INNOVA, Inc.

1749 South Westwood • Mesa, Arizona 85210
Phone: (480) 838-4854 • Fax: (480) 794-1416
Website: www.innovainc.com • Email: tom@innovainc.com

Biomimicry - Innovation Inspired by Nature

Janine Benyus

Some of the most exciting technological advances in the works today are knockoffs of naturally occurring phenomena, as scientists and inventors increasingly borrow ideas from the plant and animal world.

When sketching his designs for flying machines in 1487, Renaissance artist, scientist and mathematician Leonardo da Vinci examined the mechanisms of bird flight; so did brothers Wilbur and Orville Wright, the 20th-century inventors of the airplane. This process of transferring nature's principles to technology is called biomimicry and examples exist all around us, ranging from everyday to magnificent.

Gustave Eiffel based his trussed tower on the human femur bone; Alexander Graham Bell modeled the telephone receiver around the structure of the human ear; and in the early 1940s, Swiss engineer George de Mestral developed Velcro from cocklebur spines.

The motivation is simple: When investing time and money in research, why not take advantage of principles that have been tested for millions, sometimes billions, of years?

"Corporations are ramping up their biomimicry research, and biologists now have a seat at the design table," says scientist Janine Benyus, whose 1997 landmark book, Biomimicry: Innovation Inspired by Nature, helped to galvanize the movement. Boeing, General Electric, General Mills, Kraft, and Procter & Gamble have all called upon the expertise of Benyus's Montana- based consulting firm, the Biomimicry Guild, to create an "amoeba to zebra" report, which pinpoints the animal or plant that best solves a design problem. When Nike was designing materials that would keep athletes cool, for instance, the group recommended studying African reed frogs, which can survive in sub-Saharan grasslands and wooded areas for up to five months without water, because of a waterproof mucus they excrete.

From San Francisco to Japan, venture capitalists who believe that going green can be both profitable and responsible are also banking on the biomimicry movement, which naturally lends itself to eco-friendly materials and processes. In 2006, "cleantech" investments doubled to $1.28 billion, with a growing number of those dollars going toward nature-inspired innovations.

Governments are also getting into the game, particularly in Europe. For the past 10 years, Germany has been at the forefront of biomimicry, offering tax incentives and partnerships for research. Great Britain and Scandinavia aren't far behind.

Man-made technology will probably never really catch up with nature. After all, a car that can travel 70 miles on a single gallon of gas is pretty impressive, but that's nothing compared with, say, a tiny hummingbird that can fly 500 miles nonstop across the Gulf of Mexico. Still, nature made humans such that we can't help trying. Here we present some of the newest and most innovative examples of biomimicry.

The Car Aquatic

When Mercedes-Benz set out to create a new fuel-efficient, eco-friendly concept car, biologists, biomimicry experts and engineers initially looked at well-known speed swimmers such as dolphins and

Continued page 2

sharks. But, surprisingly, it was the slow, awkward-looking boxfish, a tropical fish found in the Caribbean, that scooped up the victory. It became the inspiration for the 2005 Bionic Car, a concept vehicle also known as the Boxfish that's been making the rounds at museums throughout the world, including an exhibit at New York's Museum of Modern Art earlier this year.

According to Bruce Mundy, a biologist at the Pacific Islands Fisheries Science Center in Hawaii, the choice was counterintuitive, since boxfish aren't exactly graceful swimmers. Because their bodies are so rigid, they have an ungainly way of swimming. Boxfish do, however, have powerful muscles that conserve energy, a streamlined shape and a unique bone structure that protects them from injury when they bump into other animals.

The boxfish's square shape reminded Mercedes engineers of a car body, and a closer look revealed that the fish's skeleton was indeed very similar to the frame of a car. The researchers used computer simulations and fish models in a wind tunnel to gauge the boxfish's drag coefficient (DC), a figure that indicates how much air resistance an object faces. A drop of water's theoretical C° value is 0.04 - the lowest of any known object; the boxfish's turned out to be a surprisingly slippery 0.06. "The car designers were really thinking imaginatively;" Mundy says. "You would never guess the boxfish's aerodynamics by just looking at it."

When the designers tested a 1:4 scale model of the car in a water tank so scientists could physically see its aerodynamics at work, it had a C° value of 0.09. Mercedes engineers went on to develop the Bionic Car with just a few tweaks to its body. The car is 65 percent more aerodynamic than compact cars on the market today and it scores 70 miles to the gallon.

The fishy design also makes for a safer ride. The car's frame mimics a layer of lightweight bony plates just beneath the fish's skin. The bones are thicker where they are exposed to the greatest strains, along the ridges or angles of the frame. Conversely, they economize on material where less is needed. When this principle was applied to the car, engineers were able to trim a third of the bodywork weight which saved on production costs and boosted the car's fuel efficiency - all without sacrificing safety.

The Butterfly Effect

Holed up in a hospital recovering from a motorcycle accident; mechanical engineer Mark Miles had an epiphany while reading a magazine article about how some butterfly wings generate color without pigment. The wings of blue morpho butterflies found in the rainforests of South and Central America reflect sunlight through layers of fine scales, producing gorgeous iridescent blue and green hues. The process, Miles believed, could be applied to creating monochromatic displays for handheld gadgets used in bright sunlight and thus, interferometric modulator (IMOD) displays were born.

Here's how IMOD technology works: Handheld devices contain many cells arranged to form colored pixels. In IMOD gadgets, these cells employ layered mirrors to produce one color, just as layered scales produce color in blue morpho butterflies. Each cell, called an etalon, consists of two parallel, mirrored surfaces. Some ambient light reflects off the top mirror, which is partly translucent, while the rest penetrates and bounces between the mirrors. With each bounce, light waves escape through the top mirror. The distance between the two mirrors determines what happens next. Waves that have the same length as the space between the mirrors are amplified and visible to the eye as a particular pixel color. Smaller and larger light waves cancel each other out and are not visible. Pixels in IMOD technology are switched on (color) and off (black) by opening and closing the gap between the mirrors. Unlike LCD screens, which require a powered backlight, they use little battery power, and are optimal in bright sunlight (a front light turns on in the dark).

Low power consumption and good visibility in bright sunlight have made this concept popular with early adopters. This year, the technology was rolled out in Blue tooth 2.0 headsets with displays, and by the end of the year, IMOD cell phones will be available in China and other emerging markets under the Hisense brand. Their strategy is to promote these phones in developing nations, where phones with long battery lives and outdoor-friendly screens are a necessity. Next up: multicolor IMOD displays, which are currently in development.

Super Seaweed
In 1995, biologists Peter Steinberg and Staffan Kjelleberg of the University of New South Wales in Sydney noticed that a type of Australian seaweed managed to shrug off biofilm, a thin layer that contains harmful microscopic bacteria and fungi, which grows on nearly every wet surface.

Bacteria in their biofilm state cause 70 percent of bacterial infections in humans. They also cause expensive damage in the form of microbial corrosion to wet surfaces such as oil and gas pipelines. The scientists figured that harnessing the biofilm-fighting power of the "delicate beauty" seaweed could be an alternative to antibiotics, which combat infections in organisms, and other biocides that target bacteria on non-living surfaces. Their theory couldn't have come at a better time: Because of the overuse of antibiotics around the world, bacteria are becoming resistant to these and other biocides at an alarming rate.

Delicate beauty, as Steinberg and Kjelleberg discovered, secretes chemicals called furanones, which prevent bacteria and other microscopic organisms from colonizing surfaces. In 2000, the two founded Biosignal, Inc., which produces similar synthetic compounds that ward off bacteria before they cause infections, rather than attempting to eradicate bacteria. Biosignal's approach decreases the likelihood that the bacteria will develop resistance.

Biosignal has tested the technology in the lab with promising early results and is working with Japanese health and sanitation company Saraya to protect water-cooling towers. One exciting everyday application may be minimizing irritation and infections from contact lenses. Prototypes were shown to be safe in clinical trials, and - with funding from cleantech investors, who are interested in Biosignal's naturally derived, biodegradable technology - the company plans to start rolling out the lenses in early 2010.

Mr. Clean
Lotus leaves have the unique distinction of staying clean and dry even in muddy waters. Wilhelm Barthlott, a botanist from the University of Bonn in Germany, is no stranger to the self-cleaning, water-resistant properties of the lotus plant. In 1974, he took a close look at the plant's leaves using a scanning electron microscope and discovered that they are studded with tiny waxy bumps. Both water and dirt end up settling on the spikes as if on a bed of nails, without any chance of penetrating to the deeper surface of the leaf. On this "superhydrophobic" surface, water beads up and rolls off the leaves, washing dirt away with it and keeping lotus leaves clean.

Twenty years later, Barthlott began negotiating with companies to industrialize his trademarked Lotus Effect technology. Now, products with surfaces that mimic the plant's nanostructures are entering the market. Several thousand homes in Europe are painted every year with self-cleaning Lotusan paint. Lotus Effect tiles and containers are in development and German scientists have created the first clothing prototypes, which could result in perpetually dry bathing suits. Plans are also in the works for self-cleaning architectural glasses, windows, manhole covers and insulation.

Seal the World
Imagine a bridge or roof that could repair itself. It's not as far-fetched as it seems. In place of steel beams, civil engineers sometimes use inflatable air beams, which are packed with cylindrical membranes filled with compressed air. Buttressed by cables and rods, these beams have the strength of steel but are extremely lightweight and easily stored and assembled, The membranes, however, are vulnerable to tearing and puncturing, which can reduce their load-bearing capacity. Fortifying them against damage would save construction dollars and time, and maybe even lives.

Since 2000, biologist Thomas Speck of the Plant Biomechanics Group at the University of Freiburg in Germany has studied how rainforest pipevines patch their own internal injuries as they age. When the outer skin of an Aristolochia macrophylla vine stops growing, the inner "parenchymal: or supportive, tissue continues to grow, occasionally causing a break in the more delicate outer layer. The parenchyma cells respond by expanding and multiplying to seal the hole. Scientists suspect that highly reactive molecules called oxygen radicals may lengthen the cell walls and initiate the process of filling the fissure.

Inspired by pipevines, Speck and his wife, biologist Olga Speck, and biomechanical engineer Rolf Luchsinger of the EMPA Research Institute in

Dubendorf, Switzerland, developed a biomimetic foam for use in air beam membranes. The polyurethane foam mimics the pipevine's parenchyma cells. Like the parenchyma, the foam cells swell as a response to the release of pressure that occurs with a puncture. Over the next three years, Speck's team and their industrial partner, Switzerland-based Prospective Concepts AG, plan to develop the first industrial prototypes of the foam, which will be applied as an inner coating on membranes used in air beams for lightweight roofing and bridge structures. The foam is sure to be a fast fix: In lab tests, it "healed" membranes in less than a second.

Hair Apparent

Polar bears aren't new to the biomimicry community. Their translucent, hollow hairs are full of air, which has an outstanding ability to insulate against the cold - an adaptation that inspired the hollow textile fibers that provide warmth to winter jackets and sleeping bags. Now polar bears are inspiring invention yet again with their remarkable fur.

For the past 30 years, Jannis Stefanakis, an engineer at Solar Energie Stefanalds in Germany, has been tackling the drawbacks of thermal solar collectors, which harness the sun's rays to heat water for indoor heating, showers and more. Engineers typically use glass because it's a good absorber of sunlight's heat, but it makes the collectors heavy and difficult to transport - a major limitation when the panels need to get to remote locations like refugee camps. The flat design of glass collectors also prevents them from collecting sunlight from multiple angles.

Meanwhile, engineer Thomas Stegmaier of the Institute for Textile Technology and Process Engineering in Germany spent a decade studying polar bear fur. The bears' hair not only camouflages them in the snow but catches sunlight and guides it to their skin underneath. Their hides, which are black, then convert the light waves into heat that keeps the bear warm.

Stegmaier and Stefanakis joined forces in 2003, turning their expertise into a revolutionary new way of collecting the sun's rays. Their invention replaces the glass in a solar collector with a 3/4-inch-thick polyester textile with the same characteristics as polar bear hair. It's lightweight and flexible, making it less expensive and easier to transport. Stegmaier is now working on lining the underside of the textile with a black, light-absorbent material that mimics polar bear hide. The textile will then be stretched over a lightweight, dome-shaped aluminum frame so the collector catches rays from every angle, squandering less of the sun's energy. If the $2 million to $3 million in funding the inventors are seeking comes through, the solar collectors could be in mass production by the end of the year, bringing heat and hot water to areas that desperately need it.

A Sharp Idea

Just as your kitchen knives lose their sharpness with use, so do cutting tools used in the production of, well, pretty much everything. Carpets, furniture, food products, paper - anything that's processed in a factory has probably involved a blade somewhere along the line. And just as a dull kitchen knife struggles to slice a tomato, an industrial blade requires more energy to make cuts as it loses its sharpness. Factories must replace blades before they dull - sometimes as often as every four hours - which costs time and money.

To reduce the expense caused by dull cutting tools, German engineers have drawn inspiration from rats, which have razor-sharp incisors that are kept that way with use. Unlike human teeth, the rodents' teeth are covered with enamel only on the front side, whereas softer tooth bone, dentine, is exposed on the reverse.

Every time a rat uses its teeth, it alternates grinding its lower incisors against either the front or the back of its upper incisors. Hard enamel on the front wears down softer dentine on the back, keeping both the top and bottom incisors' edges sharp.

Using the same principle, Jurgen Bertling and Marcus Rechberger of the Fraunhofer Institute for Environmental, Safety and Energy Technology in Germany have developed a prototype industrial blade that sharpens itself. The metal body consists of an alloy that mimics dentine, while the exterior is coated with a harder ceramic or diamond layer that acts like the enamel. As the blade cuts, the ceramic or diamond layer grinds against the metal, keeping it sharp. A version for slicing paper should be on the market by this fall, with blades for plastics, textiles and more on the way. Unlike rat teeth, which constantly grow to compensate for the grinding down of the incisors, the blades still need to be replaced - but a lot less often. ◆