Biomimicry

harnessing nature's ideas to power our world

By Katrina Verbrugge

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In ten years, when you wake up in the morning and turn on the light, the power generated to allow your room to brighten will come from a wind turbine eerily physically similar to a whale's flipper. The train you will ride to work will look like a kingfisher. The paint on the walls of your office will have the self-cleaning properties of a lotus plant, and the building will regulate temperature almost exactly like a termite mound.

No, humanity will not have started to degenerate and fall to the forces of nature. Instead, it will have harnessed nature's most intricate and efficient designs, tested by 3.8 billion years of evolution, and applied them to the biggest technological problems: sustainability, energy use, and eco-friendly material production.

Biomimicry, a field that purposefully implements nature's tested solutions, may emerge as the newest approach to saving energy and synchronizing human activity with nature.

What is Biomimicry?

Biomimicry comes from the Greek words for life (*bios*) and imitate (*mimesis*). It is an emerging scientific discipline that aims to study nature's models and emulate these forms, processes, systems, and strategies to solve many of the problems humans face. Janine Benyus, a scientist and author at the University of Montana, popularized the concept and is considered the original proponent of biomimicry. Her book, *Biomimicry: Innovation Inspired by Nature*, outlines nature-inspired solutions to six different areas: agriculture, harnessing energy, producing materials, healing, computer storage, and conducting business. These case examples outlined the breadth of fields biomimicry could impact while providing steps which shape how scientists approach innovation (1). Benyus brought multiple fields of study together under a common name and galvanized the scientific world to investigate not only what we can model after nature, but also what we can learn from it.

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Biomimicry has three main goals. The first is studying the natural world and understanding the amazing ways organisms have adapted to environments. Humans often regard limits as "a universal dare, something to be overcome so we can continue our expansion," while all other organisms find ways to function beautifully within these limits, therefore maintaining a level of sustainability unknown to humanity (1). The second goal of biomimicry is to take the knowledge gained from observations and apply it through imitation or modification to optimize manmade inventions and processes. Through each of these goals, a third emerges: to create a more sustainable coexistence with nature, from which we draw inspiration rather than resources (2).

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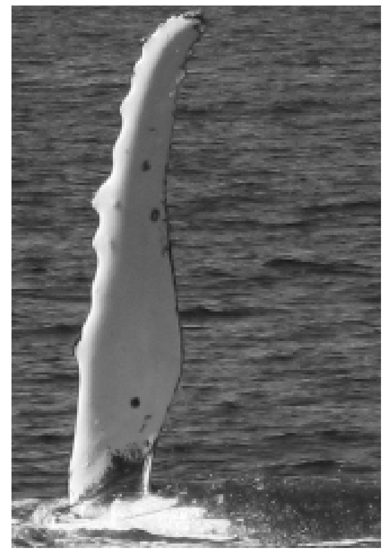
We must learn from the real survivors on Earth who have lived millions of years without depleting their "ecological capital" and natural energy resources. Nature has already solved the problems humans grapple with, so instead of exploiting her, we should learn from her innovation. Indeed, as Benyus notes, "All our inventions have already appeared in nature in a more elegant form and at a lot less cost to the planet" (1).



▲ **Figure 1.** The tubercles on a humpback whale fin that improve its efficiency and turning can be applied to wind turbine

This new approach to innovation and the environment opens up an incredible opportunity for developing energy-efficient solutions and products. Although there are thousands of projects in development with this purpose, some notable projects will help generate electricity through tubercle turbines, cool buildings, and allow commute in the "greenest" way possible.

Whale Wind Turbines

Wind turbines generate a large amount of power at high wind speeds, but do not generate as much at lower speeds. Traditional approaches to this problem included increasing the *angle of attack*, the angle the blade makes with the wind. But this approach often leads to stalling, a dramatic and abrupt loss of lift. Stalling is a function of wind speed and direction, and so is extremely difficult to predict. Therefore manufacturers have typically developed blades that limit the operating angle to minimize the risk of stalling - which subsequently decreases performance (3). How, then, is it possible to increase the operating angle to improve performance in low wind speeds while also preventing stalling?

The answer comes from an unlikely source: the humpback whale. Ironically, this successful biomimetic approach to wind turbine efficiency began with an inaccurate observation. Dr. Frank Fish, the leader of the Liquid Life Lab at West Chester University and an expert in the biomechanics of swimming, noticed that humpback whales have bumps on the "wrong" side of the flipper. These bumps puzzled Fish because they contradicted established fluid dynamics in that the leading edge of a hydrofoil (like a whale flipper) has to be streamlined (4).

In a 2006 study, a research team, including Fish, constructed two models of a humpback whale's pectoral flipper - one with bumps, or *tubercles*, and one without - in order to test how the tubercles affected performance. In the model, inter-tubercle spacing and tubercle amplitude decreased distally, reflective of the whale's anatomy. The polycarbonate models, each 2 feet high, were then mounted vertically in a wind tunnel and tested at angles of attack ranging from -2 to 20 degrees (5).

These tubercles were shown to be an effective asset. When air flows over a flipper, a vortex is created on each side of a tubercle, preventing the airflow from separating and stalling. This enables enhanced lift and decreased drag, allowing a humpback whale to use less energy when turning (4). In addition, a 2008 study showed that the tubercles alter the pressure distribution on the leading edge so that the separation of the boundary layer is delayed behind the bumps. In other words, different parts of the flipper will stall before others, and since the parts stall at different angles, abrupt stalling is easier to avoid (6). Both the vortexes in the troughs and the pressure distribution effects allow for a steeper angle of attack without stalling, while also ensuring that, if stalling was to occur, it will not be abrupt and therefore will not incur damage to the flipper.

Since low-speed water flow is analogous to high-speed airflow, this concept is applicable to wind turbines. Prototype turbines have generated more power at lower wind speeds because the higher angle of attack without stalls has led to greater efficiency of the turbine. They are able to generate as much power at wind speeds of 10 miles per hour as conventional wind turbines at 17 miles per hour. In addition, these prototypes showed improved performance and stalling at the tip was eliminated (7).

The company Whale Power has put this "Tubercle Technology" into practice developing a wind turbine that operates more efficiently and safely. The stall angle is considerably larger and the turbines themselves stall slowly, eliminating the damage that usually occurs in violently stalling turbines. Preliminary real world tests demonstrate that the tubercle turbines dramatically enhance power at low wind speeds, operate quietly, eliminate stalling at the tip, and have the highest stability and responsiveness of any turbine. The wind turbines are currently undergoing third-party tests at The Wind Energy Institute of Canada; already, more than 10 manufacturers are interested in the tubercle-leading edge blades (8).

The Anthill

Cooling and heating buildings is necessary, especially in some of the more extreme environments on Earth. For example, in Harare, Zimbabwe the temperatures ranges from 37° F at night to 107° F during the day, necessitating some kind of climate control system. In 1991, Old Mutual Properties challenged architect Mick Pearce to design an office building that did not use conventional air conditioning systems, but would still enable the appropriate environmental control for the Harare climate. With the help of Ove Arup engineers, Mick Pearce turned to nature and developed the plans for the Eastgate Centre (9).

The locals' nickname for the office complex, "The Anthill," gives a clue to Pearce's natural inspiration. In the very be-

▲ **Figure 2.** The Eastgate Centre in Harare, Zimbabwe. Due to its biomimetic design, the building uses 35% less energy than that used by six conventional office buildings in Harare combined.

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ginning of the design process, the architect turned to the natural coolers of Zimbabwe: the termites. Species of termites, especially *Macrotermes bellicosus*, construct vast above-ground structures from a mixture of excrement and mud or sand called “carton”, complete with complex ventilation systems. Common sites in the Zimbabwean landscape, “termitariums”are both monumental architectural feats and sources of great interest for scientists studying the social behavior required to coordinate such extensive efforts (10).

Why are such advanced structures necessary? The answer, incredibly, is fungi. Advanced termite species live off of the energy-rich cellulose found in leaves and other fauna. Since they cannot digest cellulose themselves, termites cultivate a “garden” of fungi that digest the cellulose for them. In this symbiotic relationship, the termite treats the fungi with antibiotics, helps it reproduce, and provides the warmth and humidity necessary for its survival (10).

▲ **Figure 3.** The Shinkansen 500 series, with a nose cone modeled after a Kingfisher, reduced electricity use by 15% compared to the previous model.

The presence of these fungal gardens and hundreds of thousands of termites generates a large amount of heat and carbon dioxide dangerous for the fungi. In order to maintain the temperature within one degree of 87ºF and remove carbon dioxide, the termites build an intricate series of tunnels and chimneys (11). Heat generated in the core flows into collecting pipes that radiate towards the periphery and connect to vertical chimneys. In some structures, instead of rising up through chimneys, the hot air will diffuse out of tiny holes at the periphery. As this humid air flows upward or outward, it draws cooler air from mud-lined chambers underground into the core of the structure, thereby keeping the internal chambers cool. The termites constantly adjust the tunnels, chimneys, and holes depending on the local condition and damage to the nest (10).

Pearce claimed, “If the termites could create a natural air conditioning system, we must be able to use that model… the metaphor is now no longer a machine for living in- it is a living system for living in” (9). With this biomimetic view, the design team developed plans for a twin nine-story block structure with an atrium in between. In the upper seven stories, double-slab concrete floors would cool overnight due to the outside air.

Heated air rises to the top of the room as cool air flows into the low level and is extracted through circular exhaust ports in the inner component of the slightly vaulted ceiling. This air then travels through vertical tunnels and finally up through the chimney. During the day, there are about two air changes per hour, while at night, a different fan circulates air about eight times per hour (9). The concrete used for the floors and the exposed vaulted ceilings also plays into the energy-efficient cooling system. The underside of the concrete has small bumps to increase air turbulence and the exposed surface area maximizes heat transfer between the cool air and the material (9).

The atrium, ductwork, and hollow floors mimic the tunnels of the termite nests, while the concrete floor slabs mimic the mud. Pearce admits that the design is still rudimentary compared to that of a termite nest. But even without a complex design and with the use of fans, this nine-story building with 31,600 cubic meters of space uses 35% less energy than that used by six conventional office buildings in Harare combined. The ventilation system costs a tenth of a comparable office building’s climate control system, allowing the developers save an estimated $3.5 million in energy costs in the first five years (11).

The Bird Train

The West Japan Railway Company’s *Shinkansen* is a Japanese bullet train- which travels at 200 miles per hour making it one of the fastest trains in the world. The engineers who designed the train could increase the speed through traditional human engineering innovation, but the amount of noise such a

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fast train would generate is very problematic (2).

A great deal of noise is generated when air hits *pantographs*, the collectors that receive electricity from the overhead wires (12). Additionally, when a bullet train exits a tunnel, the air pressure at the exit increases dramatically, producing a loud noise that can affect residents within a 400 meter radius. When the train travels at high speed into a narrow tunnel, it generates compression waves that expand and propagate until they exit the tunnel at the speed of sound. These low frequency waves, called micro-pressure waves, produce a very loud "sonic boom" (13). Since noise standards for trains are some of the strictest in the world a practical solution to quiet these trains is essential (12).

Eiji Nakatsu, the chief engineer and a member of the Wild Bird Society of Japan, attended a lecture on birds and was inspired by the quiet flight of an owl. His team of engineers conducted wind tunnel tests to analyze the noise from a flying owl and learned that owls are able to travel so silently because their plumage contains many small saw-tooth feathers, called *serration feathers*, which extend from the rim of their primary feathers. Serration feathers generate small vortexes in the airflow, thereby breaking up larger vortexes responsible for producing noise. After four years of work, the engineering team was able to replicate this principle by inscribing similar serrations on pantographs. The technology, called *vortex generators*, reduces noise considerably, and is already in development for aircraft (12).

> *"Since the solutions come from nature, they will be more sustainable. Otherwise, the organisms that this technology mimics would not have survived"*

To address the sonic boom created when trains exit tunnels, the engineers looked to another one of nature's fliers: the kingfisher. When a kingfisher dives, it goes from a low-resistance medium to a high-resistance medium (air to water), but minimizes splash and energy loss. Using computer-modeling techniques and analysis of pressure waves generated by shooting bullets of various shapes into pipes, the engineers discovered that the shape of a kingfisher's beak was actually the ideal and most efficient shape for the nose of the Shinkansen (14). Since the most effective way to reduce micro-pressure waves is an efficient design for the nose shape of the train, the kingfisher beak model subsequently produced much less noise when exiting tunnels (13).

Nakatsu comments that he "was once again experiencing what it is to learn from Nature, seeing first hand that a solution obtained through large-scale tests and analysis by a state-of-the-art supercomputer turned out to be very similar to a shape developed by a living creature in the natural world" (12). Ultimately, the train was not only quieter, but also reduced air pressure by 30%, used 15% less electricity, and traveled 10% faster (2). Commuters have also noted that the trains are more comfortable to travel in due to the smaller changes in air pressure when the train enters a tunnel (12). The biomimetic success story of the Shinkansen demonstrates how some of the best shapes already exist in the natural world, providing an unparalleled opportunity for human engineers to advance the performance of a wide range of technology that moves through air and water. Using nature as a guide, engineers may be able to maximize the efficiency of transportation vehicles, for example, and subsequently minimize the energy strain such transit places on natural resources.

Conclusion

Biomimicry is a promising approach to powering our world. The three examples above showcase the powerful applications of biomimetic technology and reshape our understanding of how to innovate new ideas. These solutions are just the beginning; scientists and engineers worldwide are joining in the initiative to find more sustainable and effective ways to generate and use energy. By studying organisms' unique adaptations and forms, scientists can foster a better understanding of not only what works most effectively and efficiently, but also which designs are most robust and long-lasting. Solutions inspired by nature must be the most sustainable. Otherwise, the organisms that such technologies mimic would not have survived the trials of nature. Translating the wisdom of evolution to useful technology will generate important innovations in a wide range of areas, improving not only our technology but also how we live on, and with, our Earth. H

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