

NOVEMBER 2013

# BIOINSPIRATION: *An Economic Progress Report*

- > Commissioned by San Diego Zoo Global
- > Researched and produced by the  
Fermanian Business & Economic Institute

SAN DIEGO ZOO



POINT LOMA  
NAZARENE UNIVERSITY

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# **Bioinspiration: An Economic Progress Report**

November 2013

Commissioned by:  
**San Diego Zoo Global**



**POINT LOMA**  
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- Fermanian Business & Economic Institute  
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# LETTER TO THE READER

For the past four years, the Fermanian Business & Economic Institute has worked extensively in the rapidly emerging and changing field of bioinspiration. We continually monitor, study, and comment upon bioinspiration's many exciting and important developments. These extend from revolutionary research and new products to an expanding global list of participants and organizations to our own work involving the business, financial, and economic opportunities that bioinspired products, companies, and innovations represent.

"Bioinspiration: An Economic Progress Report" now provides an important update to our groundbreaking November 2010 "Global Biomimicry Efforts—An Economic Game Changer". As we have discovered during the intervening years between releases of the two reports, the original has been widely read, disseminated, and discussed. In the year following publication of the inaugural study, with critical support from other bioinspiration advocates, we developed the Da Vinci Index to quantify the growth in the field in the U.S. In 2014 we will unveil the Global Da Vinci Index to give all of us an enhanced view of bioinspired efforts worldwide.

In the report that follows, we attempt to not only take a look back at what has occurred but also look forward to what steps we see as critical to realizing the full potential of bioinspiration, with an emphasis on the practical steps that policymakers, proponents, businesses, investors, and even we, individually, can take to bring bioinspiration's full potential to reality.

The tireless efforts and advocacy of San Diego Zoo Global and its Centre for Bioinspiration are to be commended. We are grateful to them for their critical and enduring leadership, not only in bioinspiration but in conservation, sustainability, and global citizenship.

Randy M. Ataide, M.A., J.D.  
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## EXECUTIVE SUMMARY

- > Bioinspiration, the field which translates ideas and concepts found in nature to practical applications in the commercial world, has demonstrated significant growth in the past three years since our first report was published in 2010. Performance across firms applying the technology, however, has varied considerably.
- > The increases in patents issued, articles published in scholarly journals, and research grants show a  $5\frac{1}{2}$ -fold increase in bioinspired activity since 2000, according to the DaVinci Index developed by the Fermanian Business & Economic Institute (FBEI). The scholarly articles component has led with a  $6\frac{1}{2}$ -fold gain.
- > Bioinspired technology has the potential to transform large slices of the economy, penetrating many industries, particularly those in manufacturing. Agriculture, mining, construction, waste management, and information technology could also see sizable impacts. The greatest inroads appear to now be occurring in chemistry, materials science, and engineering.
- > By 2030, bioinspiration could account for \$425 billion of U.S. gross domestic product (GDP) in terms of 2013 dollars. Another \$65 billion could be contributed through the savings that bioinspiration could offer in terms of reduced resource depletion and pollution.
- > Globally, by 2030, bioinspiration could generate \$1.6 trillion of total output or GDP. Resource and pollution mitigation could amount to another \$0.5 trillion.
- > Various products and solutions continue to spin off from bioinspiration. In the medical field, sunscreen and synthetic blood are being developed. 3D printing promises to be a major economic disruptor and bioinspired materials could be central to its development.
- > Investors have not yet embraced bioinspiration to a significant degree, as awareness of the field is still limited and demands for tangible evidence of success remain. The potential for substantial capital inflows into the field persists although not because bioinspiration is “green,” but because nature is becoming recognized as a “treasure trove” of innovation.
- > On balance, bioinspiration has enormous potential, but much needs to be done by leaders in the field, business, and the financial sector to move it beyond a fledgling industry or niche player in the economy to its possible role as a major game changer.
- > The possibilities and importance of bioinspiration cannot be overstated as it remains the “bridge” that can bring together and accomplish both the goals of environmental preservation and economic growth.

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# I. STUDY PURPOSE AND SCOPE

Since the publication of our 2010 report, “Global Biomimicry Efforts—An Economic Game Changer,” the Fermanian Business & Economic Institute (FBEI) has tracked the progress of the field both in the United States and globally. This study analyzes business and economic developments in the space over the past three years and updates the ten case studies investigated in the prior report. It examines the successes and failures in the field to develop insights and lessons for the future. This report also extends the forecast horizon from 2025 developed in the prior report to 2030.

The process involving the capture of ideas or concepts found in nature and applying them to practical or commercial application for mankind is referred to in this report as “bioinspiration” instead of “biomimicry.” We believe this is a more accurate and comprehensive term since the process often entails not just the literal imitating or mimicking of the natural world but rather building and expanding upon an idea inspired by nature.

Section II analyzes the expansion of bioinspiration since 2000. The FBEI has developed the Da Vinci Index to quantify the growth of the field in the United States and will be soon releasing a global version of the Index. This section of the report examines what impact the recession had on the field and whether bioinspiration appears to be accelerating, decelerating, or holding steady. It also describes the emergence of various hubs around the world.

Section III contains an extensive discussion and analysis of the case studies of the ten different ventures involving bioinspiration included in the 2010 study. Issues involving product development, sales growth, financing, successes, and constraints are explored. The section concludes with the takeaways in terms of what works and what does not.

Section IV presents estimates for 2030 in terms of the expected penetration or impact of bioinspiration on various industries and sectors, while Section V points to emerging trends in bioinspiration. This is followed by U.S. and global projections in Section VI of the contribution bioinspiration should make by 2030 in terms of gross domestic product, remediation of resource depletion and pollution, and jobs.

Section VII discusses investment channels and potential. Bioinspiration’s current progress is summarized in Section VIII. That section also presents conclusions on the future of bioinspiration, including the steps necessary to sustain its momentum. Section IX summarizes the primary methodologies employed in the study.

## II. BIOINSPIRATION'S PROGRESS

There are many ways to measure bioinspiration's progress, as detailed in this section. Bioinspiration, the translation of ideas or concepts found in nature to practical human applications, has shown significant progress since first formally introduced in the groundbreaking work by Janine Benyus. Patents in the field, research grants, the publication of scholarly articles, and the successful introduction of bioinspired products into the marketplace all point to the field's expansion.

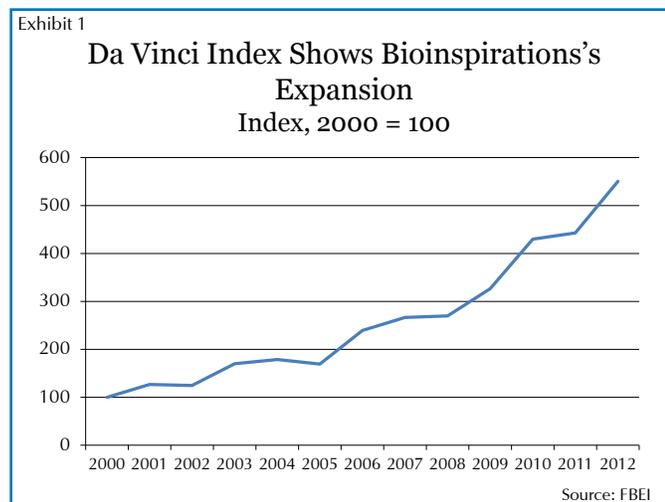
As job growth following the "great recession" continues to be subpar, finding the proper balance between preservation of our natural resources and increasing employment poses great challenges. Bioinspiration promises a "win-win" solution, enabling businesses to grow sales and profits with products that are based on the sustainable and efficient solutions found in nature.

Two very different approaches continue in the development of bioinspiration. In some cases, scientists, inventors, or even casual observers see an interesting concept in the natural world and then find a commercial application. In other cases, firms are looking to solve a particular problem and find the answer in nature.

### The DaVinci Index Documents Growth

The Fermanian Business & Economic Institute has developed an index, named the DaVinci Index, to track developments in bioinspiration over time. It should be noted that different terms have been used to describe the field. These include: biomimicry, nature-inspired, biomimetics, biomimics, and bioinspiration.

The DaVinci Index for the U.S. is based on the number of patents linked to bioinspiration,



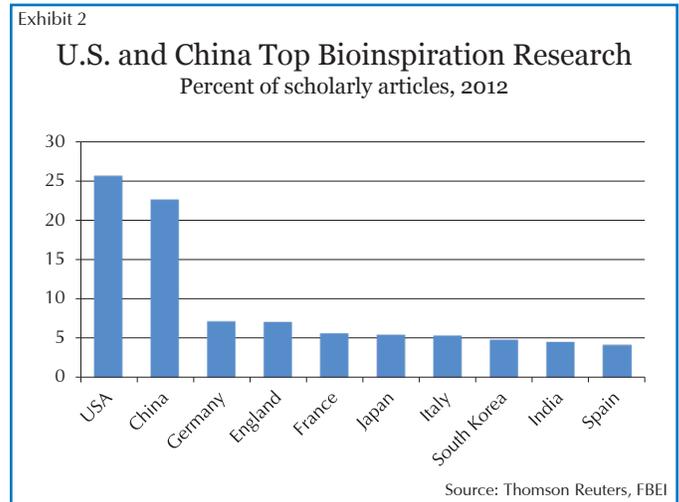
scholarly articles published, and the number together with dollar amounts of grants issued by the National Institutes of Health (NIH) and the National Science Foundation (NSF). The composite DaVinci Index showed a 5-1/2-fold increase between 2000 and 2012. (See Exhibit 1.) This represented an impressive compound annual average growth rate of 15.3%.

While annual changes have been volatile and 2008 showed the adverse effect of the recession, there has been no slowing of the underlying trend during the past

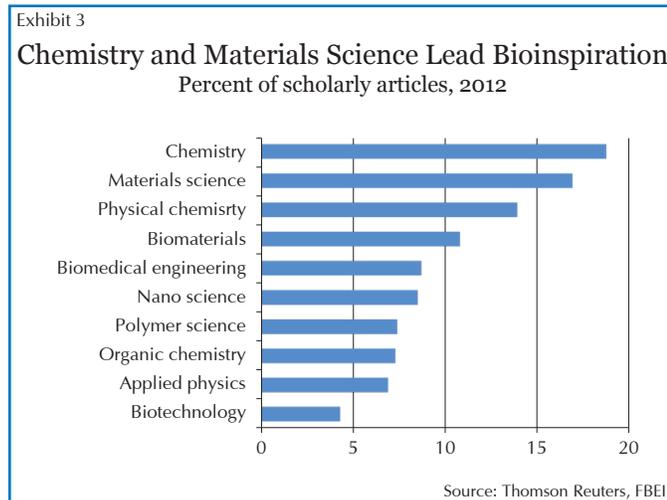
twelve years. Patents and scholarly articles have scored strong gains over the past twelve years. The weaker performance of grants relates more to the budget pressures on U.S. federal government agencies than on activity related to bioinspiration. In 2012, the DaVinci Index jumped by 24%.

## Global Expansion

An analysis of articles related to bioinspiration published in journals throughout the world depicts the field's global spread. In 2012, while the United States accounted for 25% of the articles published in the field, China was close behind with 23% of the research pieces. (See Exhibit 2.) Five of the top ten universities represented in bioinspired research papers were Chinese. Only two were American, Harvard University and Massachusetts Institute of Technology (MIT).



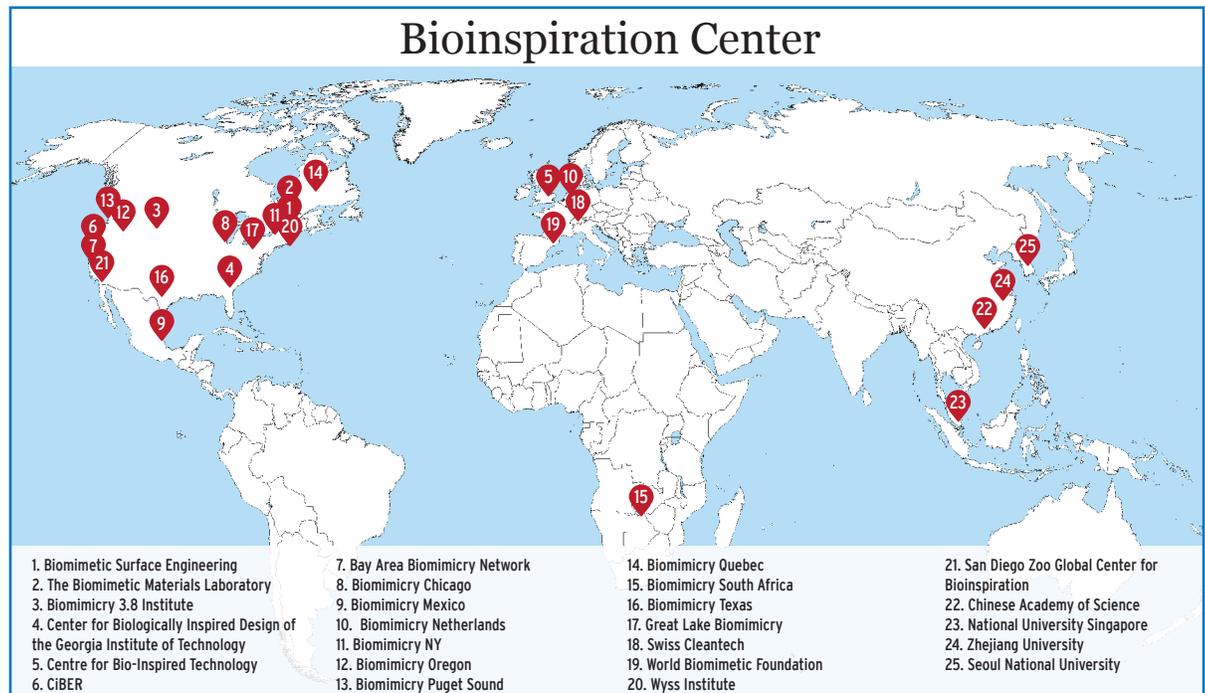
Academics from many other countries are heavily involved in research related to bioinspiration. These include several in Europe, including Germany, the United Kingdom, France, Italy, and Spain. Japan, South Korea, and India also number in the leading countries for research in the field, further demonstrating the international spread and diversification of bioinspiration.



International research related to bioinspiration is currently heavily focused on various types of chemistry and materials science. Substantial bioinspired work is also taking place in engineering, nanotechnology, polymer science, physics, and biotechnology. (See Exhibit 3.)

## Bioinspiration Centers of Influence Spread

As the field of bioinspiration gains relevance and acceptance, various incubators and centers of influence have emerged worldwide. The overall objective of these clusters is to promote the solution of local problems by observing and analyzing nature's genius. These centers also foster awareness and communications of bioinspiration among practitioners. The accompanying map shows the global spread of these circles of activity, although it is intended to be illustrative, not comprehensive. (See Exhibit 4 and Appendix.)



## Other Dimensions of the Field's Expansion

In addition to the various centers or incubators noted above, bioinspiration is spreading throughout the world through a variety of avenues, some of which are described below.

### ➤ Conferences and events

Various organizations are hosting gatherings of scientists, scholars, business people, the general public, and investors to discuss different aspects of the field. Examples for 2013 include San Diego Zoo Global's Bioinspiration Conference, a symposium hosted by the World Biomimetic Foundation in Barcelona, Spain, and a summit on 3D printing and bioinspiration in San Francisco hosted by Swiss Cleantech, swissnex San Francisco, and StartupNectar.

### ➤ Advanced research labs

A large number of research facilities around the world are pursuing projects involved with bioinspired materials or processes. These include facilities at McGill University in Montreal, the University of California Irvine, Imperial College in London, the University of California Berkeley, and a number of universities in China.

### ➤ Government support, coordination, and funding

Government agencies throughout the world are assisting advancements in the science and its applications. In the U.S., these include the NIH, NSF, and the Defense Advanced Research Projects Agency (DARPA). Other governments providing direct or indirect support include those in Switzerland, Canada, Mexico, and China.

> Media exposure

Information about the spread of bioinspiration is finding its way into a wide array of print, TV, online, and other media channels. These now extend beyond scholarly journals to include “Bloomberg Business Week,” the “The Wall Street Journal,” “BBC News,” “Science Today,” and “CNN.”

> Websites

Websites are proliferating around the world featuring various aspects of bioinspiration. These include [solution.biotrue.com](http://solution.biotrue.com), [asknature.org](http://asknature.org), [bayareabiomimicry.org](http://bayareabiomimicry.org), [ciber.berkeley.edu](http://ciber.berkeley.edu), and [phys.org/journals/bioinspiration-and-biomimetics](http://phys.org/journals/bioinspiration-and-biomimetics).

> Degrees and academic majors

A number of colleges and universities offer undergraduate and master’s degrees linked to bioinspiration through programs in engineering, sustainability, and environmental management. These include Columbia University, Stanford University, Northwestern University, Harvard, Oxford, University of Cambridge, and Aalto University, Finland.

The examples above not only illustrate the broadening of bioinspiration’s reach but also suggest that the field is establishing bases that could facilitate further growth.

### III. CASE STUDY UPDATES AND INSIGHTS

**The following pages document the experience of the companies reported in our 2010 study regarding product development, sales growth, finance, market expansion, successes, and constraints. Future expectations are also indicated. Nine companies were covered in the previous report along with a discussion of early developments in swarm intelligence. Two of these companies have been merged into other firms after bankruptcy and now operate under different management. All nine case studies are discussed in this section along with a new and primary player-- Blutronix, Inc--that has emerged in the field of swarm intelligence.**

#### Biolytix

Biolytix was initially an Australian company founded by inventor Dean Cameron who patented its process in 1994 and created a company in 1996. However, Biolytix in Australia was not as successful as planned and in 2011 it went into receivership. In February of 2011, Biolytix of Australia was merged into a surviving New Zealand affiliate.

The Biolytix BioPod features a sewage treatment process that is a much more ecologically friendly and energy efficient system than traditional waste treatment systems. The BioPod allows for waste material to be broken down and filtered, ultimately separating solid waste from water that can be used for irrigation. This is possible through the use of an ecosystem within the BioPod of worms, beetles, and billions of microbes that decompose solid waste into humus. A small pump provides the oxygen that is needed for the organisms to produce rich humus which then cleans the water. The only major technical change that has taken place with the BioPod has been the implementation of a new improved filtration cloth within the BioPod.

One of the key success factors that have helped Biolytix in New Zealand is the relatively moisture-rich environment that exists there. This type of climate helps maintain BioPods. Since Biolytix has entered the market in New Zealand, sales have doubled in the last 24 months, and they continue to grow. One of the main competitive advantages



Biolytix BioPod

that the BioPod system has is its much reduced use of electricity compared with traditional systems. On small islands where large amounts of energy are not readily available, this is a very attractive system. Biolytix has also expanded its market into commercial space which now accounts for 25% of total sales. These commercial applications include schools, vineyards, and camp sites. BioPod systems are also used in tribal communities native to New Zealand.

A major constraint to growth for Biolytix is that it is operating in a very saturated market. Another constraint that exists is that many of its competitors are already established and consumers have their traditional mechanical

units. This makes it difficult to change to Biolytix BioPods since consumers would need to install an entirely new system.

Biolytix still wants to continue its expansion and slowly enter new markets. For now Biolytix plans on focusing on repairing poorly maintained systems and making repairs to units that were improperly installed in Australia and other regions.

Biolytix recently received an award from the “New River Green 50.” The New River Green awards the top 50 New Zealand companies that are green. In order to qualify companies must earn at least half of their revenue from a product, service, or technology that benefits the environment. Biolytix was the only wastewater treatment company to receive this award.

*Based on interview with:*  
harriet@biolytix.com  
www.biolytix.com



## Biomatrica

Biomatrica is a biotechnology company based in San Diego that develops and sells products for preserving and stabilizing biological samples. Once stabilized, the sensitive samples can be shipped or stored for later use. The inspiration for the product was found in tardigrades and brine shrimp through their natural process of anhydrobiosis, which essentially involves the drying of the organism while preserving its cellular structure.

Biomatrica's main competitive advantage is reduced storage cost since the samples can be stored at room temperature. This removes the need for constant refrigeration and expensive and energy intensive cold storage systems.

Since 2010, Biomatrica has released several new products that are designed to preserve different types of DNA, RNA, and bacteria for different lengths of time. With continued expansion of the product line-up for different applications, Biomatrica's sales increased 50% from 2010 to 2012. Within the last 12 months, Biomatrica has expanded its market into India and has launched two more products. One of Biomatrica's keys to continued success has been the constant innovation and expansion of the original technology to include more and more applications. This expansion has been driven by understanding the underlying client need on a case by case basis and marketing to that demand. This marketing approach has allowed Biomatrica to enter the commercialized market.

Biomatrica now operates in a wide range of market segments including diagnostics, traditional research, forensics, and biobank storage. Biomatrica has a diverse client base, which includes government contracts that have provided some considerable continuity. This has helped attract investors and fuel growth for the company, which will be important as government support going forward may be more erratic.

The major constraint for Biomatrica is the resistance that the current market has to change. Educating potential customers about the benefits of migrating away from cold storage systems has been a challenge from the beginning and continues to be a challenge today. Some institutions simply do not have the funds or resources to make the switch from traditional cold storage systems to the Biomatrica system.

Another challenge has come from government regulation of different segments of the market that Biomatrica is trying to enter. Meeting the standards of regulation can be very costly. Even with these constraints, Biomatrica has been able to enter new markets and experience continued success. Biomatrica plans on achieving further growth in the future as more consumers demand more sustainable and energy efficient solutions.

*Based on interview with:*  
Judy Muller-Cohn, Ph.D.  
CEO and Founder  
[www.biomatrica.com](http://www.biomatrica.com)



Biomatrica system

## Seal-Tite (Formerly Brinker Technology)

Inspired by platelets in the human body blood stream, research at the University of Aberdeen, Scotland led to the discovery of a marketable platelet technology. Brinker Technology was then formed to market and sell the technology in the water and oil piping industries, using the Telepath, Plasma, and Platelets product lines. Brinker Technology went into bankruptcy in 2012 and was finally sold to Seal-Tite® in April 2013. Platelet technology was the most complementary between the two products, and as a result, Brinker Technology was integrated into Seal-Tite's Engineered Sealing Solutions line after the acquisition.

Brinker's demise ironically came in the same year, 2012, that it received the prestigious Queen's Award for Enterprise/International Trade awarded to U.K. firms for significant and valuable work. These developments underscore the conclusion that awards are no guarantee of business success.

Founded in 1995, Seal-Tite® International is a privately held oilfield leak repair service company based in Louisiana. The company has a line of unique pressure-activated sealants used in oilfield environments. The company aims to provide solutions for maintaining well integrity without the need for a rig work over, reducing the time and costs associated with locating and fixing leaks and putting wells back on line.

The first Seal-Tite® sealant was used to cure SCSSV (surface-controlled subsurface safety valve) control line leaks. The sealant product line has expanded to allow for curing leaks in oil-based, water-based, and gas environments. The most common types of leaks cured by Seal-Tite® are SCSSV's (safety valves) and control lines, wellhead tubing hangers and casing hangers, tubing and casing strings, umbilical and subsea tree components, micro annulus cement, pipe lines and ball valves, and storage caverns.

Seal-Tite® is a privately held firm, and as a result, much of its company financial information is confidential. Sales and finance performance numbers are not available, but the company expects to grow at a 15% rate per year in the foreseeable future. Moreover, the company claims to have the internal capacity to finance this growth. Seal-Tite® controls 85% of the well-integrity market, and it expects to continue its market domination since there are very few competitors in the market.

Due to the international reach of the petroleum industry, Seal-Tite® has deployed its products all over the world in well integrity applications. As the oil industry expands internationally, the use of Platelet technology should expand accordingly. Platelet technology allows Seal-Tite® to provide a safe and reliable product to the well-integrity market. In addition, Seal-Tite® is continuously developing leak sealants for new applications in different markets.

As the provider of an innovative technology, Seal-Tite® has encountered constraints similar to other first entrant businesses. In particular, the oil-field industry is opposed to change and resists a new technology, such as Platelet resist technology, even though the product has been proven in many applications.

The nature-inspired aspect of Platelet technology is beneficial to marketing in helping customers understand the invention's concept. Platelet technology is based on nature. However, since Brinker Technology was acquired by Seal-Tite® International, the

bioinspired aspect of the product does not seem to play as relevant of a role as it did under Brinker Technology. Seal-Tite® is currently conducting a market survey of industry needs to determine if the R&D budget is justified to further develop Platelet technology.

*Based on interview with:*  
Neil Cary, Vice President of Operations  
<http://www.seal-tite.com>.



## Green Wavelength

In 2010, Green Wavelength was a start-up company developing a bioinspired windmill mimicking the wings of an insect. The company aimed to apply its technology to improve the design of wind turbines, ceiling fans, and water turbines.

However, R&D expenditures for these projects have been stopped, and no further development is planned at this time. The major reason that activity was suspended was the lack of funding due to the strong presence of inexpensive traditional windmills produced in China. Investors were very reluctant to justify the investment in an untested and potentially more expensive technology.

As a result, Green Wavelength has shifted its focus from wind turbines, ceiling fans, and hydro-power to a software solution for implementation in smart-grid systems. The company has created a software algorithm that is inspired by the intelligent behavior exhibited by dolphins.

As the provider of an innovative technology, Green Wavelength has faced several major limiting factors constraining growth for its products. Protecting intellectual property in software is a major concern. For example, since the firm's new software algorithm is designed for use in smart-grid utility applications, obtaining empirical data from the few large utility firms has been a constraint on growth and development.

Green Wavelength has tried different financing sources for its products, ranging from traditional venture capital solutions to a Kickstarter.com campaign. This has proven to be a challenge. At this point, the company is not interested in investment from venture capitalists because it feels that it would have to give up too much equity and decision-making control in order to secure the required capital. Moreover, the company has not been able to take advantage of financial resources offered by agencies such as Green.com because the products are still in a very early phase.

Presently, Green Wavelength is looking for partnerships with different utilities across the country to help provide empirical data for the software and potential financing for product development. Green Wavelength is in talks with the Los Angeles Department of Water and Power about a partnership to validate its software based on the utility's available information. The company expects this partnership will help finance the development of its present software solution for smart-grid technology applications.

The company still uses bioinspiration successfully as a marketing tool to promote its products and the nature-linked ethos. If successful, the new software algorithm inspired by the intelligent behavior of dolphins will have many applications as smart-grid technology expands worldwide. Green Wavelength expects to release its bioinspired software algorithm for smart-grid application within the next six to eight months.

*Based on interview with:*  
Sabri Sansoy, CEO  
<http://www.greenwavelength.com/>



## Interface FLOR

Interface founder and CEO, Ray Anderson, who passed away in 2011, was revolutionary in adapting the principles of bioinspiration to transform his company's business. He authored two books, "Mid-Course Correction: Toward a Sustainable Enterprise: The Interface Model" and "Confessions of a Radical Industrialist: Profits, People, Purpose—Doing Business by Respecting the Earth," which document the company's evolution.

In 2000, Interface introduced its first bioinspired product, known as Entropy®. Based on observations in nature, Entropy® expanded into a product category known as i2. This product uses carpet tiles that mimic the randomization of colors and patterns that naturally occur on the floor of a forest. TacTiles® were introduced in 2006 as an alternative to conventional glue adhesives to hold tiles together and avoid the volatile organic compounds previously used to glue tiles to the floor. TacTiles® emulate the way nature holds things in place on a surface—through gravity. Pursuing a still different direction, in early 2013, Interface introduced the Net Effect carpet line, which takes its appearance from the ocean's currents and also recycles discarded fishing nets.

The i2 carpet category, now approximately 40% of Interface styles, including six of the top ten best selling styles in the Americas, significantly reduces costs for installation, manufacturing, and maintenance. The use of random, non-directional patterns with mergeable color dye-lots obviates the need to precisely match each square to the next or install them in correct pattern alignments. Similarly, any manufacturing irregularities merely add to the randomness of the pattern, so the company has been able to achieve substantial savings by significantly reducing manufacturing and inventory costs. These cost savings are also realized by the customer over the life of the product since less material needs to be purchased to replace worn-out carpet sections and the carpet retains its appearance longer since wear and staining are more difficult to discern.

TacTiles®, because they do not need to be glued to the floor, enabled tiles to be used on wood floors rather than just on slab floors. Together with their ease of use, they enabled Interface to substantially expand its residential business. FLOR now has 18 stores in the United States.

The new Net Effect carpet line represents another step for the company to move towards 100% recycled nylon in all of its nylon-6 styles. The new product repurposes nylon from discarded fishing nets from the Philippines, as well as yarn from Interface's Carpet



recycling program. This system produces savings by using recycled product as the raw input and by reducing waste in installation. The appearance of Net Effect, once installed, emulates the precise moment when the sea foams into the shore, again taking inspiration in design from nature.

With its various materials, Interface has been able to further its reach into new markets including libraries, hospitals, and schools. This has allowed Interface to increase its competitiveness and market share and lower maintenance costs. Interface increased its total sales by 10.5% in 2011.

A considerable barrier Interface faces is the need to educate potential customers of the benefits of its non-traditional, fully modular system, which includes glue-free installation of a floating floor with TacTiles, use of non-directional i2 styles, and selective replacement. This has been a factor inhibiting the penetration of new market segments. Despite obvious advantages, only 36% of Interface carpet was installed with the glue-free TacTiles® system as of 2012. Once customers become accustomed to the new system, growth is not a problem.

Interface's long-term goal is to make its entire product line and product life cycle environmentally friendly by taking recycled raw materials from used carpet squares, fishing nets, and other waste streams, and reprocessing them to make new products for future applications.

*Based on interview with:*  
Mikhail Davis  
Director of Restorative Enterprise  
[www.interface.com](http://www.interface.com)

*Interface* **FLOR**®

## Joinlox

Joinlox is an Australian company that developed a technology to connect a wide variety of objects. The inspiration for Joinlox Technology arose from the ability of clams and other shellfish to forge a tight seal on rocks using only thin high tensile bysus threads. The company develops and licenses the use of a range of proprietary mechanical systems to innovative manufacturers around the world. It also pursues new markets with its own products where it identifies an opportunity to disrupt a static market seeking a better solution.

Joinlox Technology is suitable for almost any rigid or semi-rigid material, even joining dissimilar materials, and can be integrated into the design of existing products or as an applied joining edge. In the past, this problem was solved by nuts, bolts, screws, and other permanent methods such as welding, soldering, or by using adhesives. Joinlox competitors include traditional fastening methods such as bolted flanges, screws, rivets, nails, and clips which are not only often problematic and expensive, but also only provide a 'point loaded' joint. Welding, soldering, and glues are hazardous, expensive, irreversible, and require specialist operators.

Since Joinlox is a privately owned company, revenue, profit, and financing information is not readily available to the public. However, in a few short years, Joinlox has been able to successfully grow and diversify into a range of new industries and markets by licensing applicable segments of its intellectual property portfolio to leading organizations with established products, reputation, and diversified distributions channels. This has enabled Joinlox to proportionately spend more in R&D than alternative business models that require high proportions of gross revenues to cover high fixed costs. This structure also enables Joinlox to act quickly when new opportunities arise for its clients.

Joinlox continues to demonstrate the commercial viability of bioinspiration by successfully transforming its original ideas and concepts into commercially compelling products and applications. From the first application of joining plastic and creating modular water treatment tanks, the patented Joinlox systems have now been successfully developed for applications as diverse as modular buildings and construction methods, cabinetry and flat-pack furniture, bridge and wharf rehabilitation, pipeline joints, mineral processing and mining equipment, electronics assemblies, air and surface transport, packaging, and logistics solutions. From its inception, the company positioned itself in the business of rapid assembly solutions, not just joints that are a possible alternative to fasteners, welds or adhesives.

The company continues to find new applications for the Joinlox technologies across different industries. The Joinlox design team is often engaged directly into its clients' R&D, engineering and design departments to help solve existing problem areas and develop new products and applications. Already, the new business pipeline is made up of a ratio of around 50/50 percent of outside inquiries to in-house developments. That is, around half of the new solutions originate from outside organizations that contact Joinlox to investigate if there is a suitable Joinlox solution



CrateLox system

that can solve one or more problems in their respective markets. The balance comes from in-house development projects where Joinlox identifies specific industry problems that are awaiting an improved (and often disruptive) solution.

Joinlox' success stems primarily from the adaptability and scalability of its systems to provide points of differentiation in diverse competitive markets. Joinlox Technology offers unique advantages over traditional joining methods. This has been recognized by a number of leading global organizations that are working closely with Joinlox to help their own organizations reduce costs, improve their systems and products, streamline production processes, reduce their logistics loops, and lessen their environmental footprint.

Joinlox has encountered obstacles similar to all those that are faced by any technology-driven business. In the early years, availability of adequate funding and resources tops this list. However, Joinlox does have many of the key points desired by investors. As a result, the company has been fortunate to fund its technical and business development strategies reasonably well. One specific challenge that stands out has involved convincing early adopters that the advantages and potential rewards of implementing the Joinlox systems are in fact often far greater than the apparent risks of being the pioneers in their respective industries.

Joinlox believes that it has much potential scalability with the right people and capital resources. The company's forecasts indicate that sales growth will continue on a strong positive trend for the next 1-2 years as it penetrates new markets. Following this, the company anticipates a rapid spike upwards in subsequent years as a number of long-term development projects reach the market while sales traction ramps-up simultaneously across a number of strategic global markets. In the next five years, the company aims for Joinlox Technology to be ubiquitous in numerous applications across multiple industry sectors, displacing welding, fasteners, and even the toolkit.

*Based on interview with:*  
John Pettigrew, CEO  
<http://www.joinlox.com>.



## PAX Scientific

PAX Scientific is an innovative research and development firm. Its focus is to create products that perform better by streamlining fluid movement. PAX Scientific is the parent organization of four separate companies that operate independently of each other. These companies have created designs for devices and systems, including fans, mixers, water purification, and boats, that improve efficiency, reduce drag and noise, and use less material.

Founder and CEO of PAX Scientific, Jay Harman, has recently published a major new book on bioinspiration, “The Shark’s Paintbrush.” This book details some of the technological breakthroughs that are currently transforming business from concepts found in nature.

The product that has captured the attention of many is the PAX Water Mixer. This is manufactured in northern California and was developed by PAX Water Technologies. The inspiration for the mixer came from the way ocean seaweed takes a spiral form to manage the forces of flowing water. This mixer uses 300 watts of energy and is able to maintain water quality in water storage tanks of up to ten million gallons.



Pax Water mixer

The PAX Water Mixer is now fully developed and PAX Water has begun to grow this line of mixers with other new products. Furthermore, PAX Water has been able to expand on the mixer’s application. The mixer is useful in eliminating ice formation as well as eliminating thermal stratification in hot seasons. According to PAX Scientific’s Chief Operating Officer, Francesca Bertone, “biomimicry continues to play an expected role of informing the development of new products based on natural flow geometries.”

Even though PAX Water does not have added competition in its field since it first entered the space, it has still faced many challenges. The biggest challenge that the company faced when it was driving growth for its product was the lack of consumer knowledge because active mixing of storage tanks is a relatively new market. Educating customers on the range of potential practices greatly influences the demand for the product. This is a challenge that all companies in this industry face.

Despite the difficult economic times, PAX Water has grown based on educating its market to increase sales and the introduction of new products. Today, the company has annual revenues in the multi-million dollar range and expects consistent growth of 40% per annum. It also is now selling products internationally. The mixer is currently available in Canada, Australia, and the Middle East, and it has begun selling in Europe. PAX Water credits its success with the development of its reputation as providing effective products and by maintaining high standards in manufacturing and customer service. As a result, customers are satisfied and there has been an increase in demand for PAX products.

*Based on interview with:*  
Francesca Bertone  
Chief Operating Officer  
<http://paxscientific.com/>



## Mirasol BY Qualcomm

In 2004, Qualcomm acquired the company Iridigm and formed Qualcomm MEMS Technologies (QMT). QMT is a wholly owned subsidiary of Qualcomm and is the team that is bringing the mirasol display technology to market. This technology is likely to become very popular given that society continues to increase its use and applicability of mobile devices.



Toq smartwatch

QMT has experimented with interferometric modulator display (IMOD) technology for many years. It was able to create a low power, color, video capable, and sunlight viewable display, which is a significant achievement. This unique display was inspired by the natural phenomenon that makes a butterfly's wings emit strikingly rich colors. The radiant colors are produced when specific wavelengths are reflected off the surface of the wings of a butterfly. These wings have a certain microscopic structure that allows light to be reflected in bright colors. In addition, because there is no ink or pigment, the colors will never fade.

QMT has been spending significant time marketing the mirasol displays and expanding its market during the last few years. The display was first introduced at the Consumer Electronics Show (CES) in 2010. The following year, the KYOBO eReader featuring the mirasol display was released. With the popularity of eReaders on the rise, this was an innovative and creative way to market the display and expand its market reach. In 2012, a few other eReaders featuring the display were also announced. Dr. Paul Jacobs provided the most notable mention of the display that year in his keynote at CES. 2013 has been a positive year for the mirasol display. QMT recently released the Toq, a smartwatch that features the sunlight-visible mirasol display.

For now, QMT appears to have a competitive advantage over others in the market in using a mirasol display. However, technology changes and moves forward at great speed, and QMT must remain vigilant in continuing to expand its market. With mobile phones, laptops, tablets, GPS units, and cameras becoming increasingly popular and mainstream, the mirasol technology could greatly improve these applications.

Currently, the color display screens in technological devices significantly drain batteries and reduce battery life. The mirasol screens use less battery life to operate in addition to the innovative sunlight-visible screens being easy to read in any light. The competitiveness among technology industries and between technology firms is intense. The major risk is that will not take much time for QMT's competitors to enter the market with a similar product.

<http://www.qualcomm.com/mirasol>  
<http://www.facebook.com/mirasoldisplays>



## Sto Corp.

Sto Corp is a world leader in creating a broad range of cladding and coating systems. Its products are typically used for building construction, restoration, and maintenance. In 2005, Sto Corp released StoCoat Lotusan, a patented super hydrophobic, self-cleaning coating that is inspired by a lotus leaf.

The microscopic surface structure of a lotus leaf results in water beading, which attracts and mixes with dirt and other particles and washing them away as the water beads drip off. The Sto Corp technology mimics this microscopic structure in Lotusan so that surfaces with the coating always look fresh, particularly after it rains.



Lotusan coating

Lotusan is Sto Corps' premier coatings line. It is fully commercialized and is ideal for application to most vertical exterior wall cladding or siding material and is especially useful in regions that experience significant rainfall. While the product application remains unchanged, the company is currently in the process of developing the next generation of products in order to maintain its competitive advantage. It has also implemented a new segmentation strategy to expand its product offerings to new channels of distribution.

Sto Corp heavily promotes Lotusan as a major component of its sales and marketing efforts. It is increasingly important to reinforce the unique performance advantages of Lotusan as competing products have entered the market with claims similar to that of the lotus-effect technology that is incorporated in the Sto product.

Sto Corp is confident that its product's benefits, together with improving economic conditions, strengthening business and consumer confidence, and higher home values, will support the company's double-digit growth in the period ahead.

*Based on interview with:*  
Rankin Jays  
Product Manager – Coatings  
<http://www.stocorp.com/>



## Bluetronix Inc. and Swarm Intelligence

In 2010, we introduced the concept of Swarm Intelligence and bioinspiration, which has now been implemented by Bluetronix, Inc. Swarm Intelligence is a form of Artificial Intelligence where the individuals in a swarm (like a school of fish, swarm of locusts or an ant colony) do not think independently but act together to accomplish one common goal. They organize themselves but do not have a central leader. They simply communicate with each other about information around them.

Since individuals in swarms do not think (they simply react to their peers and the environment around them), their behavior can be analyzed and predicted using an algorithm. Some of these algorithms are being incorporated in computer software to help solve complex problems that firms face every day.

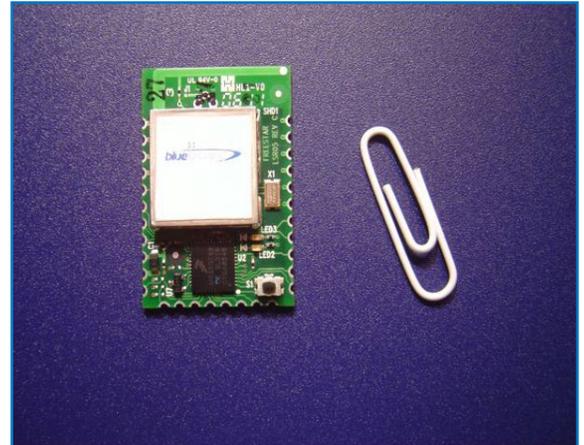
According to a white paper written by the company Ericsson, “The United States is on the verge of a vast new spectrum-driven technological evolution with the power to transform our economy, our lives, and the way we do business. This revolution is being driven by breakthrough technologies connecting us to the world around us through a vast sea of smart connected devices. Trillions of transistors, billions of sensors, and the growing ubiquity of fast wireless data connections are helping to fuel this technological transformation filled with astonishing new digital opportunities.” This latest evolution in our technology is seen as the third wave on how we will communicate through the internet. The first wave allowed us to connect locations, such as connecting a school, business, or home to the internet. The second wave came with the introduction of the smart phone and its ability to connect people. The third wave, which has yet to take place, will connect machine to machine (M2M technology).

This technology will enable machines to communicate with each other and “make decisions” without any outside guidance or influence. For example, “shoes or doors can be programmed to send a signal if they are not used for a certain period of time. Connecting your wallet, or rather turning your mobile device into a wallet or even a bank, is another example of the radical impact that connecting an everyday object may have – in this case redefining the whole financial industry. Without too much trouble, a vending machine can tell service staff when it needs to be replenished – to avoid unnecessary travel. On a larger scale, whole industries can use wireless sensors to monitor different processes and connect their entire businesses end-to-end.” By 2020, the number of connected devices could reach over 50 billion in the United States.

The significance of M2M technology cannot be under estimated. Some studies suggest M2M advancements could help reduce carbon emission, crime, traffic jams, car accidents, and fuel consumption, while adding greatly to both gross domestic product (GDP) and the creation of new jobs.

One of the biggest constraints that prevent this technology from coming forth deals with the problem that the current available wireless spectrum is not able to handle the immensely complex communication pathways necessary for M2M to function properly. Estimates state our current wireless consumption could outstrip capacity as soon as 2014. If we do not allocate more spectrums for mobile connectivity, the vast benefits from M2M devices will be delayed.

Bluetronix's technology, which is based on Ant Colonization Optimization (ACO), is an answer to the current constraints we have with limited wireless band capacity in America. Its products solve this problem by providing communication pathways with greater efficiency and that bypass conventional methods that have range, connectivity, and security issues.



Bluestar 32-bit module

New wireless sensor networking has presented a huge opportunity for users who can use wireless to gain visibility into hidden processes, assets, and activities to identify manufacturing or service inefficiencies. Wireless technology is a more cost-effective way to monitor plant equipment and production processes, and enables real-time decisions to optimize production or identify maintenance issues before they interrupt production.

Blutronix has two product lines named BluePacket and GreenLink. The company is moving rapidly to final commercial product developments and strategic licensing for wireless communications in M2M, M2M Medical, M2M Energy, M2M Cellular, and Big-Data/Meta-Data retrieval. The company's patented technologies are geared for any optimization application or problem that needs simple solutions.

The patented technologies provide a device-to-device networking solution using biological networking formats on how insects swarm and behave. Bluetronix SWARM is different from other wireless technologies in that it needs no routing tables, prior information, access points or direct links to towers. Each device/connection acts as a routing point with the capacity to learn and improve by functioning and operating while connecting wireless sources in a self-forming/organizing model.

In the last seven years, Bluetronix has developed, designed, and demonstrated fully functioning patented technologies and prototypes for the next generation of wireless communications for markets in industrials; healthcare; heating, ventilating, and air conditioning (HVAC); and the cellular industry.

Bluetronix would not release sales numbers. However, when asked about the potential economic impact for growth in industries that apply BluePacket and GreenLink products, Bluetronix's founder Mark Heiferling estimates some companies can experience 200% growth simply by reducing redundancies and eliminating bottlenecks within their infrastructure. This translates to lower costs and increases capacity for product/service expansion.

Bluetronix has been awarded over \$3.2 million from government defense agencies such as the U.S. Army, Air Force, NASA, and the Defense Advanced Research Projects Agency (DARPA). The company has invested in R&D, recent patents, and product development.

Blutronix has expanded into new markets with the introduction of GreenLink, a technology that focuses on energy monitoring and building automation. Blutronix has not expanded globally at this time. The application of Bluetronix technology can be applied to any type of machine that can be monitored. As the industry evolves, Bluetronix technology can be modified to help machines communicate more efficiently. Blutronix has recently expanded its application in Big Data, mobile payments, and energy monitoring. The use of swarm technology in this workspace has been very beneficial. Mr. Heiferling claims it is a totally different way of solving complex problems utilizing a decentralized approach.

The biggest constraint currently facing the enterprise is finding investment dollars to expand its products into the private sector even though there is no direct competition. The competition is rooted in conventional technology as there are no major competitors using bioinspired methods. In addition, because this technology is so new, it is not as readily adopted because the market generally is unfamiliar with how it works.

Blutronix is currently developing a few strategic product systems that are proprietary and could not be disclosed. These products require additional investment to become fully operational and ready to be brought to market.

*Based on interview with:*  
Mark Heiferling  
President & Founder  
Blutronix Inc.



## Takeaways and Insights

Over the past three years, the tracking of these various firms involved in bioinspiration yields some valuable observations and lessons for the future.

### Common Positive Developments

Certain common favorable themes have emerged. A number of bioinspired products investigated generally have experienced rapid initial growth, with sales in many cases doubling each year after inception. The advantage over existing products in terms of reduced energy, transportation, or other costs, in addition to improved efficiency, has often been striking. Impressive rates of return can be achieved in relatively short periods of time and the various products hold the potential for major advances in market share.

### Varying Results and Constraints

The constraints faced by firms with bioinspired products vary substantially. As documented in the case study updates above, results have ranged from failure to mediocre performance to significant success. Overall, the outcomes have been encouraging but somewhat less favorable than projected in the 2010 report.

Funding is not generally a problem in large or mid-sized firms that are well capitalized and that are looking for new areas of growth or seeking ways to be more environmentally friendly. In contrast, new ventures or small firms cite capital as a major challenge and limitation.

Education and information present formidable obstacles for firms operating in long established markets where buyers have embraced certain technologies and systems for many years. Resistance to change can be strong. Firms with new bioinspired products can also face pushback from customers focused on a near-term versus long-term cost-benefit analysis. For example, whereas cost savings from the new product over a number of years can be impressive, potential customers may focus on the initial price premium for the bioinspired product.

To find commercial applications, companies generally cannot just “copy” nature because, for example, of the quantity of materials and other inputs that will ultimately be required. Substitute materials must be found or manufactured to imitate or emulate the natural phenomena.

The costs and complexity of designing and ramping up new production facilities can be high. These include the requirements of setting up new supply chains, assuring a smooth flow of production, and maintaining quality control. All of the products analyzed are currently operating at relatively small scales. Achieving much higher rates of production with extensive economies of scale could present new challenges but also large profit gains.

### Key Takeaways

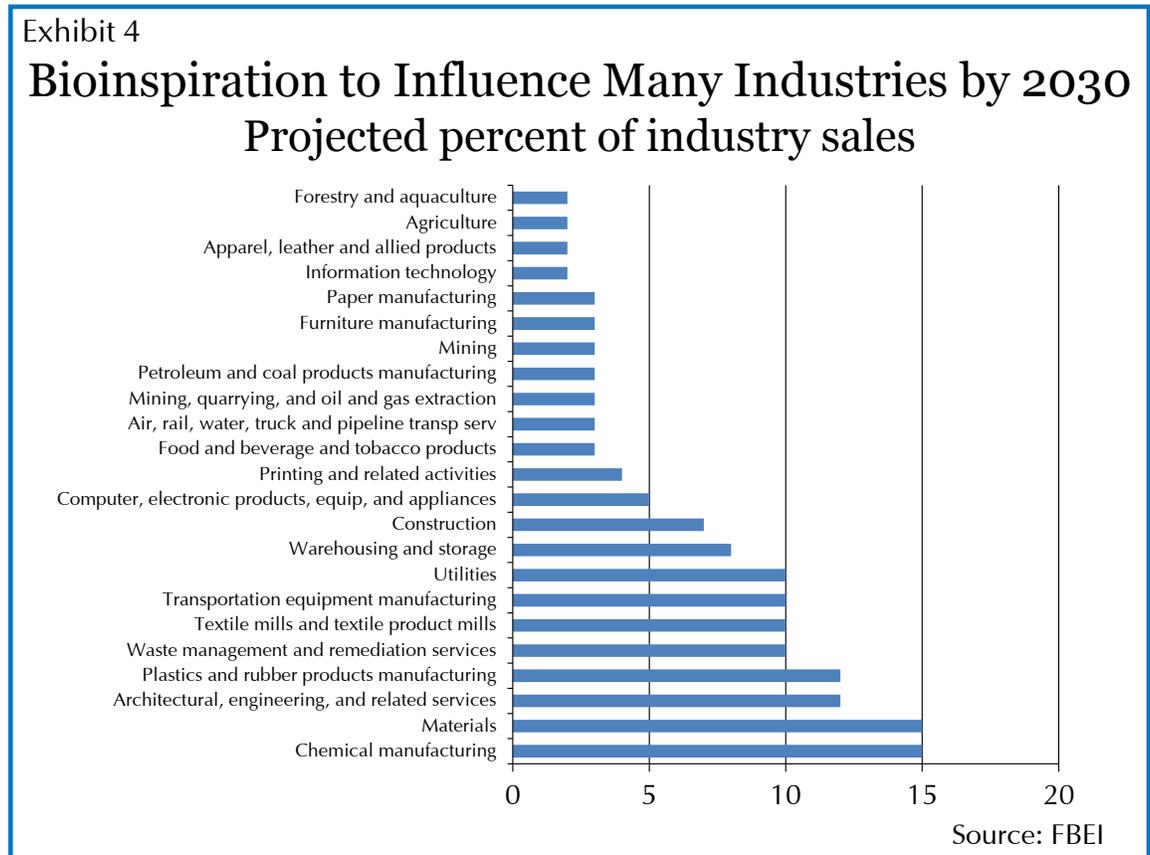
Five key conclusions or lessons emerge from the analysis of these case study updates.

- › **The product needs to stand on its own merits in terms of the value added that it offers to the market place with respect to cost savings, efficiency gains, or business applications.** The link to nature may be useful in marketing, including an illustration of the product's use, but the connection to nature beyond that dimension is limited.
- › **Breaking into markets with a new bioinspired product is very difficult.** Customers in many industrial markets have developed a comfort zone with existing products and are reluctant to change. They are also reticent about being “early adopters.” Moreover, once a product is successful, competitors may often quickly move in to capture or recapture market share.
- › **Management is central to success.** The ventures that have failed often were started by brilliant scientists or inventors who either did not have the management expertise or failed to hire the necessary operations, financial, and marketing talent. Entrepreneurs need to know how to take a business venture beyond the concept stage and then continue to grow the enterprise if it succeeds in the early stages of product launch. Knowledge and skills in building client relationships, developing employees, pursuing marketing opportunities, and dealing with various government regulations and compliance issues all need to be cultivated.
- › **Established small or mid-sized enterprises or businesses (SMEs) may be the optimal framework for launching and expanding bioinspired products.** Large corporations may be skeptical of nature-based solutions while de novo firms face numerous challenges and potentially high failure rates. SMEs selling traditional products may see the value of bioinspired items as a complement or substitute in their existing product lines and be capable and willing to devote the capital and marketing resources to developing bioinspired business.
- › **Capital is king.** Bioinspired products need strong capital backing for product launch and growth. Product inventors will frequently underestimate the amount of capital needed. Start-up funding is scarce with venture capitalists often demanding evidence of a product's success in the market. Inventors may also be reluctant to cede control over the company that venture or other investors may require. Government funding may be scarcer as budget pressures continue. The last few years have also demonstrated that bioinspired products are just as vulnerable to economic downturns as traditional products in the same product channel. Despite these constraints, private investors will be seeking channels for their funds that promise attractive returns in a generally low interest rate environment and will be particularly interested in innovative new products and services emanating from bioinspiration.

The disparity of performance among bioinspired products and companies is certainly not unique to the field. However, it does underscore the point that bioinspiration can only gain traction in the economy if it is treated not as a philosophical goal but as a business.

## IV. SALES AND INDUSTRY PENETRATION

Bioinspiration is influencing various industries at various speeds but continues to hold the potential of transforming large slices of different sectors over the next two decades. (See Exhibit 5.) Based on the numbers of patents, scholarly articles, and commercial products either in development or on the market, bioinspiration is making the most significant inroads in three primary areas: chemistry, materials science, and engineering. These advances, in turn, are beginning to affect industries ranging from agriculture to transportation equipment to construction.



### Agriculture, Mining, and Forestry

New techniques for drilling, exploration, and extraction could affect approximately 3% of the oil, gas, and mining industry by 2030. Understanding the ecosystems in nature could also lead bioinspiration to shape about 2% of the agriculture, forestry, and aquaculture industries over the next 15-20 years.

### Manufacturing

Over the coming two decades, bioinspiration is likely to have the greatest impact on manufacturing as it affords ways to make products in a more efficient manner with a smaller environmental footprint. Numerous manufactured items could see changes or substitutes, with new products requiring fewer raw materials, reduced energy, and less waste, while also featuring lower costs in some cases. Many of the materials and compounds found in nature could cause bioinspiration to influence around 10% of

the textile, 12% of the plastics, and 15% of the chemical (including pharmaceutical) industries by 2030. These new products could result in dramatic reductions in product toxicity.

New, more aerodynamic and energy efficient designs could transform up to 10% of the transportation equipment industry (including cars, trucks, planes, and boats). The example of enhanced display screens with better energy efficiency developed originally by Qualcomm MEMS Technologies, cited in Section III, illustrates some of the future changes that could take place in electronics manufacturing. Bioinspiration could penetrate about 5% of that industry by 2030.

### **Construction and Utilities**

Ten percent of the utilities sector could be impacted, with new products and processes used for various segments, ranging from energy generation to water treatment. Construction could also be significantly impacted at the 7% level by 2030. For example, studying the structure of termite mounds has inspired the construction of buildings with major enhancements in the efficiency of heating and cooling systems.

### **Warehousing, Storage, and Waste Management**

Improved methods of refrigeration, such as suggested by innovations by Biomatrixa in Section III, plus other naturally-inspired products and systems could affect approximately 8% of the warehousing and storage industry by 2030. More efficient transportation, illustrated by the products of Joinlox, could impact some 3% of the transportation services sector. Waste management could see 10% of its industry transformed if some of the “closed loop” systems of nature are replicated or simulated.

### **Information Technology**

Work done involving swarm intelligence discussed in the previous section suggests the significant impact on information technology that bioinspired applications could achieve. An estimated 2% of the industry could be affected 15 years from now.

### **Other Sectors**

Larger effects of bioinspiration on the economy could be achieved if some of the feedback mechanisms, symbiotic relationships, and behavioral patterns found in nature can be applied to significant parts of the services economy. These would include the retailing, financial services, health care, and government sectors.

## V. EMERGING TRENDS

A number of fascinating advancements in research and development are taking place that can further bioinspired technology in the coming years. New discoveries and experiments are too many to mention in just one report. However, a few interesting findings are listed below to show the potential impact within this space in the future.

### Medical

**Sunscreen.** A research institute in Norway (SINTEF) has built a library of microorganisms taken from the Trondheim Fjord that absorb sunlight. These organisms have the ability to shield the human body from longer Ultra Violet light waves that are known to cause skin cancer. This would improve the effectiveness of current sunscreen on the market today because currently available products do not block UV light at the higher 320 to 470 nanometer range. Promar, a Norwegian company, plans to market this sunscreen as “UVAbblue” whenever it becomes ready for use.

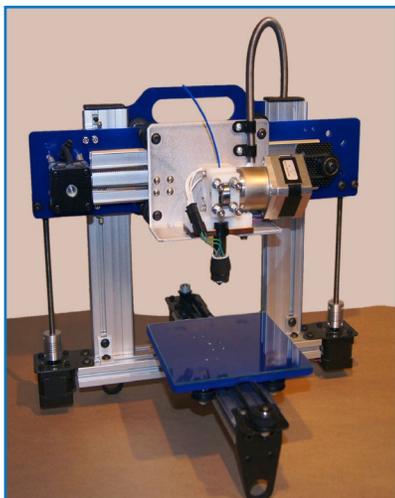


**Synthetic Blood.** Scientists have studied the oxygen-storing protein, myoglobin, in whales and seals. What researchers have found in studying these tissue samples are properties that allow these animals to hold their breath for extended periods of time under water. By emulating this chemistry, this invention could aid the development of oxygen-carrying liquids that could be used to deliver emergency supplies of oxygen to someone's tissues instead of using a blood transfusion.

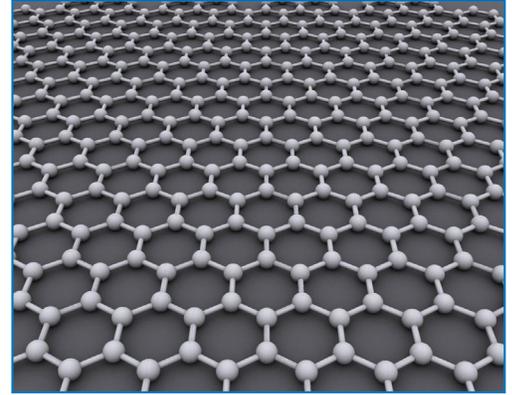


### Materials Development

**3D Printing.** There is talk among researchers on developing a new material for 3D printers that is nature-inspired. Materials that make up an antelope's hair, hooves, and horns are all made of keratin, but each body part has very different properties and different functions. Scientists are looking for bioinspired materials that would be able to print an object with multiple properties. This technology would not just print an object but also print multiple pieces and “assemble” them together. For example, a pair of glasses could be printed that varies in transparency instead of creating separate pieces (glass lenses and a plastic frame) and putting them together. Theoretically, materials could be invented that produce objects that adapt over time. The material would respond to light, heat, force or humidity, making an object adjust automatically to its surrounding environment.



**Manufacturing.** Perhaps, the answer to this 3D printing “mystery” material lies in the recent discovery of graphene, a one-atom thick substance derived from graphite. Graphene is currently the thinnest material known to scientists. One gram can cover an entire football field. It is stronger than a diamond, has superior heat conductance, and conducts electricity a thousand times better than copper. Because graphene is so strong, it can be used to reinforce plastics, making them conductive at the same time. Future applications include mobile phone screens, touch screens, and next-generation integrated circuits. Major work is being conducted using bioinspiration for various materials. For example, Aaron Kushner at the University of California Irvine is conducting primary research on self-healing materials.



## Big Data

**Data Storage.** Scientists have found a way to use DNA to store data. Successful experiments have been done that encoded DNA with an audio clip of Martin Luther King Jr.’s “I Have a Dream” speech, a photograph, a copy of Francis Crick and James Watson’s “double helix” paper, and 154 sonnets from Shakespeare. Retrieval of this information was done with 99.99% accuracy.



The properties of DNA offer additional benefits that traditional storage devices cannot provide. Because DNA is not alive, it can sit passively in a storage device for thousands of years. Compare that to today’s data-storage devices that consist of magnetic tapes that can degrade in ten years. In addition, since DNA is so small, it is extremely space efficient. A cup of DNA-based storage could store 100 million hours of high-definition video. This technology could be available for commercial use in the next ten years.

## Robotics

**Soft Robotics.** Robotics has typically relied on a mechanical approach, using wheels, electrical motors, pneumatic devices, or hydraulic systems, to move hard body parts. These parts are typically composed of metal structural pieces and traditional joints.

An alternative technology is moving towards “soft robots”, which use soft or elastomeric materials. This approach emulates the structures found in nature, such as in marine organisms or in the non-skeletal parts of land animals. Examples are the tongues of lizards, the trunks of elephants, or the tentacles of squid.



Softer materials and structures offer the possibility that a future generation of robots can be manipulated much more easily and achieve greatly enhanced mobility compared with the current genre of robots relying on rigid materials and structures.

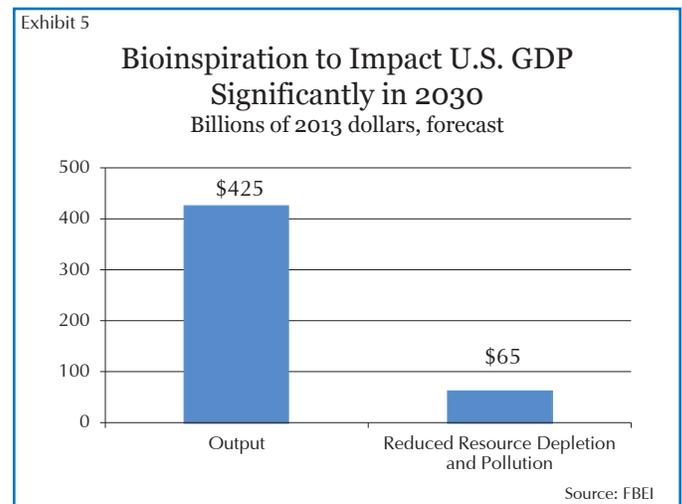
## VI. POTENTIAL IMPACTS ON U.S. AND GLOBAL ECONOMIES

### U.S. Effects

Bioinspiration's influence on various large industries should translate into a sizable impact on total U.S. gross domestic product (GDP) and employment by 2030.

#### GDP Contributions

Using estimates of bioinspiration's penetration of various industries discussed in the prior section and projections of those sectors' total output for 2030, bioinspiration is projected to account for approximately \$425 billion of U.S. gross domestic product (GDP) by 2030. (This number is calculated in 2013 dollars or abstracting from inflation). While small relative to a total U.S. economy estimated to generate approximately \$25 trillion of goods and services in 2030, bioinspiration will still have a significant impact that can be expected to continue to grow as knowledge and awareness of the field expands. (See Exhibit 6.)



#### Mitigating Economic Losses

Biomimicry could also help reduce the economic losses from the depletion of the nation's energy, mineral, and forest resources and from CO<sub>2</sub> and other pollution. Beginning with estimates developed on resource depletion by the World Bank, FBFI projects that such losses could amount to about \$637 billion by 2030 or 2.5% of U.S. GDP. The capability of bioinspiration to shrink these costs by slightly more than ten percent could yield an additional impact on the nation's economy of about \$65 billion.

#### Job Impact

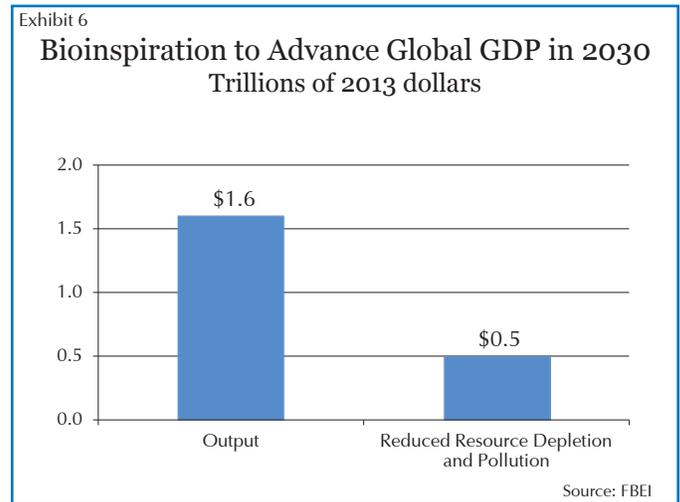
The number of jobs yielded by bioinspired goods and services could also be large by 2030. Based on the projections for the output of various industries, the impact of bioinspiration on them, and the related employment ratios, biomimicry could account for approximately 2.4 million U.S. jobs by 2030. While some of these positions would represent substitutes for the production of older products and technologies, many others would represent whole new markets for additional and improved goods and services.

Bioinspiration thus has the capability of both contributing to economic growth and jobs in the U.S. while also helping to safeguard the environment.

## Global Effects

### GDP Contributions

Research and activity involving bioinspiration is occurring throughout the world, as documented in Section II. FBEI estimates that bioinspiration will be responsible for about \$1.6 trillion of GDP worldwide by 2030. (See Exhibit 7). This will represent FBEI's estimate that the field will represent about 1.1% of total global output by that time compared with 1.7% of U.S. GDP. The smaller share of world GDP represents the assumption that bioinspiration will have penetrated a smaller share of the economies of less technologically developed nations by that time.



### Mitigating Economic Losses

Using World Bank estimates as a starting point, FBEI projects that resource depletion and various forms of pollution will amount to about 3.8%, or \$5.5 trillion, of global GDP by 2030. Helped significantly by the strong interest evident in China, FBEI assumes that bioinspiration could help mitigate these potential economic costs by about 9% or \$500 billion.

Bioinspiration's global spread represents a valuable dynamic in the global economy's progress over the next two decades as emerging markets continue to develop and expand at a faster pace than their industrial counterparts.

### Job Impact

Because consistent global employment data is not available, no estimates were feasible for the number of jobs internationally that could be generated by bioinspiration by 2030.

## VII. INVESTMENT IMPLICATIONS

Bioinspiration remains a future magnet for capital inflows, driven by the prospects of rapid growth and high rates of return. At this point, the field is still too new and unproven to be a primary destination for such funding. Investors need more information and data on results.

Public or private funds looking for “green” investments or investments that will support environmental objectives or sustainable growth are finding bioinspiration a promising field. Awareness and information is, however, still limited.

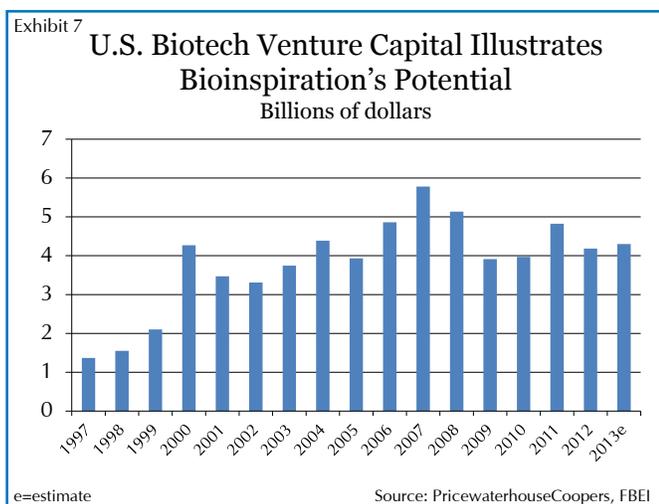
Mainstream investors have not yet embraced the concept. The general attraction they find in the field is the possibility of innovation with new products or new processes. The fact that nature is the origin of the idea is irrelevant, but a leading edge new technology is compelling to them. They are generally looking for more case studies and evidence that bioinspired products can deliver the growth and rates of return they desire.

If investors can receive more knowledge of success rates, bioinspiration can potentially be extremely attractive. The ability to boost efficiency, create products that perform better than those now available, and sell at lower costs than competing items all speak to its value.

### Returns on Investment

Although firms are reluctant to say much about results for individual products, returns of 40-50% on new bioinspired products can be achieved. Annual sales growth rates of 50-100% in the initial years can also be accomplished. Although production expansion can be challenging along with stepped up competition, the possible economies of scale and advantages of dominant market share should yield advantages. Significant licensing fees also may be earned.

### Capital Flows



Venture capital into the different aspects of bioinspiration could follow a pattern similar to that seen for biotech. (See Exhibit 8.) In 1997, such venture capital for biotech totaled less than \$1.5 billion. Ten years later at the height of the economic boom, it peaked at close to \$6.0 billion. For 2013, it is expected to total about \$4.3 billion.

As credit markets continue to heal and investors seek out higher returns, venture capital should rise significantly over the coming decade after slumping substantially

in 2009 and 2010. Compared to the keen interest recently expressed for “green tech,” bioinspiration could offer less risk since it is much less reliant on possibly varying

regulations (e.g., mandates for alternative energy sources or reduced pollution) as well as fluctuations in subsidies.

Investment returns for bioinspired products could be highly variable, with returns limited in markets where distribution channels may work against new products. Still, investors looking for new ideas and themes could direct increasing amounts of capital to the field as it becomes better known with documented records of success.

### **Investment Vehicles**

Current investor options and products in bioinspiration are limited. Two fundamental areas for bioinspiration investment could be pursued. Investors could invest in bioinspiration in one of two fundamental ways. They could fund research, consulting firms or organizations scanning nature for possible ideas that can then be applied commercially. Alternatively, they could put capital to work in firms or groups of firms that have bioinspired goods and/or services.

Investment options incorporating the bioinspiration theme could involve: (1) stocks of individual firms; (2) mutual funds of several such firms; (3) exchange traded funds (ETFs), involving an index which would track the performance of a number of companies engaged in bioinspiration; (4) venture capital for individuals or start-ups in the field; and (5) private placements of equity capital in firms looking to expand markets for bioinspired products that have achieved favorable sales and profit results in the first one or two years after product launch.

The major barrier to expanding the investment potential for bioinspiration will be the education of individual stock analysts, mutual fund managers, equity index designers, financial advisors, hedge funds, and the investing public. They need to become aware and much more knowledgeable of the field's potential.

### **Investment Risks**

The bursting of the “dot-com” bubble, the failure of nanotechnology to gain major traction, the resistance to genetically modified (GM) foods, and the slower-than-expected development of genomics following the successful mapping of the human genome suggest the risks that an investment theme of bioinspiration could encounter. The domain is likely to take longer to develop than seemed likely just three years ago.

Led by chemistry and materials science, bioinspiration still has enormous potential. The opportunities for diversification across a wide array of firms with different types of products and solutions plus sizable potential returns suggest noteworthy benefits for this investment area.

## VIII. CONCLUSIONS

Bioinspiration continues to hold the promise of being a major economic game changer by forging a positive instead of an adversarial relationship between business and the environment. Because nature possesses so many solutions that are efficient and sustainable, bioinspiration offers a door to businesses to better optimize their operations.

Interest in bioinspiration has achieved impressive strides over the past decade. The emergence of various circles of activity around the world is encouraging as is the climb in the numbers of scholarly articles, patents, and research grants. Business ventures employing the technology have displayed more uneven success. While some have done exceedingly well, others have stumbled. Although such disparity of performance is not uncommon, it does underscore the importance of management, access to capital, and effective marketing.

Bioinspiration is still in its very early stages of development and should be able to expand substantially over the next two decades. However, in order to move beyond existing as a small and specialized niche in the economy, some of the following actions will be important.

### Next Steps

In the three years since our 2010 study, no single, geographic hub for bioinspiration has emerged. Instead, the field has evolved into a number of centers of influence, research facilities, and incubators dispersed around the world. This decentralized model can succeed if these disparate circles of activity communicate and collaborate.

#### **For policymakers and proponents of bioinspiration:**

- Ensure that various bioinspiration centers of influence around the world cooperate and work with one another rather than compete in separate silos
- Establish networks to bring together scientists and biologists with nature-inspired ideas with companies seeking solutions to various problems
- Support incubators to help investors or new ventures acquire the necessary business skills to take bioinspired concepts successfully to market
- Form mentoring links to help firms using bioinspiration meet the challenges of growth after the initial launch of a new product

#### **For individuals or businesses entering the field:**

- Recognize that the marketplace will give little explicit value to a product's link with nature but will focus on cost, efficiency, and applications
- Expect and be able to overcome strong customer resistance to change from existing products, methods, and suppliers
- Ensure that a strong management team is in place, including solid resources in operations, finance, and marketing

**For investors in bioinspired products and financial firms:**

- Recognize that nature is a “treasure trove” of innovation with vast potential
- Distinguish between firms whose “green” stamp is used primarily for marketing versus those that have developed a nature-inspired product offering customers cost savings and/or efficiency gains
- Carefully monitor major advances in chemistry and materials science that the field is producing
- Develop investment and financing vehicles together with metrics for the field

On balance, bioinspiration has enormous potential, but much needs to be done to realize its possibilities.

## IX. METHODOLOGY

The DaVinci Index data presented in Section II is based on annual and quarterly data on the number of patents issued in the U.S. linked to bioinspiration, grants in terms of both numbers and dollars from the National Institutes of Health and the National Science Foundation, and the number of scholarly articles published worldwide. The data has been revised relative to earlier releases of the Index. These factors are weighted and compiled into a composite Index by the Fermanian Business & Economic Institute (FBEI). FBEI researchers also canvassed various bioinspired circles of influence and activity globally either through direct contacts or via various web links.

The case studies presented in Section III were developed from personal interviews with the principals of the firms and products studied in the initial 2010 FBEI report on Biomimicry. FBEI researchers used a common set of questions to obtain information on the various issues related to sales, financing, market expansion, successes, and constraints. This information was supplemented in some cases from publicly available websites or other sources. Disclosures were made to each of the firms as to the intended use of the information obtained from the interview. Draft copies also were submitted to those interviewed for confirmation of accuracy.

The analysis of the sales potential or penetration of bioinspiration in various industries in Section IV began with a segmentation of the U.S. economy into 51 distinct sectors, sub-sectors, or industry groups. Based on the experience of the firms analyzed by the FBEI and the information or literature on bioinspired applications, estimates of the sales penetration by 2030 were developed. The base figures for shipments (sales) and value added for the various industries were obtained from the U.S. Bureau of Economic Analysis and Haver Analytics.

FBEI then forecast annual numbers for total U.S. real GDP through 2030 as well as the estimated shares of the 51 various sectors and industries relative to total U.S. GDP for 2030. Summing the products of the expected output of each sector and the expected penetration of bioinspiration into each yielded a total estimate for bioinspiration's expected contribution to GDP for 2030.

To derive 2030 estimates of U.S. resource depletion, FBEI began with estimates developed by the World Bank for 2010. This number was equal to approximately 0.9% of GDP. Including the estimated impact of pollution, a total figure of 2.5% was used for 2030. Bioinspiration was assumed to be able to reduce this impact by about 10%.

Historical numbers on total U.S. employment (both full time and part-time workers) was obtained for the 51 sectors and industries from the U.S. Bureau of Economic Analysis and Haver Analytics. FBEI developed annual forecasts for total U.S. jobs through 2030 based on its own models. FBEI then calculated the expected total employment shares of each of the 51 groups for 2030. The total job impact of bioinspiration was then derived as the sum of the product of each sector's projected employment and its corresponding bioinspiration penetration factor.

The global impact of bioinspiration was based on expected effects on overall GDP for 2030. The U.S. figure was calculated as 1.67%. Assuming that less developed countries will not have moved forward as rapidly as the U.S. and other advanced countries in technological research by that time, FBEI projected that bioinspiration would

influence a smaller 1.1% of total world output by that time. Using that percentage and FBEI's estimate for total world GDP for 2030 yielded the overall global contribution of bioinspiration.

World Bank estimates of 2010 resource depletion at 2.6% of global GDP were used as the starting point for analyzing the waste mitigation potential for bioinspiration. Including the project effects of CO<sub>2</sub> and other pollution, FBEI calculated the total negative impact on worldwide GDP of resource depletion and pollution at 3.8% of GDP by 2030. FBEI then assumed that bioinspiration could lead to a 9% reduction in these costs on a global basis.

While long-term projections out as far as 2030 are subject to a wide range of varying forces, FBEI believes it is important to quantify the projected path of the important field of bioinspiration. The precision of various estimates may also be challenged, but FBEI has made every attempt to base its forecasts on reasonable and objective assumptions as well as a careful analysis of all the existing data, case studies, literature, and results that are now developing in the field.

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