PRESCOUTER

HOW BIO-INSPIRED MATERIALS ARE REVOLUTIONIZING INDUSTRY

PRESCOUTER

How Bio-inspired Materials Are Revolutionizing Industry

2017

CONTENTS

INTRODUCTION

Nature serves as one of life's most creative and innovative scientists, and can sometimes provide us with examples of highly optimized and efficient systems. In this whitepaper, we go over some of these examples. The **bio-inspired materials** covered span across a number of industries.

The first bio-inspired material we cover is the development of an **ultrastrong reversible adhesive** inspired by **Geckos**. How this innovation was created and the potential applications are described in detail.

Next, we delve into a material that was inspired by the natural **porous structure found within leaves and insects**. Scientists have taken this inspiration to develop a **highly efficient material** that can be used in **energy-related applications** like rechargeable batteries.

Textiles is the next area we cover. Inspired from the super-hydrophobic **nanostructures found in nature** (like the Lotus leaf), scientists have devised nanomaterials that work with **self-cleaning fabrics**.

Then, we talk about a bio-inspired material that can serve as a **'hard' biodegradable alternative to plastic**. The inspiration here is derived from the **shells of crustaceans**.

Our last area of focus is **water filtration**. Inspired by **biological membranes**, scientists have developed biomimetic membranes that can be applied in **water purification systems**. Future prospects of this promising innovation are also covered.

ADHESIVES: GECKO-INSPIRED ULTRASTRONG REVERSIBLE ADHESIVES

Heidi Reidel

In 2012, a team of researchers at the University of Massachusetts- Amherst, led by Al Crosby and Duncan J. Irschick, unveiled a new super adhesive called Geckskin, modeled after the ability of geckos to stick to almost any surface. The applications of this breakthrough are so broad that even NASA and the U.S. Military are eagerly awaiting further developments.

How Does it Work?

Tiny hairs called "setae" on the feet of geckos allow them to cling to smooth surfaces. These setae branch into even tinier spatulae, which interact with surfaces on a molecular level to create adhesion. Similar to hair sticking to an inflated balloon, the charges of the molecules cause attraction. This is called *van der Waals intermolecular forces*.

Geckskin, however, doesn't work to simulate the setae, but rather simulates the relationship between the skin, pad, and tendon on gecko feet. Geckskin uses stiff fabrics such as carbon fiber (representative of the skin) and soft, rubbery materials which represent the pad; the materials are then woven into a synthetic tendon.

Geckskin becomes more impactful because this results in "draping adhesion," where the stiff material forces the synthetic setae to drape over surfaces like a tablecloth. The product is a super adhesive material strong enough to hold up to 700 pounds and can be removed easily only if pulled in the correct direction, leaving behind no residue.

Applications of this Super Adhesive Material

To test the strength and durability of his creation, Al Crosby donated his own 42-inch flat-panel television for the cause. The TV held for over three hours using Geckskin. The research team produced a video proving the material can stick to nearly everything, but not enough testing has been done to commercialize the product for television mounting.

Home-Decorating:

Geckskin could change the way people approach home-decorating by eradicating holes in walls from screws, tacks, tape, etc. This adhesive material would essentially revolutionize decorating and home repair. This could take a large amount of stress off of renters, homeowners, and college students in dorms.

Military:

The military jumped on the applications of this innovative material immediately. The Geckskin team's research has been funded by DARPA (Defense Advanced Research Projects Agency) which is the advanced research arm of the U.S. Defense Department. The military is using this research to develop climbing aids that would allow soldiers to scale walls. They've experimented with a 218-pound researcher with an additional 50 pounds of gear climbing a 25-foot glass wall. These climbing aids could also potentially be used by emergency responders or even construction workers to reach high places safely.

Labs and Hospitals:

Labs and hospitals could also benefit from Geckskin. Because it doesn't leave a residue or cause a chemical reaction, it would be safe to use in a lab environment without compromising anything. Though it hasn't yet been tested for use on skin, Geckskin also has potential applications for wearables like patches or heart monitors.

Robotics and Space:

Even NASA is looking into the creative uses for Geckskin, from catching space debris and reducing collisions to allowing robots to grip the exterior of ships to perform inspections and maintenance.

What Does this Material Mean for Sustainability?

Duncan Irschick, one of the scientists behind the development of Geckskin, assures that once the product is commercialized, consumers should be able to get it from a hardware store for a low cost. Geckskin is made of everyday materials that can be easily constructed and manufactured. Now, the team is using 100% renewable materials such as natural rubber and hemp. Unlike tape and Blu-Tack, Geckskin can be reused, which would deter waste from alternative products. The Geckskin team even suggests that their product could be used to detach and reattach solar panels at different locations to charge electronic devices.

Between cleaning up trash in space and reducing waste on Earth, Geckskin could have an enormous environmental impact. Geckskin is a truly innovative material. It could lead to new scientific or medical discoveries and transform gear for soldiers.

HEIDI REIDEL

Heidi Reidel is a recent graduate from Knox College in Galesburg, Illinois with a BA in Creative Writing and a minor in Psychology. She is a freelance writer and an advocate for victims of domestic violence at a local shelter.

ENERGY: HIGHLY EFFICIENT POROUS MATERIALS INSPIRED BY LEAF VEINS AND INSECT SPIRACLES

Ezinne Achinivu

An international team of researchers led by Professor Bao-Lian Su have discovered a way to emulate the natural porous structure found within leaves and insects in synthetic materials. This could yield highly enhanced materials and effective systems that demonstrate up to 20 times improvement in their performance with respect to applications like rechargeable batteries, photocatalysis and gas sensing.

From Murray's Law to Murray Material

Plants and animals have similar tissues that contain multi-leveled networks of pores, which have evolved to maximize transport and reactions. The underlying physical principles of this optimized multi-level design are embodied in Murray's law. Murray's law defines the basic geometric features for porous materials with optimum transfer properties. Until now, researchers have not benefited from copying nature's Murray networks into synthetic materials due to the challenges in developing these porous structures.

The team of researchers used a generalized Murray's law to design and optimize the structures of the multi-leveled porous materials via a bottom-up approach. Well-defined microporous zinc oxide (ZnO) nanoparticles were used as the primary building blocks. They were assembled into the multi-level porous Murray networks with interconnected macropores, mesopores and micropores. The secondary and tertiary mesoporous and macroporous networks were constructed by a bottom-up layer-by-layer evaporation-driven self-assembly procedure.

This concept has led to the development of materials, termed as the Murray material, whose pore sizes are multiscale (macro–meso–micro) and designed with diameter ratios obeying the revisited Murray's law. The resultant materials have a multi-leveled network of pores, similar to that of the leaf veins and insect spiracles, which will improve their transport properties and reactivity. According to Professor Su, this new material could be beneficial to a wide array of porous materials and enhance functional ceramics and nano–metals used in environmental and energy applications.

Extending the Life of Batteries

The Li-storage performances of the ZnO Murray materials (ZOMM) were presented for application in Lithium ion batteries. The multi-leveled ZOMM exhibited a long-life cycling ability of up to 5,000 cycles with a reversible capacity that was 40 times that of a ZnO macroporous material and 25 times higher than that of state-of-the-art graphite. Utilizing the bio-inspired ZnO Murray network as an anode material delivered ultrahigh capacities and rate capabilities, along with long-life cycling stability. According to the research published in Nature,

> *"Murray materials can meet both the criteria of fully space-filling pores, enabling ultra-short solid-phase Li-diffusion, and an optimum electrolyte-filled porous network favoring full and rapid Li-ion transfer with the electrolyte."*

Other Industrial Applications

Photocatalysis:

Photocatalysis, the acceleration of a chemical reaction by light, has widely been used for degrading organic pollutants based on fully dispersed nano-semiconductors—amongst a variety of applications. Using the bio-inspired 3D Murray networks, the relative photocatalytic rate of the ZOMM is compared to that of fully dispersed ZnO nanoparticles. The results show that the ZOMM yields one of the best photocatalytic activities ever reported for ZnO nanomaterials—displaying up to 17 times higher rates than that of the ZnO bulk sample. Additionally, the ZOMM film is also easily recyclable for repeated reactions.

Gas-Sensing:

The gas-sensing performance of the ZOMM under ethanol vapor exposure is also demonstrated. The fully branching and

space-filling porous network enables the material to have increased surface area for oxygen adsorption, as well as, full and fast diffusion of gas molecules. According to the results, the ZOMM achieves a sensitivity of 457, the highest value ever reported for ethanol detection, which exceeds by at least 20 times that of commercial SnO_2 sensors. The Murray material has a structure similar to the breathing network of insects, thereby, allowing gas detection over a broad concentration range with a higher, faster and much more stable response compared to state-of-the art material.

Enabling the Future

Professor Su and his research team anticipate that this strategy could be used effectively to design porous materials for energy and environmental applications. Utilizing a bio-inspired Murray network can enable a vast range of porous materials with enhanced transport properties and reactivity for high-impact applications in several industries.

EZINNE ACHINIVU

Ezinne has a PhD in Chemical and Biomolecular Engineering and is currently a Research Scientist/Engineer at '525 Solutions/University of Alabama' leading process development & scale-up efforts for the production of biofuels and novel bio-products. Her career goal is to be at forefront of those forging through barriers to sustainable development, especially with regard to utilizing and developing renewable resources.

TEXTILES: BIO-INSPIRED NANOMATERIALS WORK WITH SELF-CLEANING FABRICS

Olimpia Onelli

Enjoying some sun while the laundry takes care of itself might be a dream not that far away. Researchers at RMIT's Ian Potter Nanosensing Facility in Melbourne have developed a new way to fabricate self-cleaning cotton using light. Their approach is extremely innovative and promises exciting applications in terms of multifunctional fabrics like nylon and polyester.

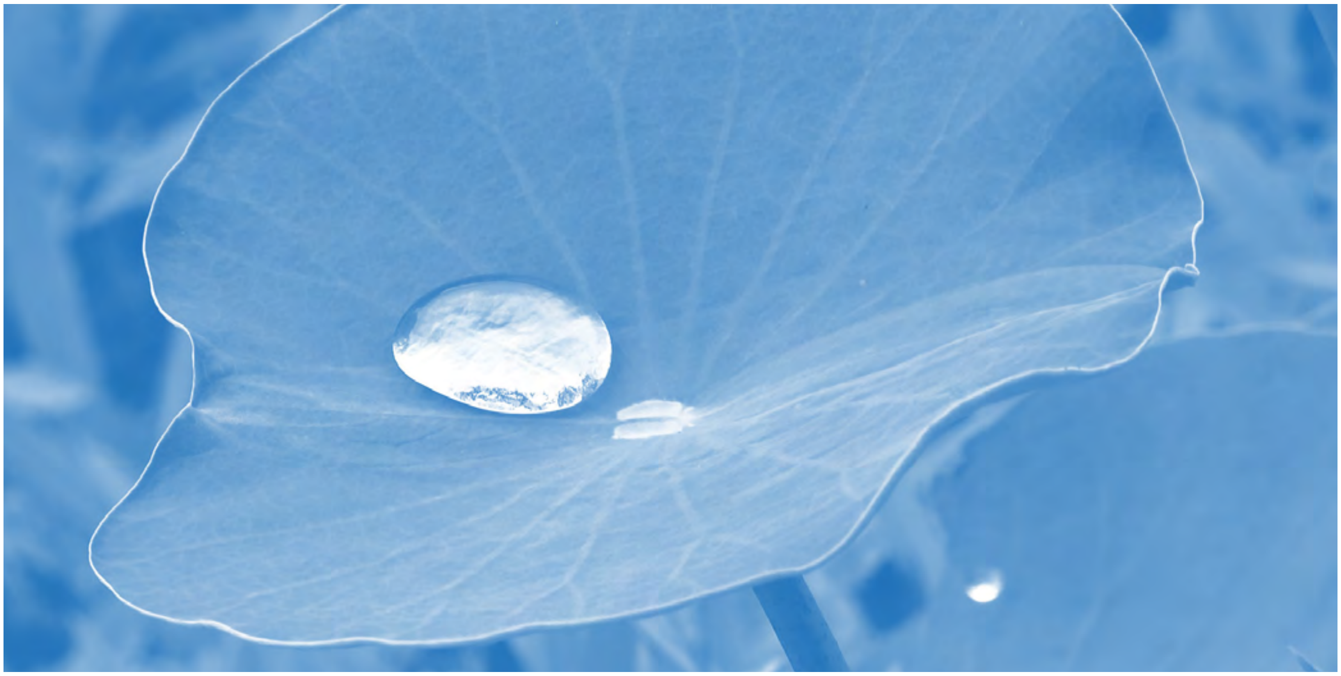
The Science Behind Self-Cleaning Clothes

Traditionally, self-cleaning materials are inspired by the super-hydrophobic nanostructures found in nature. The most famous example being the Lotus leaf, whose high water repellency is due to micro- and nano-sized architectures that minimize the adherence of droplets to the surface.

However, the approach of Anderson and colleagues is quite different: by using metals such as silver and copper, they are able to exploit the resonant oscillation of conduction electrons (known as "surface plasmon resonance") to degrade organic materials that get stuck in between the cotton fibres of shirts, pants and other garments. In other words, when the metallic nanoparticles get excited by light, they stimulate chemical reactions that deteriorate molecule strapped in fabrics. Thus, you have self-cleaning clothes.

Cotton and Other Fabrics That Can Self-Clean

It is important to mention that this enhanced reactivity works best with cotton because the hierarchical structure of the cotton fibres form micro-sized meshes and nanoscale structures that maximize the surface area involved in the reaction. Though, the process might work in other fibers such as polyester and nylon, where the team at RMIT university has also reported successful trials.



From Science to Market

The possible shortcomings of the self-cleaning clothes method have also been assessed. One of the major concerns is that the fabric might lose its properties if washed in a traditional way. Luckily, the new material has been shown to resist up to 15 washes without damaging clothes.

Furthermore, the amount of light needed for the self-cleaning reactions to occur has also been minimized and it's currently around 40 minutes. However, some questions are still standing.

Environmental Concerns:

First of all, there is the problem of scalability. Anderson and collaborators are using electroless deposition to coat the fabrics with metal nanoparticles. As a benefit, this fairly straightforward method coats clothes evenly without using electrical power. However, it poses a different environmental risk. This technique involves high waste treatment costs as the chemicals involved have to be renewed very often.

Health and Safety Concerns:

In addition to this, nanoparticles pose health and safety risks. In the lab, they have to be handled with extreme care and this might pose a problem when it comes to scaling up to the industry-level.

Affordability of Self-Cleaning Clothes:

To be a real hit, self-cleaning fabrics need to be affordable. In this early stage of research, it is difficult to estimate the production price of a single pair of jeans that don't need the washing machine. However, this is a crucial factor for the future applications of this technique.

Overall, the new developments in the field of nanotechnology, and such an invention - a potential disruptive technology - is exciting to hear about. Only time will tell if it will enter our everyday life and change the way we do laundry for the better.

OLIMPIA ONELLI

Olimpia Onelli has a Doctor of Philosophy from the University of Cambridge.Olimpia's research focuses on the analysis and understanding of structural colour in the animal kingdom.

PLASTICS: BIO-INSPIRED MATERIALS THAT CAN REPLACE HARD PLASTIC

Marija Jovic

The majority of biodegradable materials on the market today are being based on cellulose, a polysaccharide material derived from plants. These materials find widespread applications in packaging, as containers for food or drinks, for example. However, the major drawback of these materials is their hardness, which is not as high as in conventional plastics. The Wyss Institute has developed a new material, called Shrilk, derived from the shells of crustaceans that can serve as a 'hard' biodegradable alternative to plastic.

The Concept Behind Shrilk

Researchers at the Wyss Institute for Biologically Inspired Engineering at Harvard University have developed a new material based on chitosan that is able to overcome these issues. Chitosan is a tough polysaccharide found in crustaceans' shells, and is responsible for their toughness.

By studying complex interactions in the original biomaterial and then by recreating their unique chemistry and laminar design in the lab, it was possible to create the new material, named "Shrilk". Shrilk is made by forming a laminate of chitosan and silk fibroin protein. This formation mimics the microarchitecture of a natural insect cuticle, thus providing the unique mechanical and chemical interactions giving rise to the unique mechanical and chemical properties.

Properties:

Not only does the material have the strength of an aluminum alloy, but it is also two times lighter. The material is also clear, biocompatible, biodegradable, micromoldable and low-cost, as chitin (precursor of chitosan) is readily available as a shrimp waste product.

Applications:

This material could be used in a variety of applications. As a cheap, environmentally safe alternative to plastic, it could be used to replace plastics in consumer products such as trash bags, packaging, and diapers that degrade quickly. And, as an exceptionally strong, biocompatible material, it could be used to create implantable foams, sutures and heal wounds that bear high loads, or as a scaffold for tissue regeneration.

How the Chitin-Based Bioplastic Was Developed

The original article was published in Advanced Materials by Dr. Javier G. Fernandez, and Dr. Donald Ingber. Three years after the first publication, the research continued by developing a method for large-scale manufacturing using a variation of this material. In the study, published in Macromolecular Materials & Engineering, the team used the shrimp shells but abandoned the silk in order to create an even cheaper, easier-to-make chitin-based bioplastic meant for manufacturing of everyday objects.

The key in doing so was in understanding the molecular geometry of chitosan, and that it is very sensitive to the method used to manufacture it.

The idea and the goal were to fabricate the chitosan in a way that would preserve the integrity of its original molecular structure, thus preserving its strong mechanical properties.

After analyzing how factors such as temperature and concentration affect the mechanical properties of chitosan, the researchers were able to find "just right" conditions that would make it possible for the material to be processed using large scale manufacturing methods, such as traditional casting or injection molding manufacturing techniques. Adding wood flour helped in another issue the researchers were facing – shrinkage – which made chitosan maintain its original shape after the injection molding process.

Using this know-how, it is now possible to manufacture complex three-dimensional (3D) shapes using chitin-based materials that can be made into robust items used in toys and cell phones for example.

In addition to that, the material does not present any threat to the environment, and to plant growth. In order to demonstrate that, the research team grew a California Blackeye pea plant in soil enriched with its chitosan bioplastic over a three-week period. The plastic material even released nitrogen-rich nutrients that efficiently supported plant growth.

The Next Step

The next step is taking the technology out of the laboratory, and into a commercial application with an industry partner. The technology is available for licensing.

MARIJA JOVIC

Marija is one of PreScouter's Project Architects at PreScouter. She specializes in packaging. She finished her Master's degree in Chemical Engineering from Belgrade University and completed her PhD in Organometallic Chemistry and Catalysis at the Swiss Federal Institute of Technology (ETH Zurich). Marija's research was focused on understanding reaction mechanisms in order to rationally design catalysts for polymerization and metathesis reactions. Prior to her PhD, Marija worked in the industry on synthesis of new textile dyes.

FILTRATION:
HOW BIO-INSPIRED MATERIALS ARE LOOKING TO REPLACE CONVENTIONAL WATER PURIFICATION SYSTEMS

Rebecca Alexander

Water accessible for human consumption is estimated to be about 0.007% of fresh water, which itself amounts to barely 3% of water resources on Earth. The UN World Water Development Report of 2016 highlights the problem of water scarcity which is expected to affect about 1.8 billion people by 2025. This scarcity arises due to the predicted depletion of the Earth's fresh water in the coming years and the current inability to 'tap' salt water resources. This poses new challenges for water purification that can only be addressed by development of specialized water purification methods.

The use of bio-inspired materials has become fairly common for medical applications due to obvious reasons. Though not as common, these materials are also promising candidates for efficient water purification.

What Makes Up Natural Membranes?

An amphiphilic molecule, called phospholipid, forms the natural biological membranes. The word 'amphiphile' comes from Greek words amphis (meaning: both) and philia (meaning: love or friendship). A chemical compound is considered amphiphilic when it contains both a water-attracting (hydrophilic) part and a fat-attracting (lipophilic) part.

Common amphiphiles, like proteins and some block copolymers, can have many of both hydrophilic and lipophilic parts. The amphiphilic nature of such molecules influences the structure they assume by means of self-assembly. Examples of some common supramolecular structures are spherical micelles, bilayered vesicles and planar vesicles (Figure 1). Such structures are useful for the development of mesoporous materials, which in turn can be used in water purification.

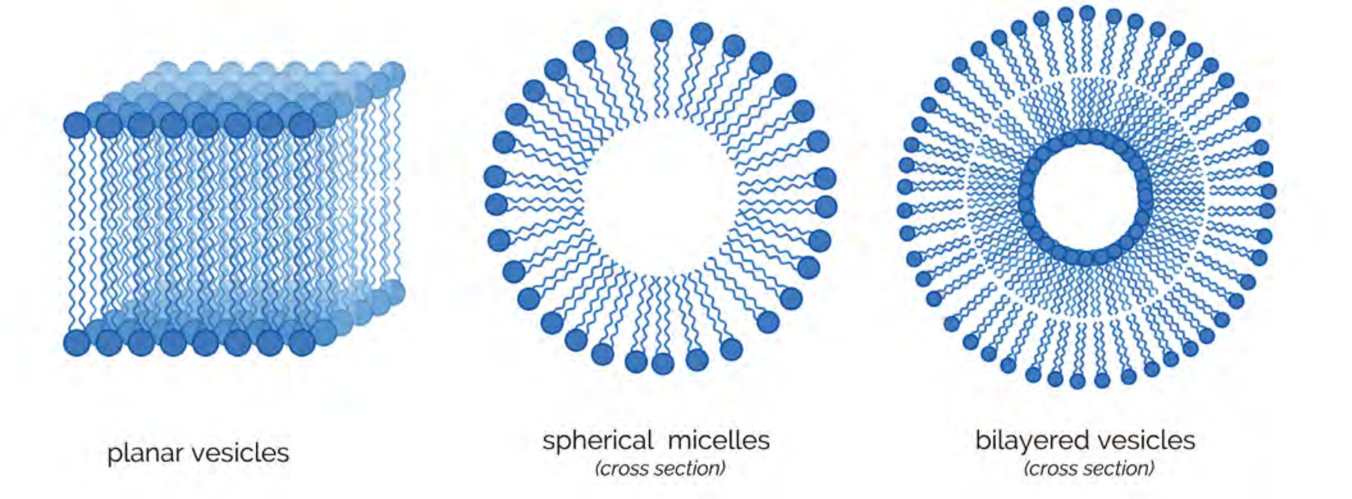


Figure 1. *Supramolecular structures based on amphiphilic molecules such as lipids.*

Biomimetic Membranes

Biomimetic membranes are prepared in a way that mimics biological membranes. Various kinds of membranes have been used for decades in different separation methods. These membranes can be classified based on how homogeneous they are (isotropic and anisotropic) or its pore sizes in case of synthetic polymers (e.g. 1 nm for reverse osmosis, 2 nm for nanofiltration, etc.).

An economical and popular method of water purification is **reverse osmosis**. Filtration by reverse osmosis involves the application of pressure to the contaminated water. This drives water across a semipermeable membrane and removes up to 90-99% of impurities. Current reverse osmosis water purifiers use thin-film composite membranes which are anisotropic biomimetic membranes.

Aquaporin Z, a naturally occurring water channel, improves the water permeability as compared to conventional polyamide composite membranes when incorporated in a triblock copolymer and thus, forms a promising biomimetic material. Another possibility for improved water filtration is the use of aquaporins in conjunction with carbon nanotubes due to their high water flux. The major drawback here is the higher cost of preparing membranes with aquaporins or carbon nanotubes compared to the typical polyamide composite membranes. A recent study shows that the use of new biomimetic membranes with artificial water channels has a smaller characteristic size of 5-25 nm as compared to a commonly-used composite membrane consisting of one layer each of polyamide, a polysulfone and a polyester adding up to about 140-150 µm. This is clearly an advantage over the conventional counterpart for potential manufacture of small, portable filters.

Future Prospects of Biomimetic Membranes

Although many new and promising candidates for efficient water purification exist, their commercialization will require further research in order to tackle all the associated challenges. As mentioned earlier, the cost of aquaporins is a major disadvantage. Additionally, carbon nanotubes might pose safety issues which require further investigation. In spite of the great promise shown by biomimetic membranes, a number of issues have to be resolved before they become acceptable as efficient, cost-effective and environment-friendly solutions to address the issue of water purification and eventually tackle water scarcity.

REBECCA ALEXANDER

Rebecca is currently working as a postdoctoral researcher at the University of Lille-1, France. Prior to this, she completed her Ph.D. at the French Atomic Energy Commision (C.E.A., Saclay), integrated Master's degree in Nuclear Science and technology at the University of Delhi, India in collaboration with the University of Paris-Sud and Bachelor's in Science degree at St. Stephen's College, Delhi. When not studying the properties of irradiation-induced defects in metals, she enjoys reading up on the latest advances in Science.

"I don't know enough about X, and I don't have the time to research and learn it. Quickly get me up-to-speed on what I (specifically for my role and context) need to know, so I can understand my options."

Spend less time on tedious, tactical activities	Spend more time on high-impact, strategic activities
Calling external innovators for information	Collaborating with external innovators
Searching databases	Analyzing landscapes that are state of the art
Studying research journals	Road-Mapping internal programs
Mining large amounts of data	Making decisions

Have top tier advanced researchers work on your project

Our clients value the unbiased insights and innovative thinking that our network of over 2,000 researchers provides.

We take care of everything

Our proven system removes the stress of interviewing, selecting and managing talent to produce high quality results.

"PreScouter made us aware of 23 emerging technologies that we probably would not have become aware of (otherwise)"

Dr Richard Demke

SUNSTAR

PreScouter is trusted by over 400 clients - and counting

Micron · Coca-Cola · Afton Chemical · BD · Clorox · Aftron (True Value. True Quality)

EXPERIENCE IN MULTIPLE INDUSTRIES

Materials · Packaging · High Tech · Financial · Consumer Goods · Natural Resources · Medical · Food and Beverage · Transportation

PreScouter quickly gets Corporate Innovators up-to-speed on what they need to know to make informed decisions.

PreScouter, Inc. 1 N. Franklin St, Suite 1850, Chicago, IL 60606 • info@prescouter.com • (872) 222-9225

PRESCOUTER

PreScouter, Inc. 1 N. Franklin St, Suite 1850, Chicago, IL 60606
info@prescouter.com
(872) 222-9225
www.prescouter.com