Biomimicry - Innovation Inspired by Nature

Janine Benyus

Moderated by Joel Makower

Sunday, July 9, 2006

THE MODERATOR: Good afternoon -- no, it's morning still. I don't know. Well, good morning everyone. Sorry for the late start, but we are going from Karl Rove to Janine Benyus, or otherwise from the ridiculous to the sublime, I like to think, but I'm Joel Makower from, GreenBiz.com and Clean edge.

One of the great joys of my life in the 20 years or so, in which I've been working in the areas of sustainable business practices and clean technology, is getting to know a core of people who have become not just my friends, but my teachers, and my mentors, and my heroes. And certainly, at the very top of that list is Janine Benyus.

I'm not going to do much of a bio on Janine, you have whatever information you need to know that she is not going to tell you, but Janine has elevated the already noble cause of nature writing, and interpretation, and storytelling to an extraordinary place through her coinage of the word "biomimicry," and the power that is bringing to a new generation of designers, and industrial types, and companies, and communities, and just the inspiration that we all get out of that. So if you heard -- if you were at the Belly Up last night, you've heard a little bit of the incredible work she's doing.

And so I'm just thrilled to have her here that we tried and worked and succeeded to get her here at the Ideas Festival. Before we get to Janine though, just a little bit about you, how many of you are in the design or the product design field or the creating products of any sort? Really quickly, anyone who want to just quick -- just, like, two words or three words, what kinds of things you're doing?

SPEAKER: Work online services in the website.

THE MODERATOR: Okay.

SPEAKER: Marketing and stuff.

THE MODERATOR: Okay.

SPEAKER: Sculptor.

THE MODERATOR: Sculptor, great.

SPEAKER: Building materials.

THE MODERATOR: Building materials, and –

SPEAKER: Marketing.

THE MODERATOR: Marketing. Great, great, and –

SPEAKER: Jewelry.

THE MODERATOR: Jewelry, and others of you in -- what other -- just other education field, nonprofit world, just -- good, okay. What am I missing, science.

SPEAKER: Medicine.

THE MODERATOR: Sorry?

SPEAKER: Medicine.

THE MODERATOR: Medicine, great, okay. The last thing I will say about Janine -- we're going to -- she is going to talk for 30-40 minutes or so, and then we are going to sit and have a little bit of a conversation, and of course, with all of you. If you ever in your life are lucky enough to take a hike in a forest with Janine, strap on your boots as quickly as you can.

I had that privilege a few years ago and it was an extraordinary experience. Not only will you come away from that with a better understanding of just the natural world, but the better understanding of all of our worlds, and where we are coming from, and the processes, and the ways that we live, and the way society were. It's just -- it's an amazing opportunity, so I hope that -- I think you will get a taste of that in a minute, so please join me in welcoming Janine Benyus.

(Applause)

MS. BENYUS: Thank you Joel. We should go outside right now. I've -- I'm the official representative of the "No Engineer Left Inside Program."

(Laughter)

MS. BENYUS: It is a privilege to be here with a group of people who would spend the time of your lives discussing really what the world needs now. And what the world needs now in addition to a lot of love, and compassion, and wisdom, at this point, are some really good ideas, fast, and what I'd like to talk about today is a place to look for some ideas that are not new, that are actually very, very old.

They're new to us in Western industrial culture, and they are invisible to us increasingly because they reside in organisms and ecosystems that don't necessarily look like us. So I'm going to talk about the ideas of the chlorophylled, and the exoskeletoned, and the furred, and the winged, and the four-legged, and the single celled, who have been here far longer than we have.

And their ideas, as E.O. Wilson says, have been burnished by not just millions of years, but billions of years of R&D on the same planet on which we're trying to invent things that will allow us to stay here. We are surrounded by genius. This is -- I live in Bitterroot, luckily enough, and that's where I live.

These systems, I went to school to learn about these systems, and I learned about them, and there is quite a difference, there is a different muscle that is used, there is a different kind of stance, there is a different set of questions when you're learning about something than when you're learning from something, and biomimicry really is about that profound switch between not just learning about, but learning from these organisms, so put yourself into these settings.

If you're a snorkeler, or you want to walk on that beach, walk on that prairie, put yourself in that setting, and what I would suggest to you is that these are high-tech manufacturing zones. There are hundreds of thousands of chemicals being made every single second silently, and you need no gas mask to go in there. There are miracle materials being made, you need no hard hat. There are homes being built, there is water being filtered, there is water being pumped silently, there are young being cared for.

These systems are, I now realize through working on a book called Biomimicry, I now realize that these are the most elegant and high-tech technologies that we could possibly imagine. We just are not in the practice of looking at them that way, but what I'd like to show you and tell you about are people who have made that their practice, designers, engineers, architects, inventors, who have realized that these survivors have learned what works and what lasts here on earth.

This dragonfly amazingly has a sensing apparatus that is able -- they feed on mosquitoes. When a mosquito zigs, the dragonfly zigs with it, so precisely that all the mosquito sees is the dragonfly getting larger, and larger, and larger, and the mosquito, of course, is tuned to react when there is something moving out of the edge of its vision, so when something's just looming it never sees it.

Now, you can imagine the sensing apparatus of this dragonfly that is able to do that. Some folks at Berkley have now created a camera based on the 10,000 lenses of the compound eye of this dragonfly. As E.O. Wilson reminded us 3.8 billion years of R&D, 10 perhaps as many as a 100 million species, probably more, if we think about the microbes, their are survivors and their solutions are judged by a different criteria than the solutions or products that we put into market.

They are successful, because they are well adapted. Well adapted to where they are on earth, for what they need to do, at the time they need to do it. And designers and engineers are now trying to come to the point where their solutions are better adapted. So as you listen to this, no matter what field you're in, this is not just -- I think we're all designers, I think we're all designing something.

We're redesigning our world. We wakeup in the morning, and we make a lot of choices about what to buy, and what to drive, that's a design decision. Whether you're literally at the design table designing a car or designing what lives or dies in the next generation, in the market, you are sill designing your world.

So if you were to ask nature one question, to help you make those decisions to inform your decision, what would it be? This is from -- this a picture from a trip. These are the kinds of things that there is a group of biologists called Biomimicry Guild that has come out of this work, and what we do, literally, is sit at the design table with engineers and tell them how life works because they're interested in biology, in bio-inspired design, but they don't know how biology operates. They don't know how life works.

So sometimes we are lucky enough to get to take them places. We went out with a group of wastewater treatment engineers called, Corollo Engineering and they make the water purification systems, for instance, in the City of San Francisco, that's a Corollo designed engineering system.

We went to the Galapagos Islands with them -- with their head engineers in a boat for seven days, and it's very, very typical of when people say to me, "Why aren't we looking to the natural world for inspiration?" I tell this story. We are on the boat, and the first night there was a lot of resistance. They were, sort of, walking around like this, and sort of, looking right past me, and I thought, "Oh, Oh."

So I just, kind of, whistled and said, "Hey, what is going on here?" and they said, "Well, you know, we already do biomimicry," and I said, "What do you mean?" And they said, "Well, we use bacteria to purify our water." And I said, "Okay, well, that's bioprocessing. That's something we've done for a long time. It's a bio-assisted technology like using yeast in bread, but biomimicry is a little bit different."

It's about asking the advice of an organism or looking for its recipe or its design. Getting an idea rather than thinking we couldn't possibly learn from the organisms in the Galapagos Island. I said, "Well, what do you do for a living? Give me a verb, give me a function," and then they said, "Well, we filter, we separate out something from water."

And I said, "Okay, well, let's see if we can find any filters. Let's go snorkeling." And we saw lots of filters. In fact, we saw amazing filters. Most of the organisms that we were swimming with were in someway, or another, filtering oxygen out of water, or filtering solutes out of a fluid. There were filter feeders, all different kinds of filters.

So they started to get the idea of this and they said -- I said, "Okay, well, what's another -- give me a problem statement that you have." And this is how biomimicry works, and they said, "Well, we have this thing called scaling." It's the same thing you have -- that mineral build-up inside your pipes.

In your home pipes, you know, that when minerals build up, they call it scaling, and it's really energy intensive in the sense that they either have to dig up the pipes when the aperture becomes too small because of the minerals, or they flush it with toxins, so it can be toxic as well. And so they said, "Well, what in the natural world could help us with this?"

And so we went walking on a beach and I picked a handful of these shells and I said, "Well, what is your -- what's the mineral build up inside your pipes?" And they said, "It's calcium carbonate," and I said, "Well, that's what these shells are, they are calcium carbonate." And they said, "Okay, well, how do they form?" And I said, "Well, it's very similar to a scaling process in a sense."

I mean, this is a picture of that beautiful mother-of-pearl on the inside of abalone shell. This is mother-of-pearl forming out of sea water, so it's a crystallization process, basically, out of sea water, so it's very similar to what's going on inside the pipe. So one of the engineers said to me, "Well, if it's basically a self assembly process, and it's crystallizing automatically out of sea water, then why aren't shells infinite in size?" which was a really good question, and I said, "Well, because they're able to stop that crystallization process."

Well, at that point, they all just, sort of, came in towards me, and you could have heard a pin drop, and they said, "How do they do it?" At the moment when they realized that what they do as engineers and the problem they've been trying to solve their entire professional lives that there might have been a 300-to 400-million-year-old organism who has solved it, and indeed, they have.

What they do is, to start the crystallization, they release proteins into the water that act as a template, and the crystals come down and they form the shell, but then they also release other proteins that stop the crystallization. They're called stop proteins. And there is actually -- down here I'm going to put actual companies that are now making biomimetic products, so Donlar is the company and the product is called TPA, and it's a nontoxic way to coat the inside of pipes. You allow some scaling, and then you stop the scaling.

They didn't know this, and the whole week changed after that. It was really quite amazing. They were like little seven year olds running around, "Janine, Janine, Janine," on their hands and knees, and they became naturalists. It was fun to watch. And so it's the conscious emulation of life's genius.

Many people have come up, like Buckminster Fuller and Leonardo da Vinci. It has come up a little bit in the past, and it's popped up, and now it's becoming more systematized. I'm going to talk about some of the levels of biomimicry and this is the mimicry of hairdo.

(Laughter)

MS. BENYUS: And that's the first level, and Al's trying to work on that owl look. But here are the three levels that I found going on, and since the book came out in '97, I've really been following the story, and this story has been following me, and it, kind of, breaks down into these three groups.

One is mimicking form, which is just shape, and I will talk about all three of these. It would be like mimicking the hooks and barbules of that feather, in order say, to make a fabric that didn't need a zipper, that you literally -- the way bird's feathers -- hook back together with their -- they use their beaks. It's the way theirs -- their feathers are shaped. Those hooks and barbules zip back together naturally.

So that would be mimicking form, but the key thing in moving towards a more sustainable society is in how we make things we change. How that owl makes that feather is what's called -- now there is an effort to become more like nature's chemistry, it's called Green Chemistry. So mimicking process or how is it made is in the realm of Green Chemistry.

And there is an effort afoot to replace the Industrial Chemistry book -- Industrial Chemistry recipes with nature's recipes, so when you look at oxidation reactions, and how we do them in -- in Industrial Chemistry, replace those with, perhaps, how fungus do oxidation reactions and breakdown wood, OK.

The next level is even harder, that's the level of looking at a whole ecosystem like a coral reef, or a forest, or a prairie and say, how does that system manage to enhance the place where it is, and make the most of what it has in place, where it has to live for hundreds of years with a set amount of materials, abundant energy coming in, but a set amount of materials. How does it reuse, and reuse, and reuse, those -- that material.

It's looking at the forest as a model and remaking our economy, based on that model; it is called Industrial Ecology. And that's a -- again, that's harder, but all of these, I think, are necessary before you can truly say you're coming towards a biomimicked product or process. So what I've done was, is divide up some of these case studies.

I'm going to run through these case studies, I'd rather give you breadth at this point, than depth. So I'm going to run through the case studies quickly, so you have an idea -- you have a sense of the spectrum of things going on in biomimicry. There are many labs and these are just a few of them. There are many, many labs, dozens, and dozens of labs who are working on looking at leaves as a model for a new kind of solar cell, okay.

And the Arizona State University group that I talked about in the book, their goal is to actually mimic, and they have mimicked the photosynthetic reaction center. Life central, basically, inside a leaf, and they have mimicked that 10,000 atom assembly in a very simple five part molecule that gets excited by light and that moves in a negative charge to one end of a molecule and the positive charge to another end of the molecule and holds them apart for long enough to do work.

Their goal is to create, sort of, a molecular sized solar battery, so as they envision it, the first use will probably be to do chemistry in water, in small little bubbles called liposomes with a power pack and do chemistry in those tiny vesicles powered by light. It's a very crude and simple mimic of how photosynthesis works.

Another goal might be at the point where we can reproduce these -- create these in our labs. We could mix them into paint for instance, or coat the highways with them. It's the size of the -- make ubiquitous solar cells. The technology that's come out from this work that you can buy today is called a dye-sensitive solar cell, and again, many, many labs are at work on this, let's note the et cetera.

This is using, basically, a very different kind of approach to photovoltaic cells, and you could -- and they are cheaper. They don't -- they are not as efficient, they work better in low light, they are certainly not as efficient, but they are a lot cheaper. I just talked to the managing director of Dyesol, and she said six years ago there were about four or five labs doing dye-sensitive solar cells. There are now a 1,000, so this work is really growing.

Coating something like dye-sensitive solar cells or even traditional PV cells, we might be looking to the moth. There is company called Autotype that has made a thin film covering for solar cells, and what it does is, it -- light comes in, but it doesn't bounce out, it's called an antireflective coating.

You want as much light as possible to gather solar energy, and moths, that's a moth eye. Moths want to do the same thing, they want to -- they are night predators, and yet there are predators looking for them. So they don't want light to shine from their eyes, they don't want to be detected, and so light comes in and they have the structures -- the pillars on their eyes actually trap that light, and that has been mimicked exactly into a film that Autotype has come out with.

Fuel cells, one of the reasons they are so expensive is the platinum, the membranes. It's -- what's interesting about a fuel cell to me, while it's a very, very high-tech -- to us it is a very high-tech piece of equipment. The basic functions going on in a fuel cell are going on in organisms all the time, in different organisms.

For instance, a fuel cell breathes in hydrogen and it breathes in oxygen, and at the membrane level -- and then it becomes hot water and electricity. At the membrane level, there is some chemistry that goes on. To take that hydrogen -- to take that hydrogen and that oxygen, and to smoothly combine them, there is chemistry. This is a cyanobacteria, one of the oldest organisms we know of, who does that same sort of hydrogen chemistry.

On the left is an actual molecule of what's called the hydrogenase, it is an enzyme that does that chemistry, and on the right is a mimic of that molecule. The scientists at the John Innes Center, when coating the membranes with this molecule, are finding that they can have a performance that is as good as the platinum catalyst membranes in a fuel cell, and of course, very, very inexpensive.

Again, our lungs might be contributing to fuel cells, the study of optimized branching structures in the natural world. Every time you breathe in, there is fluid or gases and how they flow, it's the same sort of, branching laws. Mathematical branching laws -- you will find in lungs, you will find in tree leaves, you will find in your own veins.

When applied to -- this is Morgan Fuel Cells -- when applied to a fuel cell, what's called a bipolar plate, they were able to increase peak power on a fuel cell by 16 percent. Again, unusual sources of inspiration, you may not think of a whale as helping you with wind energy. There is a -- I love this, there is something about nominal determinism in the natural world -- I mean, in natural sciences.

Frank Fish actually studies a mammal. He studies these humpback whales, and he now has a company called Applied Fluids Engineering. He looked at the scalloped edges of a whale's flipper, and he thought to himself, the whale is such a maneuverable animal especially when they are doing that bubble feeding, where they come up in a spiral, blowing a bubble, and then they create a cylinder of bubbles, which trap fish, and then they'd come back under and they turn around with their mouths open. It's a fabulous event if you've ever have a chance to see it.

Those scallops on its flippers are actually giving it amazing maneuverability. When Frank Fish put -- he made an airplane wing model that was smooth like ours are, and a scalloped airplane wing. Put it in a wind tunnel and found that there was 32 percent less drag with the scallops, which is huge if you're at Boeing. I was -- I gave this talk at -- in Seattle once, and literally, a Boeing engineer sort of rushed me. I felt like I was at a rock concert.

(Laughter)

Well, during the talk just came up with his card, like, "Hi, I need to know --" because 32 percent is amazing, and yeah, there is a 6 percent increase in lift, and you can go into a 40 percent steeper angle before stalling, so in an industry in which we're, you know, talking about percentages, imagine if there was a 32 percent less drag on your airplane that you came here on, that's a lot. Now, putting it on a wind turbine is the thing that they are looking at now.

So let's look at water, because we've been talking a lot about that this week. How will we procure it, and then how will we purify it? Procuring water, we always think of digging a well, maybe, getting salt out of water. There is a lot of water in the air, and this is a beetle called the Namibian beetle, and you see those little bumps on its wing scales, those are shaped in a particular way and they have a particular chemical profile.

What that organism does is, in the desert, it's got this fog that comes through, this advective fog and it's going -- the fog is going at 50 miles an hour, so in order to drink from the fog it lifts its wing scales, and the bumps -- the tips of the bumps have water loving tips, and the sides are water shedding, and a ball starts to build up -- ball of water, and then it goes down the shoot into the critter's mouth.

Okay, very simple, this is what you find in the natural world. It's over millions and billions of years, this evolutionary elegance. There is a company called Kinetic that has mimicked this and is putting it now as the sides for desert refugee camp tents and sheets in arid areas to allow agriculture. It's four times better than our fog collecting mesh nets that we have, so it's just -- this is just one.

Here's another, this is both bio-inspired and bio-assisted. This is Dean Cameron of Biolytics, and what he's done is look at how the soil column near a riverbank works to filter water, and what he's done is create a very small septic system -- the company is called Biolytics, it is in Australia. A very compact and 50 percent cheaper, you can see all the stats there.

Small septic system for homes and what he does is he invites in soil organisms, who then create a humus filter for him. They create, sort of, a sponge and then the water is filtered through that. And then irrigation water is put out into the yard. It might be -- I know we have a lot of rain today, but this is really going to be necessary for the west.

So again, what he's done is mimicked the pattern of a soil ecosystem. How about other raw materials besides water? There is one way of procuring raw materials. I think increasingly, we're going to be needing to mine our landfills and our smokestacks. I think there is a lot of material out there already.

Metals, for instance, are abundant in water, but we don't think of it as a mining operation in water, because they are so dispersed, but a lot of organisms have what are called chelating molecules. They scavenge metal out of water very, very efficiently, and a lot of microbes do that, so there is a company called MR3, and as I mentioned, this is not about using the bacteria to do this.

What they've actually done is mimic the different molecules, a particular microbe will be really good at pulling a certain kind of metal out, so they mimic that molecule and they coat a filter with it. And there is -- imagine a waste stream coming out of a landfill or out of a manufacturing plant.

They make a breadbox that has different filters in it. Each coated with the molecule to chelate a certain -- to scavenge out a certain kind of metal, so what they basically have is a mining operation in a box and they pull out those filters and they are able to recover recoverable amounts of metals, a whole different way of thinking.

This is one of my personal heroes. This is Jeff Coutts, who was one of the youngest, was one of the top 100 scientists to watch in the coming century. He -- there is a holy grail in chemistry, and it is to just be more plant like. Plants take -- what is the wood on the top of your -- of this dais made of?

SPEAKER: Cellulose.

SPEAKER: Cellulose.

MS. BENYUS: Right, and what is that -- where does this carbon come from for that cellulose? What's their raw material, plants?

SPEAKER: Carbon dioxide.

MS. BENYUS: Carbon dioxide, which is what, the poison of our era. Plants don't think of it as poison, and what they do is they make long chain molecules out of it, but we haven't -- and so people have always said, "Well, why can't we make plastics, long-chained molecules out of CO_2?" Well, CO_2 is notoriously non-reactive, that's why it is in fire extinguishers.

Plants have a way -- they have enzymes, they have ways to speed up these reactions, so Jeff Coutts [phonetic] of Cornell found a catalyst that speeded up that reaction and he now has a company called Novamer [phonetic]. Check this out, if any of you are investors. Please, this is an amazing technology. Biodegradable plastics, you know, it is making polycarbonates like you have in your glasses, and thin films out of carbon dioxide, and they are biodegradable at the end of their life. Seems like solving two problems with one -- with one idea, borrowed from plants.

Another place for getting raw materials are bio-based carbohydrates. We're starting to go to agricultural residues. You've heard about bio starches and that's a great way to go, in that you can compost the product at the end of its life, you can have it composted, right. And so we are happy about that, we are excited about that rather than plastics -- the oil based plastics. We're happy to be going at carbohydrates, but you know, I fear we're rushing headlong into a new fossil resource.

This rootlet is the new oil rig, and our topsoil and the fertility within that topsoil is the new fossil resource that we're going to be pulling on. We have got to -- if we're going to carbohydrates that are grown in our crops, are grown on soil, we have to get really good at agriculture, really quick, because we're not only going to agriculture for our food now, we're going to go to agriculture for all our stuff and we're going to go to agriculture for our bio-fuels.

The question is, the new oil well is soil fertility. So everybody's got to be really, really good at farming, and the question we ask about our products has to be how are they grown, and this is how most of our crops are grown in the United States in our plains area. They are annual crops and they are in monocultures, so you dig them up every year, and you put one plant.

The same species for miles, which means you lose a lot of soil during that digging it up, it bleeds away into the Mississippi, it's a lot of fertility so you add an oil resource, you add fertilizer, which comes from natural gas, and then you've got one species for miles, so pest -- it's an all you can eat pest restaurant, and so you put on pesticides, that's another oil product, and herbicides.

And David Pimentel of Cornell says it is 10 kilocalories of oil for every kilocalorie of corn. And a bushel of topsoil going down the Mississippi -- six bushels of topsoil, excuse me, for every bushel of corn in Ohio. Okay, these are scary when you're talking about a fossil -- what I would consider a fossil resource because bringing back soil fertility of the depth that we have it in the prairie -- the ex-prairie region is way beyond our human lifetimes.

So what's the alternative? Prairies when -- and biomimicry always works like this, what was there before we got there and can we learn anything from the patterns that were there before, and prairies -- the amazing things -- thing about prairies is that -- one of the amazing things is that incredibly deep root level -- root zone, not just deep, but varied.

Each of those plants has a different root composition and length, and so they are, kind of, using a different part of the environment to get their needs met. They also -- and they're perennial. They stay on -- you know, they stay on the soil, so you're not, you know, you're not losing that soil every spring. They also are a poly-culture. Instead of an annual monoculture, there is a -- there are a perennial poly culture, lots of different species with different ways of using that habitat.

The Land Institute in West Jackson has been working tirelessly on this for about 25 years. What they're trying to do is turn our crops from annuals to perennials, to breed perennialism back into our crops, they used to be perennials. We've bred them into annuals so we could carry those seeds in our pockets. Trying to breed perennialism back in and to plant our crops -- our perennial crops in mixtures, and then harvest them at different times a year, very interesting work, and really pretty essential.

Manufacturing, this is Joanna Aizenberg's hand. She is at Lucent Technologies, what used to be AT&T, and you see those little filaments at the base. This is a sea sponge, Venus sea basket, it's called or sea -- Venus sea flower -- sea flower, I believe it's called, and those filaments at the base there are -- they work as well as our fiber optics, but what's interesting about them is that you can tie them in a knot, so unlike our glass made at Corningware fiber optics, these you can tie in a knot.

The other thing that's amazing is the way they are manufactured, okay. This is the way we manufacture things. The recipe is called heat, beat, and treat. Heat it up, high pressures, right, and treat it with chemicals. That's our recipe that material scientists use, but we can't -- life can't possibly -- the sea sponge can't possibly do that, so it's found a different way.

This is a picture of -- thanks to Dennis Kunkel, a picture of spiders -- business end of a spider. Those are the spinnerets and that's silk, color enhanced, that's silk coming out. When this spider manufactures it can't do what we do with Kevlar, which is heat petroleum up in the sulfuric acid to 1,400 degrees and then draw it out at huge pressure, but it's found a way to make a fiber that's five times stronger, ounce for ounce than steel.

Silently and to do chemistry in water rather than a solvent like sulfuric acid, so this is what I mean by Green Chemistry. Borrowing the recipe of this organism and I don't mean taking its gene and sticking it into a goat, which is what's happening at a company called Nexia. You take the gene from the spider, and you put into the goat, and you clone the goat, and the goat milks out spider silk from its mammary, and I don't mean that.

That's domestication, that's a bio-assisted technology. Biomimicry is doing the hard work of figuring out the recipe and the chemical processing and doing it yourself. It's not easy, this is not easy, but it's -- it is happening. Here's -- on the -- on hard materials, here's the abalone shell again, and the mother-of-pearl, the nacre.

This is a picture of its self-assembling. Those are the layers of protein, the yellow is the layers of protein and the blue is the minerals, layers of protein actually template. This is outside the critter's body, between the soft body and the shell. It templates this particular kind of crystallization, so this is existence proof -- oh, by the way, this is twice as tough as the high-tech ceramics we have in jet engine ceramics, twice as tough.

So this is Jeff Brinker at Sandia. He is just amazing, and work is also going on at these universities and many more, again, Princeton, and lots of universities. This is a picture of -- on the left there he is creating self-assembling ceramics out of a beaker of water. He is doing optically clear glass. It's a coating technology at this point.

There is no heat, he dipped something into the -- liquid, beach sand basically, the precursors of glass, and an organic, and a detergent to herd them all together. He dips it in and he pulls it out, as it evaporates, the molecules self-assemble, they jigsaw together into layers of glass separated by a soft layer. There are hundreds or thousands of layers of optically clear glass, a completely new way of making ceramics.

This is a bullet going into another mimic of the abalone shell, and being stopped by it. These are diatoms, the shells of diatoms, and their body -- their skeletons are made from the glass family, the silicones. And silicon is also in that family, that's what we make our computers with. Only when we make them there is a lot of carcinogens involved.

The folks at U.C. Santa Barbara and Princeton have been working to do what's called biosilification, which is a mimicry of the way glass-like structures are formed in the ocean, and they have actually been able to do that. Now, the question is, can we make something with this kind of architectural elegance.

This is Haeckel's -- you guys, any artists in here know about the book Art Forms in Nature by Ernst Haeckel? I mean, if you ever have a chance to buy one of those, buy them. They are amazing, these big prints of nature's, actually architectural wonder and structures. If you look at that second layer there on the left, there was actually a structure in Paris for one of the exhibitions that looked very much like that, but these are radiolarian. These are actually organisms or their skeletons anyway.

Here's one we've been working on for a long, long time in the scientific community, I don't mean me personally. The glue, the underwater glue of muscles, we can even keep a band aid on our finger in a -- well, in the sprinkler, and this glue has finally been mimicked by a Professor Li at Oregon State University and Columbia Forest Products is now making a plywood adhesive that is completely waterproof and has no formaldehyde in it, mimicked from that.

Organisms adhere in a lot of different ways. Here's an organism that adheres without glue. That's a close-up of the bristles at the -- from -- that come off the fins of a gecko, and it's how a gecko sticks to the charges, positive and negative charges in a wall. Wall is charged with little nooks and crannies and those bristles actually adhere through what's called van der Waals' forces, which is a very, very -- it's the minimal attractive force, and yet when you add it by the millions, you have a really -- you can suspend about 280 pounds from a fully engaged gecko.

Okay, that which is amazing, and that's why geckos walk like this. They have to actually peel their foot up. They couldn't put like this; they have to peel it. When you peel it at a 30-degree angle, you release that. So the idea here is what if we could put our products together. Products like this, not with glue because when you go to recycle it, it is contaminated by the glue.

What if you could put it together with gecko tape? So you buy a product like a computer case and it is put together on the edges with gecko tape, and then you send it back to the manufacturer and when they go to recycle it, they are able to pull it apart. That's what I mean by designed for disassembly, and it has actually been mimicked.

This is a group at the University of Manchester, where -- they were actually going to use a graduate student hanging from a flag pole outside, but the -- I guess, the -- the university insurance found out about it, and so they just did this little superman guy, but a piece of dime-sized gecko tape could suspend a liter bottle of milk. That's about the strength of it, and then it's releasable.

So the question, you know, this kind of, sort of, changes the game. It's not a question of how do we reduce the toxins in commercial adhesives; it's how does nature adhere. There is lots of different ways nature adheres. This is one organism; this is a picture from (inaudible) collection of insect feet. There are lots of ways that nature grips.

The idea is: How do we give designers these new patterns? There is a pollen grain. Julian Vincent, a premier biomimic at University of Bath, said, "Shape is cheaper than material." That pollen is using that shape to surf the wind to get up your nose. You know, it doesn't put a propeller on, it doesn't go to the Middle East to drill for oil, the energy in the wind is out there. It uses its shape.

And that's what life does, one of the most ubiquitous shapes is what's called the Fibonacci sequence, logarithmic spiral. It's what you see in seashells. It's what you see when you turn on the faucet and the water is in a vortex. It's what you see if you look at your skin pore, there is a spiral staircase. If I would -- I don't have a close-up of a skin pore, I need to get one. It looks like the Guggenheim Museum staircase basically.

And the reason that life uses that sort of a shape is that it's the way flow goes, you know, when there is a hurricane, the cloud is in that shape as well. It's the way flow goes, and yet with our fans and our water moving equipment our propellers, we haven't used that shape. So a guy named Jay Harman, when he put that shape, he took pieces of that shape he is holding and made fan blades out of it.

And now has a company called PAX Scientific, and those fans are 50 percent -- they use up to -- between 35 and 50 percent energy savings, and 75 percent quieter. So listen, do you hear the fans in this room? There are fans everywhere. If we were to replace all fans with this sort of a shape, here is the one I talked about last night. This is the kingfisher which been -- has been mimicked on the nose of a bullet train in order to make it quieter and it actually makes it about 10 percent faster and uses about 15 percent less energy.

This is a car that is mimicked -- it's mimicking the shape of a boxfish, small coral reef fish that deals with incredibly turbulent flows and is able to hold itself in place in the coral reef. You assign that to the body of a car and you get great slip streaming and then they also -- they also light-weighted it by using a software that mimics the way we -- our bones reform themselves along the lines of stress.

Lotus -- how many people have heard of the lotus effect? This is the next Velcro. This is really going to be everywhere. This is how leaves clean themselves; this is not just lotus leaves. They clean themselves -- this is a water droplet, you know, how there is dew in the morning. That's because the surface of a leaf is not smooth, it's really rough, and it's got these little pillars. These little bumps that are a certain distance apart, and what that means is that dirt particles, that's the red thing, it is dirt particles.

You can't quite see in here, but on a rough surface, on the right, the dirt particles, sort of, teeter. And then the ball of water, the water balls up and then it lifts off the dirt particles. So this is being put into all kinds of things. This is a building that -- was painted eight years ago in Germany with this, and this is called Lotusan paint, and when it dries it has that bumpy structure, which rainwater cleans the building, okay. And it's also in -- it's in all kinds of things now, roofing tiles, it's going to be in paint, car paint, auto paint, windows. The auto paint is still matt, but -- and fabric.

Again, what are the ubiquitous things that we see everyday, that we pass that have these answers for us? We argue about paint and paint formulations. There is no blue pigment in this bird. Life has a couple of ways of making color to your eye. One is pigment, but it's expensive, it's a chemical, it's expensive. Another way is just to change the last few layers of its wing structure to create the color to your eye, to play with light, basically.

Structure is cheaper -- shape is cheaper than material, so all of these organisms are brown. It's the only pigment they have in them, every single one. What's happening is some of them are layered, some of them have little holes, and they have all different kinds of mechanisms for structural color. The simplest ones, think of it this way, they're made -- the feathers are made of keratin. It's like your finger nails, okay.

And think of layers of your finger nail being transparent and they are a certain width and that gives it what's called a refractive index, and they're layered, so light comes in and then it goes through some of them and it bounces and it starts bouncing back, okay. And it gets -- a certain color gets amplified. Change the width of the layers; change the color.

So here is a fabric that has no pigment in it whatsoever on the left there, that has no pigment, so we are away from the idea of toxic pigments. While we are manufacturing we give it a shape that plays with light. Imagine all of these products never having to be painted again. Imagine your car being sort of transparent in your garage until you drove it out into sunlight.

This is Qualcomm who bought -- who looked at butterfly technology and is making PDA screens that the pixels -- each pixel has basically a little sandwich that it changes the width of the layers, basically, and creates a different color to your eye. So the sunlight actually creates the color display.

Another -- you know, just there is a lot of things to have to -- that have to do with the saving of waste, saving of materials. 300,000 fender benders a year is a big waste of materials. Volvo the University of Newcastle looked at locusts. You know, how locusts are in huge swarms, but they do not collide. And the reason they do not collide is they have the phenomenal ability to sense and respond before collision, and so Volvo -- so the University of Newcastle biologists studied this.

That's the giant neuron, that's in the locust, and then they took that idea and they put it into an anti-collision device. And there is -- I'm not going to go into sensing. I'm not going to go into computers or genetic algorithms; there is all kinds of things. I wanted to get into -- there is some people here from healthcare.

This is the Lazarus shark. A Lazarus shark can survive for three hours without oxygen, if you did that you would be so far beyond stroke, you know, that's what -- you know, you go in and you have a stroke and they have to quickly help you or else you start to have problems because of the anoxic conditions.

Three hours without oxygen, because it's a tidal feeder, it's in the tidal pools, hangs out, depletes all the -- the oxygen gets depleted, by the time the water comes back in it comes back to life, basically, it's called a Lazarus shark. And ER docs -- they're looking at how to treat patients who come in, not with a chemical from this guy, but just learning a mechanism from this guy.

This is a really, really important one, I think. In an era of super bugs, when you go into a hospital, you've got antibiotic resistance that has created -- you all know what that is? That's created super bugs, right, when you just keep dowsing on with antibiotics and the strong ones survive and we actually create an epidemic of super bugs from that, right.

Organisms are surrounded by bacteria, including us they're inside of us, they're all around us. The question for biomimics was, what in the natural world is surrounded by bacteria, but has no bacteria on its surface? And this is some brilliant work, I think. It was done by Peter Steinberg, at University of New South Wales.

That red kelp has no bacteria on its surface, Botany Bay, Australia. What it's doing is really like an aikido move, it – bacteria -- when they land on a surface, a few of them will hang out and then they will start communicating with bacteria floating by. And then those bacteria will come down and they will form what's called a bio-film, that slimy layer that you have inside -- if you haven't cleaned your toothbrush thing in awhile, that's bio-film.

And that layer is formed because of this -- it's called quorum sensing from bacteria. What this plant does is it releases a molecule that jams the communication signals of the passing bacteria. The folks at Biosignal has -- have mimicked this. What's interesting is you're not killing the bacteria, so you are not encouraging resistance. They just pass on by, and the ones that have landed, they won't form a bio-film if there is not enough of them, so they drop -- they come off the surface. That's why that surface is free of bacteria.

Hospital surfaces, contact lenses, the really important one for antifouling -- I mean, for sustainability is to put this in an antifouling paint for boats, because now we use this stuff that uses nasty releases tin and heavy metals into bays. This is a whole -- in other words, it's a new approach to dealing with germs, with bacteria.

This is another, kind of, Holy Grail in the -- in public health. Vaccines -- half of vaccines don't reach their intended recipients, because at some point along the line the cold chain is broken. Meaning, it -- the refrigerator breaks down, refrigeration breaks down. So how do you create a storage device for vaccines that you can take a vaccine and put it in your glove compartment?

So a guy named Bruce Roser at Cambridge Biostability looked at these organisms, the guy -- does anybody know what that guy on the left is?

SPEAKER: (inaudible)

MS. BENYUS: What? Good guess. Right -- it's smaller than that. It's really small. You could be drinking it in your water right now -- well, in tap water.

SPEAKER: It's lovely.

MS. BENYUS: Do you know what it is? Anybody?

SPEAKER: It's a Water Bear.

MS. BENYUS: Yes, it's a water bear. It's not fair. Tom Lovejoy. He knows everything. Everybody but Tom -- yeah, it's a tardigrade, it's a water bear, and what's interesting, what's similar about the tardigrade and what's called the resurrection fern is that both of these organisms are able to dry out, lose the water in their bodies, almost completely, and then go into a suspended state of animation.

And a water bear can do it for a very, very long time. The resurrection fern can do it for months on end and it will turn brown like that and then you add water and it greens up again, but what's interesting is that it is a perfect storage device. Because in our cells, if we dried out, the sugars in our cells would crystallize, and they'd get sharp points and they'd poke thorough our cell membranes and we would die, but these guys have a sugar called trehalose and the sugar turns to a glass, like an amber, it's soft. Like a maple syrup, think of it that way.

So it's a different kind of sugar, so what Bruce Roser did was he took that sugar, he mimicked it and he used it to coat vaccines in, like, a tiny time capsule coating, put those vaccines, and you can put five or six different vaccines, multivalent vaccines, into an inert liquid in a vial attached to a hypodermic needle and that can -- it's thermally stable. This is an important technology. It's being tested right now by Panacea Pharmaceuticals in India. But I think it's -- where is the guy from WHO? Hey, do you know about this?

SPEAKER: No, I don't, but I'm (inaudible)

MS. BENYUS: Oh, man. I mean, you know, my -- I filter feed for these case studies all day long, you know, all the time and so I'm finding -- but a lot of this stuff is small and languishing, but gosh, if we could just daylight some of this. Here is another one; malaria. This is the crested auklet, who breeds in Alaska on an island, that's like a tundra heather really, really, wet and the mosquitoes are in clouds, you know, you could like draw your name in the mosquitoes, right.

I mean, it's -- and no mosquito -- if these guys were bled to death by those mosquitoes, I mean, their chicks would just -- they would be bled to death, I should say. Not a mosquito on these guys. So what's happening with the crested auklet, and there is -- that's just a typically biomimicry question, what in nature has already solved the question I'm trying to -- that's the work being done at University of Alaska.

There is a whole -- I wrote a whole chapter in the book on zoopharmacognosy, which is a really melodious word for self-medication. It's looking at animals that are self-medicating. Picking particular plants, and making themselves -- and literally dosing, preparing the plants and dosing, and then following them are in their rounds around the jungle and picking those plants and saying, "Is there a potential, what's called secondary compounds, is there a potential drug in this plant?" So letting these organisms that have been pharmacists for a long time take the first cut, in seeing what they eat, very interesting field.

Finally, at the level of ecosystem, I won't go deeply into this. I will just mention that, if I was talking to an industry crowd or a manufacturing group, they are very interested in this kind of work. On the left is a food web of -- it's a picture of a coral reef at foodwebs.org they have these amazing things where these are, you know, eating -- who's eating and being eaten kind of thing.

But I just wanted you to see the incredible -- you know, when some -- when poop falls in a coral reef it gets used, you know, it gets used and we would need to start to connect our economy in that way so that there aren't landfills and there aren't dumpsters in the back. This is a diagram of what is called an eco-industrial park in Kalundborg, Denmark, and there are many of these now around the country.

And what it basically is, is that the waste product of one company becomes the raw material for another company and it's a matter of hooking up those information, those material brokerages so that nothing is being wasted. So I didn't know who was going to be here. This is such an interesting group. If you are a company there is an opportunity to train your innovators at a biomimicry workshop, okay.

What we've -- what's happened now is that -- this is really a methodology, it's a problem solving method, and so I've been talking to you about where it's gone from lab to product. Well, now if you are a company and you want to solve a problem, how do you take your problem and say, "I want to reduce noise, I want sound dampening."

How do you then find the best natural model, study it or -- in many, many, many cases it's already been studied. This is about pulling the literature and then finding a mechanism that might work and then developing it into a product, but we teach biomimicry workshops in Costa Rica for designers and engineers that are phenomenal. If you are a biologist, we also teach biologists at the design table training, we have one in two weeks in Montana.

So we're training on both sides. We are training biologists to sit at the design table and work with designers and engineers, and we're training designers and engineers to begin to think this way and then to pull in biologists when they need them. If you're a designer, begin to practice this.

We're working on -- one of things we realized was that a lot more bio-inspired innovation would go on if the people who are making our world new about biology, but they're not going to become biologists. You very rarely have it all in the same person. They are going to have to learn to get -- to get biological knowledge somewhere, so they go to Google and they type in a biological concept like -- well, they type in something like lubrication.

Now, in the natural world, the best lubricant really is at the bottom of slugs, you know, the slug slim, but in a paper -- you can have paper after paper after paper and it will never mention lubrication, it is mucin. You know, so you might not find -- it's difficult to put in your search term and find the biological knowledge.

So what we are trying to do with this biomimicry design portal is to create a Google of nature's solutions, in which designers, engineers, anyone solving a problem can go to the site, type in a function, and up will come selected articles about how nature does that, and pictures of insect feet and then an expert that you can actually call up.

It is a way -- it is part Google and part eharmony.com for biologists and engineers. Because Tom, you know, as a -- I was trained in the biological world. I don't know how the world works. I never worked with an engineer or -- but it's time to get us together. So this will be a collaborative design space. It will be a place where industry can post challenges with bounties attached like the express.

And hopefully, biologists out there will say, "Gosh, I know an organism who does this," and they will upload their paper and their information, and teams will form and start to create, new, more sustainable products and processes. There will also be an education lobe of this thing, because right now there is five universities teaching -- biology taught functionally, and then teaching a biomimetic design lab that we've been working with.

And so we will have all of their curricula on the web, so you can take a class and we will have all the students' designs on the web. And this will grow because it's an open source thing. This is something that we're trying to get instituted. Tom, this is something I'd love to talk to you about too. If designers and engineers take one biology course, teach biology functionally, so it mimics their own engineering book, but it's how nature would do this, so you know, biomechanics stuff and how nature pumps and movement in fluids.

Biomimicry -- stay tuned on biomimicry.net for this kind of stuff. Our company is called Biomimicry Guild and then we have an institute as well to do the nonprofit stuff. How did a nature writer -- I'm a nature writer. I wrote five books on plant and animal adaptations before this. How did a nature writer get to where I am now, talking with designer and engineers?

I wrote nature books to increase people's respect and admiration for the natural world. I wanted to say, "Look at how amazing this is." And four people read these books, you know, five people, my parents included.

(Laughter)

MS. BENYUS: And I'm still -- biomimicry was just another effort to say, "Look at how amazing this is," and take your stance as a student, what could we learn, and it's really -- it is a way of creating new inventions, but for me it is much, much more than that because it's a whole new way of seeing the natural world. It's a whole new relationship for us as a species, to the rest of -- we are nature -- to the rest of the natural world.

And I've just talked about nature as model, but it's also nature as measure. What would nature do here, is what we've talked about and what wouldn't nature do here. And nature as mentor is, I think, a stance that we need to get to, so that all good decision-making emerges from that, from that sense of respect for the rest of the natural.

I guarantee when you -- when you walk back to your car today, you will be looking at these organisms in a slightly different way. And it will be much more difficult for you to know that they are going extinct, that's the whole. There is still an enormous amount to learn, and these guys are blinking out as we speak, these geniuses.

So one of the things that we are trying to institute, now, is a thanksgiving piece. Now, biomimicry is about quieting human cleverness, and then listening, and then echoing what you hear, and then somehow giving thanks, because if you don't give thanks, it becomes another rip off. It's becomes another extractive technology.

So what we are trying to do is say to companies that come up with these bio-inspired inventions. We're trying to ask them to donate a percentage of their proceeds to conserve the habitat of the organism that inspired it, and it's called Innovation for Conservation. And I have a feeling this is going to really possibly -- I mean, imagine if Mercedes Benz, DaimlerChrysler makes the boxfish car, and if they put 1 percent of the retail price of those cars to preserving coral reefs, because at -- you know, at the end of the day you really do need to preserve the wellsprings of these good ideas.

And it is good for us as a culture to say thank you, it's a good gesture, but it's also a very practical one to preserve the wellsprings of these ideas. Before I leave, I do want to say that life is not just a collection of different technologies at all. What's really amazing about these organisms is what they do in total. In ensemble all the guys I talked about are managing to filter the air we breathe and to filter the water we're drinking, and to build soil.

And at some point that's our real design challenge, that's our design brief. Life creates conditions conducive to life, and that's the trick that if we hang in there long enough and we really pay attention to these organisms that's the one we have to get to, I think. Thank you very much.

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