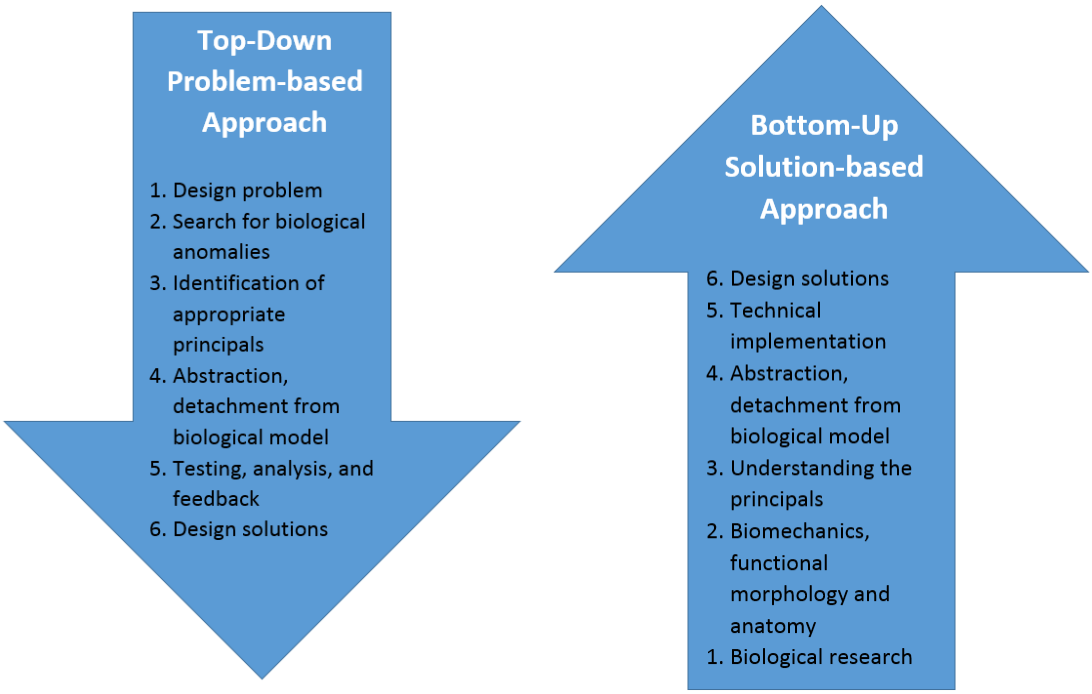

Figure 2: Biomimicry Approaches [2] [4]

C. Biomimicry as an Innovation Engine

Emerging trends and opportunity areas in the biomimicry discipline are reflected in the growing numbers of biomimetic innovations (***figure 3***). Nature's materials, systems, and processes are a treasure trove for innovation [9]. Bio-inspired innovations serve a wide variety of benefits – from reducing the amount og time and cost associated with development, opening avenues for new products and markets, efficiency gains, and sustainability goals [9].

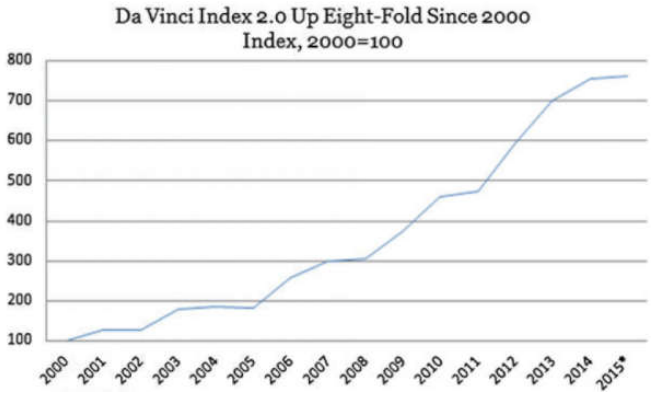

Figure 3: Da Vinci index of Biomimicry growth-updates to 2015 [10]

Because biomimicry is considered a method for generating ideas, it naturally drives innovation growth. Additionally, biomimicry has been established as a "means to address the current need for sustainable innovation [10]." Utilizing biomimicry as a tool for sustainable inspired innovations has renowned implications relative to how it can influence the world.

IV. Sustainability

It is evident that the sustainable use of natural resources is a global concern [11]. This growing distress is even reflected in the 2013 European Union Manifesto for a Resource-Efficient Europe which emphasizes the "EU has no choice but to transition to sustainability" [12]. This transition entails that resource-efficient and regenerative circular economy is not only a desire, but an imperative [6]. The biomimetic approach to innovation has been received as a welcoming alterative to innovations and technologies of the industrial age. The industrial age is characterized by technologies and materials that pertain ecosystem disruptive qualities whereas biomimicry aims to harmoniously learn from and explore nature. This contrast presents an interesting paradigm shift – the global economy exploits nature's resources, so how can a balance be achieved while still influencing economic interests?

A renewed focus towards sustainable growth would achieve this relative balance between. In fact, biomimicry has been deemed an "economic game changer" and has the potential to represent $300 billion annually in U.S. GDP by 2025 [13]. The economic cost of pollution, waste disposal, and natural resource depletion have a vast cost reduction potential. This entails that a balance between nature and global

economies can not only be maintained but also thrive.

Bridging business with environmental interests presents a cohesive relationship through sustainable innovation. This was widely ignored by the industrial revolution as economies multiplied at a scale faster than previously ever observed. The outcome of the industrial revolution presented factory systems and mass production. This offered a way to improve both efficiency and profit however, sustainable practices were not widely used nor promoted. The shift towards sustainability presents a renewed global imperative. Unsustainable "patterns of production and consumption" require rethinking through sustainable development and innovation [14].

A. Sustainable Value Framework

Sustainability entails that there is no negative implication on the environment. Having sustainable credentials aims to reduce resource utilization, consequence on the environment by displaying nontoxic, recyclable, and energy efficient attributes [2]. Essentially, the practice of sustainability invokes reducing the contamination of resources, efficiently utilizing required resources, and reducing the amount of waste produced while utilizing resources.

Similar to the industrial revolution, the sustainable revolution has a similar profound impact on the way we approach innovation and design [15]. A couple questions arise from this statement: (1) why is sustainability important and (2) what is the motivation for sustainability. The short answer to both questions is that the resources we use and waste we produce far surpasses what the earth can sustain long term. The so called "regenerative circular economy" does not currently exist with our current model of resource utilization and waste generation.

The sustainable value framework (***figure 4***) identifies practices and strategies that contribute to sustainability while concurrently delivering value. Sustainable value creation is delivered by presenting four core dimensions: clean technology, sustainability vision, pollution prevention and product stewardship. Each dimension corresponds with a strategy pertaining to relative payoffs. This visually

presents a clear answer to why sustainability is important and what motivations exist.

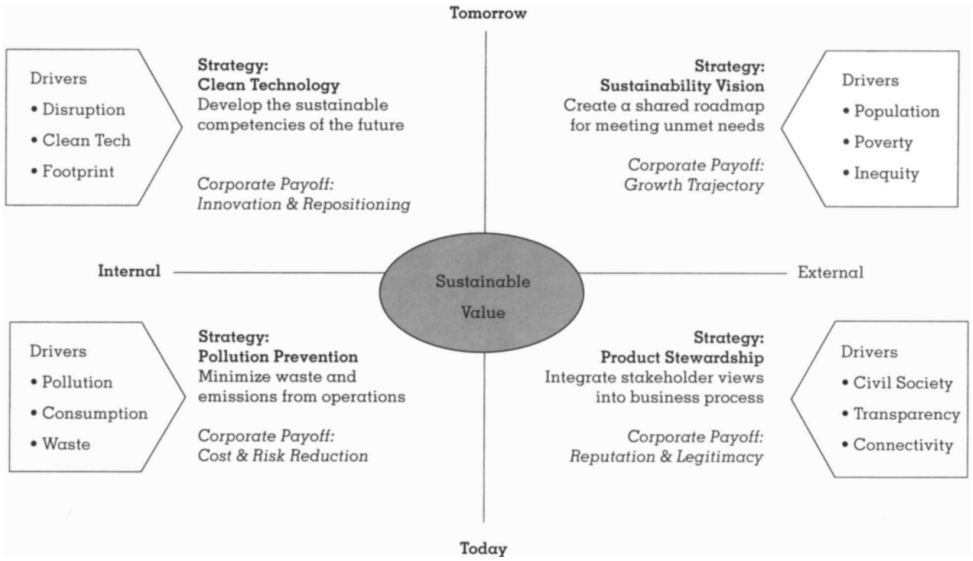

Figure 4: Sustainable Value Framework [16]

B. Sustainable Orientated Innovations

Sustainable oriented innovation premise is the introduction of a new or improved product or service that leads to environmental or social benefits [17]. The earths finite resources paired with consumption-based business models imposes a global threat [18]. Sustainable oriented innovation intends to overcome these global challenges by promoting innovation beyond typical boundaries. Redefining the way we approach innovation by promoting sustainable practices continues to present new and improved products and services.

Sustainable oriented innovations can be represented with three environmental dimensions: process, organizational, and product [19]. Process innovations involve the production of good or services with the aim of improving efficiency or chemical consistency. Organizational innovation pertains to reorganization of routes and processes. Finally, product innovations are improvements or new developments in products or services. These dimensions represent how innovations can pertain sustainable qualities in an extensive slew of industries. Sustainable oriented innovation has the potential to impact the way be produce and process chemicals, capture and create energy, and utilize materials

more efficiently.

V. Biomimicry & Sustainability

Innovation is approached using various strategies - biomimicry is one approach to innovation which is oftentimes viewed in context with sustainability. The era of rapid technological change has put increasing pressure to innovate. Biomimicry has proven to be a powerful approach towards sustainable driven innovation [14]. The symbiotic relationship between biomimicry and sustainability might be contradictory depending on how it's viewed. For instance, a bio-inspired innovative design may be manufactured using toxic materials and large quantities of energy [10]. However, the principals of biomimicry reiterate that the mechanism of emulating nature involves a clear emphasis on what we can learn from nature rather than what we can extract from it.

A. Creating Sustainable Value in the Biomimicry Discipline

Similar to the concept of sustainable oriented innovation spanning various dimensions, sustainable value in biomimicry based disciplines extend to materials optimization, energy savings, and waste reduction. In biomimicry, an innovation is influenced by observations from nature - emulating form, function, patterns and strategies. ***Figure 5*** links the relationship between technology, inspiration and environmental sustainability improvements in context to biomimicry [20]. It is evident that not all technologies necessarily need to positively impact all sustainability improvement dimensions although, it's clearly possible.

Technology	Primary Inspiration	Environmental Sustainability Improvements		
		Material Optimization	Energy Savings	Waste Reduction
Double-acting bladder pump	Human heart	Parity with current solutions	Less energy used per wash (energy of one chamber recovering helps compress sympathetic chamber)	Parity with current solutions
Elastic bladder dispenser	Vertebrate arteries	Reduced weight Reduced batteries	Less energy used per wash (energy stored in stretched bladder wall used to eject product)	Reduced weight Reduced batteries
Pillow bag with integrated foam pump	Squid locomotion	Reduced part count	Parity with current solutions	Reduced weight
Pressurized, collapsible liquid container	Xylem in plants	Parity with current solutions	Less energy used per wash (air pressure vs. mechanical force facilitates collapse)	Ejection of totality of product

Figure 5: Potential sources of sustainable value in biomimicry-based dispensing system technologies [20]

Bio-inspired innovations spawn improvements to existing products or services while also opening new avenues for innovation. Sustainability drives materials optimization by delivering reduced quantities, weight, and improved manufacturing processes. Energy savings can be viewed similarly in terms of delivering reduced resource requirements or improving efficiencies regarding how we collect and store energy. Waste reduction represents a plethora of processes that can either reduced, improved or eliminated. Reiterating how sustainable value can be created from biomimicry based solutions further cements how both disciplines, when applied correctly, have a synergetic relationship.

B. Biomimicry and Sustainable Innovation

Biomimicry and sustainability present a few obstacles with respect to scalability, materials, and manufacturing [10]. Overcoming these obstacles is a matter of remaining true to three core tiered biological lessons. Striving to emulate biomimicry through sustainable design is accomplished by deliberately applying biological lessons on three levels: form, process, and ecosystem [21]. These effectively enable bio-inspired innovation solutions that equally display sustainable performance while also delivering value. Emulating ***form*** is self-explanatory. The simple form of bio-inspired design may not necessarily be sustainable thus requiring cost benefit analysis. Although something may be lighter, faster, etc. it does not entail that it has sustainable pertaining qualities. Emulating ***processes*** looks at how nature manufactures by taking into account materials, energy, and waste in the "biological manufacturing" process [21]. Emulating the ***ecosystem*** is the final level of bio-inspired sustainable innovation because it takes into account the overall environmental impact. Seeing the big-picture allows for a clear understanding of the supply chain for a given sustainable oriented innovation. This three-level approach ensures sustainable viability in a biomimicry approach to innovation.

C. Biomimicry's Market Impact

Biomimicry is becoming an innovation engine opening avenues for a new class of products and services while also reinvigorating existing industries. The potential of the biomimicry discipline is

astounding when viewed alongside with its projected market impact (***figure 6***). Spanning from chemical manufacturing, textile, utilities and electronics, it's evident that the biomimicry discipline has much more to offer. These industries equally represent opportunities in sustainability. Chemical manufacturing, more specifically, presents the largest projected impact because the industry is overclouded with thousands of synthetic chemicals, containing compounds of toxins. Reevaluating a holistic way to replicate nature in the chemical industry can introduce avenues for more sustainable practices. Similarly, waste management's projected impact can be characterized by opportunities to reevaluate processes and resource consumption.

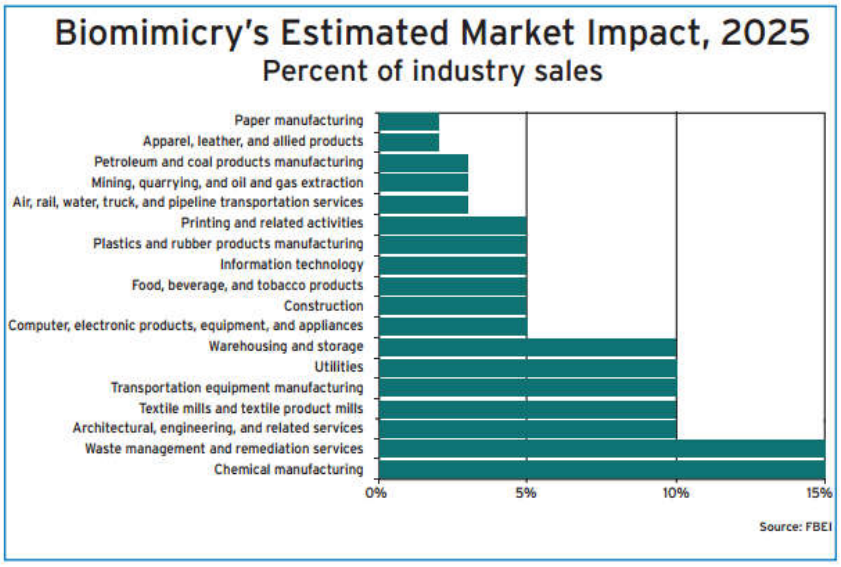

Figure 6: Biomimicry's Estimated Market Impact, 2025 [13]

The common theme in this analysis is that the biomimicry discipline has substantial coherence with sustainability in terms of market impact. Biomimicry offers time tested solutions that endorses recyclable, non-toxic, and energy efficient attributes, to name a few [2]. Bio-inspired innovation continues to challenge the way we harness energy, utilize materials, and manage waste. Spanning a wide range of industries, it's evident that there is mass market potential for the discipline.

VI. Examples of Biomimicry Influencing Sustainability

To solidify to influence of biomimicry on sustainability, examples relating to energy, materials,

and waste reduction (***table 1***) are summarized.

Example	Source
Energy	
Wind Turbines	[13] [22] [23]
Lights (LED)	[24]
Energy Production	[25] [26]
Solar Collection	[27]
Materials	
Carpet (Entropy Carpet Tiles)	[2] [13]
Cement (Eco-Cement)	[2]
Clothing (Morphotex)	[28]
Waste	
Waste Management (BioPods)	[13]
Food Processing (Cereol)	[29]

Table 1: Examples of Biomimicry Influencing Sustainability

Perpetuating natures form, function, pattern, and strategies is at the core of the biomimicry discipline. The following examples highlight the influence of biomimicry on sustainable innovation.

A. Energy

Biomimicry inspires the way be capture and emit energy through various mechanisms ranging from wind turbines, efficient lighting, artificial photosynthesis, and solar collection strategies. The windmill company Green Wavelength created a prototype (***figure 7***) that mimics the movement observed by bumblebees and hummingbirds [13]. The design gains credibility by capturing green energy while achieving 35% efficiency, making it more efficient than traditionally designed windmills [13]. This particular example highlights how design can be re-imagined by emulating nature's solutions and applying it to solve human problems. Rendering increased productivity within the context of biomimicry influencing sustainable innovation, the Green Wavelength windmill design is one

Figure 7: Rendering of Green Wavelength Windmill [13]

example how exiting solutions can be changed.

An additional example in the wind power industry is Whalepower, a company that re-designed blades based on bumps on humpback whale fins [22]. The bumps on humpback whale fins make them surprisingly maneuverable for such a large creature allowing them to easily hunt krill. This re-design (***figure 8***) has the potential to increase production at existing wind farms by 20%, yielding superior energy production than traditional windmill technology as well [22]. Bio-inspired windmill innovation demonstrates how existing products and processes has the potential to be more efficient. Efficiency gains in green energy paves a path towards more feasible sustainable solutions.

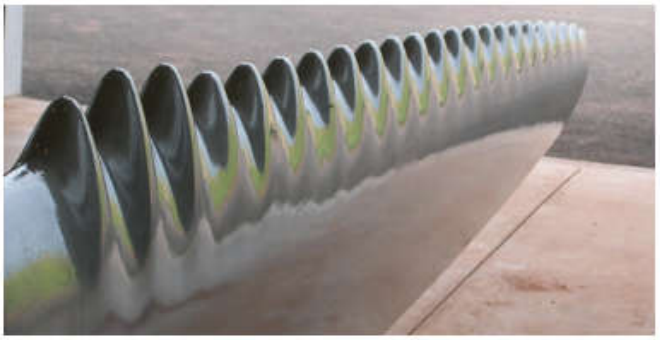

Figure 8: Whalepower Windmill Blades [22]

The ecosystem interpretation of wind farms has also been a subject of redesign from biomimicry's influence. The way wind turbines are placed relative to one another impacts how much wind they can capture, thus affecting how much energy they produce. More specifically, fish clusters were observed in the context to array performance [23]. Turbine farms often isolate and spread out turbines relative to the amount of land available. Contrarily, placing turbines in close proximity to neighboring turbines was thought to degrade performance. However, schooling fish were observed showing performance increase when clustered in closely spaced formations. This sparked new inferences based on how wind farms can be organized in geometric arrangements to make better use of the land, while also yielding much higher power outputs [23]. Observing how fish work together to increase overall performance offered similar positive performance improvements with wind farms.

In addition to reassessing how we capture energy, the way we emit energy has opportunities to be more efficient as well. Light emitting diodes (LED) were derived from observations of the Photuris insect. The light radiating from the firefly's belly displayed scales protruding with jagged abnormal tips

[24]. The specific design presented an optimized light extraction structure that could be applied to artificial light sources. Thus, optimizing brightness by 55% with the added advantage of less electricity consumption [24]. The widespread use of LED's is a result of biomimicry based observations. Worldwide, there are several billions of annual energy savings as a result of LED's.

Learning from natural photosynthesis, artificial photosynthesis is the next generation of efficient energy production. The blueprint of photosynthesis provides useful insight on energy conversion and storage [25]. An artificial leaf was developed by researchers at MIT that converts sunlight and water into energy [26]. This process is nearly as efficient as the real thing, presenting countless future opportunities on how we produce energy and more importantly, producing sustainable energy.

The antireflection qualities of the Troides aeacus butterfly wing was studies relative to its solar collection qualities [27]. Black butterfly wings, in fact, are natural solar collectors. The unique biomimetic design was applied to develop a technology that can create hydrogen from sunlight and water. Using the technology as a catalyst, there was enough energy to separate hydrogen from water [27]. Because hydrogen is a renewable energy source, this is another specific example of bio-inspired innovation influencing sustainable solutions.

B. Materials

Biomimetic materials have the potential to alter the way we utilize natural resources. For the most part, materials today are mined and transported without much consideration of the toxic ramifications. In contrast, natural systems utilize materials much differently and often within a close loop system. This means that needed materials are often nearby and minimally used based on needs.

The way we utilize materials can generally be optimized based on the specific application. Carpets for example, can become sustainable closed-loop products. Entropy carpet (***figure 9***) worked in conjunction with the biomimicry institute to create carpets based upon the "organized chaos of a blanket of fallen leaves and a bed of river stones" [2]. This collaboration prompted a whole new category of carpet tiles. The concept of carpet tiles allowed for easy installation and repairs, while also reducing total waste as a result of eliminating dye lot issues and the requirement for traditional adhesives [2]. The new process resulted in a 90% lowered environmental footprint, further showing how reimagining our current materials and processes can be improved by simply observing nature [2]. Innovative solutions with integrated sustainable qualities present countless market opportunities for improvements.

Figure 9: Entropy Carpet [2]

Pavement coverers nearly every corner of populated cities, resulting in high environmental impacts due to energy requirement and materials utilization. Drawing inspiration from organism's ability to synthesis structural materials, eco-cement incorporates bacteria as a binding material [2]. The raw materials required to make eco-cement consists of waste materials while the process to create the cement uses significantly less energy. Traditional cement production outputs approximately 5% of global carbon emissions. Contrarily, eco-cement sequesters carbon through biomimetic processes. Although eco-cement is in its infancy, it has the potential to alter the way be pave cities, while producing less carbon and making use of waste materials.

Mophotex is a type of fabric that achieves pigment free coloring inspired by the iridescent morpho butterfly [28]. The morpho butterflies wings appear to be blue due to the way they refract light, even

though they lack color pigmentation. Morphotex fabric uses a similar optical illusion with layered stack structures containing different reactive indexes to show variations in color [28]. Sustainability benefits include water and energy savings when compared with conventional dyeing.

C. Waste

Bio-inspired waste management practices present significant prospects for sustainability in the biomimicry industry. Biolytix, an Australian sewage treatment equipment manufacture, developed an ecologically friendly and efficient system that far surpasses traditional sewage treatment technology [13]. Inspired by forests ability to maintain pristine water streams while surrounded by impeding bat colonies, it was observed that the forests "waste processing" took place at the rivers edges where the soil was moist [13]. Emulating nature's strategy, Biolytix created BioPods (***figure 10***) containing microbes that decompose waste that essentially processes wastewater into irrigation water. In addition to significantly reducing operating costs, the BioPods process waste efficiently and repurpose resources that would have otherwise exposed toxic waste into the environment.

Figure 10: BioPod [13]

Food processing tends to use a significant amount of water, additional chemicals, and produce excess waste. Cereol, a German company, applies bioprocess based technology to clean vegetables [29]. This process is based on the enzymatic processes that occur in nature. The reinvented biological treatment system utilizes 92% less water, produces 88% less waste while also eliminating the need to use acids in the vegetable degumming process [29]. The way we process food, although benign, can be change and improved to emanate sustainable qualities.

Existing industrial processes ranging from the way be manage, process, and treat waste can be

altered based on ecosystem practices. Beyond the waste management solutions mentioned, the closed loop processes in ecosystems present a plethora of opportunities for revising the way we utilize and recycle materials. Closed loop systems use exactly the amount of resources needed, while producing waste that serves recyclable functions. Our consumption based economy proves to learn from the way nature efficiently utilizes, discards, and recycles materials.

VII. Conclusion

By investigating applications of biomimicry, it can be deduced that advancing this field will greatly influence a renewed focus on sustainable innovation. As sustainability becomes increasingly important, looking towards biomimicry will pave the path towards a sustainable inspired innovation platform. Eco-innovation in energy savings, materials optimization and waste reduction display further insight on how biomimicry is influencing sustainable innovation. The examples relative to energy, materials and waste were chosen to reiterate the symbiotic relationship between biomimicry and sustainability.

There is a renewed global imperative to transition to sustainability. This shift entails that we must reevaluate how we use energy, utilize materials, and manage waste. Accomplishing a circular economy between these three dimensions emphasizes the importance of sustainable inspired innovation. It is evident that biomimicry offers insight on how we can reinvent products and services, while also opening avenues into new industries.

The purpose of this paper is to highlight the influence of biomimicry on sustainability. Sustainable innovations inspired by nature continues to demonstrate how every imaginable process, product or service has opportunities to be improved based on observations from nature. Looking towards the future, biomimicry will continue to impact a wide range of industries. This broad impact displays that change is eminent - more specifically in bio-inspired sustainable innovation.

VIII. References

[1] Lurie-Luke, Elena. "Product and technology innovation: What can biomimicry inspire?." Biotechnology advances 32.8 (2014): 1494-1505.

[2] Oguntona, Olusegun Aanuoluwapo; Aigbavboa, Clinton; “Sustainable technology and product innovation in the built environment: Biomimicry potentials.” The Ninth International Conference on Construction in the 21st Century (CITC-9) (March 2017).

[3] Benyus, Janine M. Biomimicry. New York: William Morrow, 1997.

[4] Aziz, Moheb Sabry. "Biomimicry as an approach for bio-inspired structure with the aid of computation." Alexandria Engineering Journal 55.1 (2016): 707-714.

[5] Peters, Terri. "Nature as measure: The biomimicry guild." Architectural Design 81.6 (2011): 44-47.

[6] Blok, Vincent, and Bart Gremmen. "Ecological innovation: biomimicry as a new way of thinking and acting ecologically." Journal of Agricultural and Environmental Ethics 29.2 (2016): 203-217.

[7] Zhang, M., Gu, Z., Bosch, M., Perry, Z. & Zhou, H. 2015, "Biomimicry in metal organic materials", Coordination Chemistry Reviews, vol. 293, pp. 327-356.

[8] Biomimicry Group: Life’s Principles Biomimicry DesignLense. [Online]. Available FTP: http://bio-sis.net/wp-content/uploads/2016/04/Biomimicry38_DesignLens_Lifes_Principles_WEB.pdf

[9] Tapping into Nature: The Future of Energy, Innovation, and Business. Terrapin Bright Green LLC (2015), [Online]. Available FTP: https://www.terrapinbrightgreen.com/wp-content/uploads/2015/03/Tapping-into-Nature-2016p.pdf

[10] Cohen, Yael Helfman, and Yoram Reich. Biomimetic Design Method for Innovation and Sustainability. Springer, 2016.

[11] Dhakhwa, Imila (2016, September 15). “Does nature hold the answer to sustainability? Biomimicry as ecological innovation.” [Online] Available FTP: http://environment.yale.edu/yer/article/does-nature-hold-the-answer-to-sustainability-biomimicry-as-ecological-innovation#gsc.tab=0.

[12] Blok, Vincent; Gremmen, Bart. “Ecological Innovation: Biomimicry as a New Way of Thinking and Acting Ecologically.” Journal of Agricultural and Environmental Ethics (April 2016): Volume 29, Issue 2, pp 203–217.

[13] Global Biomimicry Efforts an Economic Game Changer. Commissioned by the San Diego Zoo (2010). [Online]. Available FTP:
http://www.sandiegozoo.org/images/uploads/BiomimicryEconomicImpactStudy.pdf.

[14] Bakirlioğlu, Yekta. “Biomimicry for sustainability: an educational project in sustainable product design.” A thesis submitted to the graduate school of natural and applied sciences of middle east technical university (2012).

[15] Cohen, Yael Helfman, and Yoram Reich. Biomimetic Design Method for Innovation and Sustainability. Springer, 2016.

[16] Hart, Stuart; Milstein, Mark; Caggiano, Joseph. “Creating Sustainable Value [and Executive Commentary].” The Academy of Management Executive (1993-2005), Vol. 17, No. 2 (May, 2003), pp. 56-69.

[17] Hansen, Erik G., and Friedrich Grosse-Dunker. "Sustainability-oriented innovation." Encyclopedia of corporate social responsibility. Springer Berlin Heidelberg, 2013. 2407-2417.

[18] Jay, Jason; Gonzalez, Sergio; Swibel, Mathew. “Sustainability-Oriented Innovation: A Bridge to Breakthroughs.” MIT Sloan Management Review (November 10, 2015). [Online]. Available FTP: http://sloanreview.mit.edu/article/sustainability-oriented-innovation-a-bridge-to-breakthroughs/.

[19] Klewitz, Johanna, and Erik G. Hansen. "Sustainability-oriented innovation of SMEs: a systematic review." Journal of Cleaner Production 65 (2014): 57-75.

[20] Kennedy, Emily Barbara, and Thomas Andrew Marting. "Biomimicry: Streamlining the Front End of Innovation for Environmentally Sustainable Products: Biomimicry can be a powerful design tool to support

sustainability-driven product development in the front end of innovation." Research-Technology Management 59.4 (2016): 40-48.
[21] Kennedy, Emily, et al. "Biomimicry: A path to sustainable innovation." Design Issues 31.3 (2015): 66-73.
[22] “Whale Fins Influence Wind Turbine Design.” Windpower Engineering and Development (Spetember 2009). [Online].
Available FTP: http://www.windpowerengineering.com/design/mechanical/blades/whale-fins-influence-wind-turbine-design/
[23] Whittlesey, Robert W., Sebastian Liska, and John O. Dabiri. "Fish schooling as a basis for vertical axis wind turbine farm design." Bioinspiration & biomimetics 5.3 (2010): 035005.
[24] Bay, Annick, et al. "Optimal overlayer inspired by Photuris firefly improves light-extraction efficiency of existing light-emitting diodes." Optics express 21.101 (2013): A179-A189.
[25] Zhou, Han, Tongxiang Fan, and Di Zhang. "An insight into artificial leaves for sustainable energy inspired by natural photosynthesis." ChemCatChem 3.3 (2011): 513-528.
[26] Dillow, Clay. “MIT Lab Creates the World's First Feasible 'Artificial Leaf'.” Popular Science (March 2011). [Online]. Available FTP: http://www.popsci.com/science/article/2011-03/mit-lab-creates-worlds-first-practical-artificial-leaf.
[27] Zhao, Qibin, et al. "Art of blackness in butterfly wings as natural solar collector." Soft Matter 7.24 (2011): 11433-11439.
[28] Fletcher, Kate. Sustainable fashion and textiles: design journeys. Routledge, 2013.
[29] Organisation for Economic Co-operation and Development. The application of biotechnology to industrial sustainability. OECD Publishing, 2001.