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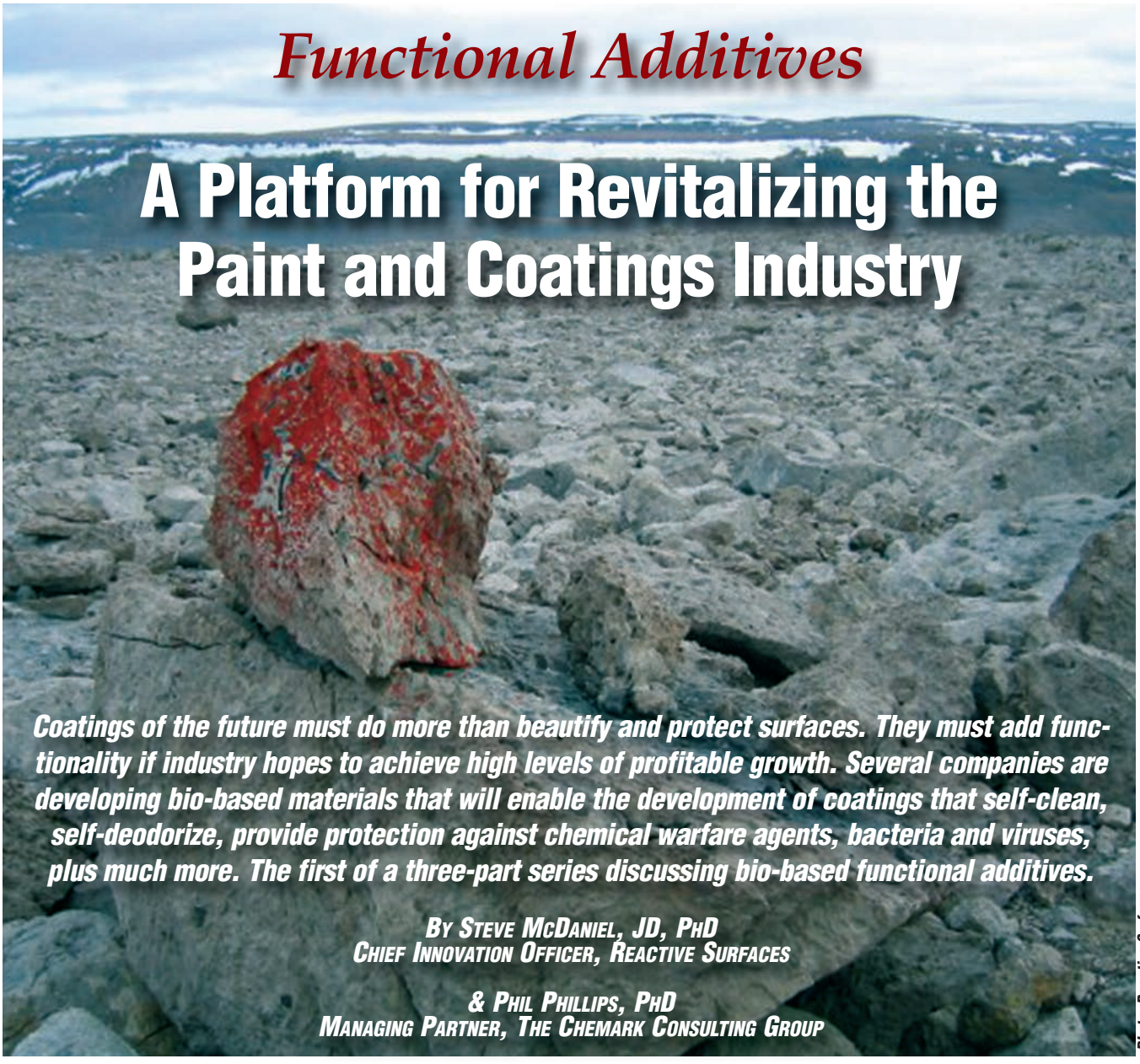
Functional Additives

A Platform for Revitalizing the Paint and Coatings Industry



Coatings of the future must do more than beautify and protect surfaces. They must add functionality if industry hopes to achieve high levels of profitable growth. Several companies are developing bio-based materials that will enable the development of coatings that self-clean, self-deodorize, provide protection against chemical warfare agents, bacteria and viruses, plus much more. The first of a three-part series discussing bio-based functional additives.

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Photo: Reactive Surfaces

Paints and coatings have long been recognized to provide both protection and aesthetic appeal. Over time, however, they have garnered increasingly less value as customer perception of these materials has changed. Instead of being viewed as high value, specialized products, many paints and coatings now fall into the commodity category—common characteristics offered by many supply sources.

Commoditization offers only two sources of differentiation, service and through pricing, rather than performance. The industry needs to take action to stem this negative trend by finding alternative methods for reintroducing value and product differentiation and ultimately raising customer expectations.

Functionalized coatings containing bioengineered additives designed with targeted performance capabilities are one such proactive approach. Use of such naturally-derived, novel additives will create value and opportunity in both existing and new markets without presenting any new concerns such as those raised with nanomaterials, thus expanding the role of paints and coatings beyond traditional applications.

COMMODITY CRISIS

Despite notable technological advances, the paint and coatings industry faces serious challenges if it hopes to retain a measurable level of profitability and growth in the future. In the last 35 years in fact, the value of the U.S. paint and coatings industry has declined significantly: 38% for coatings in general as compared to the Consumer Price Index (CPI) and over 70% for powder coatings (*see Figure 1 on the next page*).

Only very high performance coatings, designed for demanding applications, can be considered as relatively high-margin, specialty products commanding commensurate prices. Most architectural paints, by far the largest segment of the coatings market, are viewed strictly by consumers as commodities. With little expectation of different performance profiles from one product to the other, their buying decisions are most often deter-

mined by price and this is reflected in the narrow pricing differences between top name brands (*see Figure 2 on this page*).

In this segment, where the do-it-yourself (DIY) consumer/contractor is the main customer, paint companies have generally not succeeded in building close relationships with customers upon which higher demand and higher prices can be based. Consequently, these consumers see paint as "paint" and nothing more.

In addition, sharp changes have occurred over the past 50 years, forcing paint and coatings formulators to develop VOC compliant systems. In order to address this demand, most R&D efforts have been focused, at least over the last few decades, on meeting increasingly strict environmental compliance requirements (*see Figure 3 on this page*). This trend will clearly continue even though, in a high percentage of the cases, the performance of compliant VOC systems does not equal the original non-compliant formulations.

While there has been growing demand for paints that contain natural ingredients that do not pose concerns for human health or the environment (low odor, low VOC, zero toxicity components, etc.) this consumer-driven demand is negative rather than positive. Paint companies have reacted to this interest and introduced "greener" products, but have found that buyers are unwilling to pay noticeably higher prices and will reject any that do not provide equal or better performance.

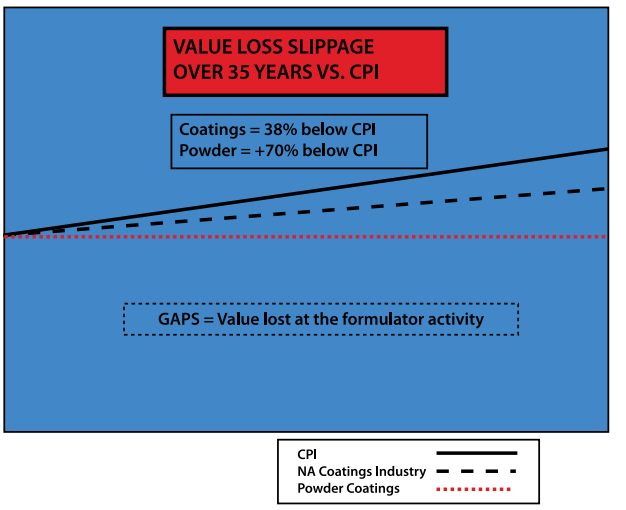
For the OEM and special purpose segments, this reactive approach has been tempered somewhat. Some paint companies have established closer relationships with customers in many of these markets—automotive, aerospace and marine, for example—and worked to develop products and processes that meet the highly specific requirements for individual applications. Even so, in many cases paint and coatings producers are not perceived as being truly involved in the discovery and development phases of new projects.[1] It is not unusual in OEM product design projects for the coating to be an after-thought. Many times, design projects go forward with the assumption that a coating can be simply selected "off-the-shelf," yet history has proven this is not accurate.

Overall, much of the industry has failed to adapt its manufacturing, product development and marketing strategies to meet the needs of modern world economies. This is not the case for other industries with which the same consumers routinely interact. Customers—both consumers and businesses—with access to the Internet and the many new social networking systems have much greater access to information (and opinions). They now seek pre-purchase information to make informed decisions and use these networks to share experiences, results and opinions. Yet 35% of the paint formulator companies continue to utilize antiquated circa 1950s manufacturing, marketing and communication methods, another 45% are estimated to have updated methods slightly, while only 20% have overhauled their manufacturing, marketing and sales techniques completely.

INNOVATION, INNOVATION, INNOVATION

History is clear. Companies and industries that reinvent themselves during economic downturns exit such downturns much more robustly than those that do not. Clearly, the paint and coatings industry needs innovation, but not innovation for its own sake. Massaging techniques to gain minor improvements in product characteristics or manufacturing

Figure 1: Commoditization of the Paint and Coatings Industry



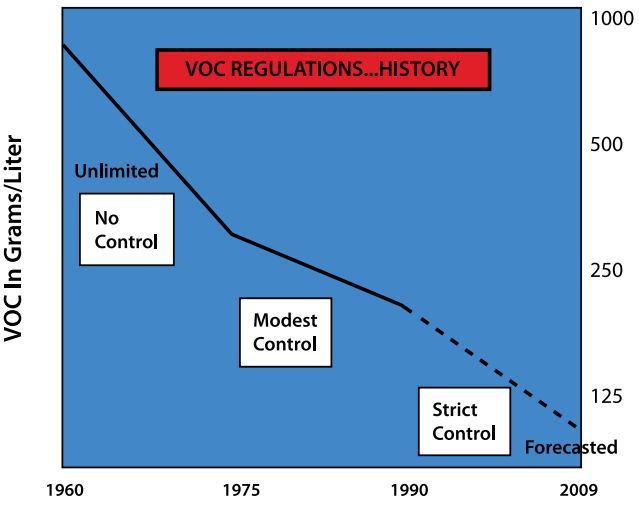
Source: The *CHEMARK* Consulting Group

Figure 2: Architectural Paint Price Comparisons

TYPE PAINT	MARKET	PPG	Sherwin-Williams	Valspar	Others
Interior	Contractor	$14.00/gal.	$13.50/gal.	$13.75/gal.	$13.50-$14.50/gal.
	DIY	$18.00/gal.	$17.00/gal.	$17.50/gal.	$16.50-$18.25/gal.
Exterior	Contractor	$20.00/gal.	$18.50/gal.	$19.00/gal.	$18.00-$20.00/gal.
	DIY	$23.00/gal.	$21.50/gal.	$21.50/gal.	$21.00-$23.50/gal.

Source: The *CHEMARK* Consulting Group

Figure 3: Average VOC Complaint Levels in Last 49 Years



Source: The *CHEMARK* Consulting Group

technologies are not enough. Developing new surfactants, leveling agents, etc. will not meet the challenge either. To change the way customers perceive coatings, the additives will need to provide additional dimensions. These novel coatings must not only provide protection and aesthetics, but perform a needed function that helps solve a problem more efficiently and effectively than previously possible. And it must do so in an environmentally benign manner.

What is needed is a significant innovation shift, or step-change, that will create an entire new role for coatings to play in a whole array of end-use markets. The innovation must be easily adopted and implemented without the necessity for large capital or resource investments.

A successful reinvention of the paint and coatings industry must clearly demonstrate significant value added to the point that consumer demand will quickly turn the industry "push" into a market-driven "pull." Ideally, this market-driven demand will soften the natural reluctance of consumers to recoat surfaces and create the desire to repaint with novel coatings. It is important to keep in mind that the creation of increased profit margins in combination with greater sales volumes are key objectives of paint and coatings formulators. Therefore, charging higher prices for added value and stimulating the consumer to recoat more frequently in order to access increased or novel functionality are the two main pillars of a well-planned strategy for achieving de-commoditization of the industry.[2]

NOVEL BIOENGINEERED FUNCTIONAL ADDITIVES TO THE RESCUE

Where can such specialty additives be found? Surprisingly, the answer is in nature. One example of where to "mine" such additives is from natural biofilms that form on almost all surfaces that can support life (*see image above*). The organisms creating these natural coatings bring a wide array of functionalities to the surface. It is also certainly the case that living organisms have been coating their own exteriors for time immemorial, and the functional molecules they have evolved for this purpose can be tapped for additives in non-living surfaces.

Carefully designed biologically active compounds with tailored functionality in fact meet all of the criteria for a technology paradigm shift. Enzymes, peptides, receptors, antibodies and other biological actives are non-persistent, non-bio-accumulating and almost always non-toxic, resoundingly meeting the definition of a "green" approach. These natural materials can be engineered to be readily incorporated into traditional coating formulations, thus no special equipment is required either for the manufacture or application of paints that contain them. In addition, bioengineered additives do not affect the ability of coatings to protect and beautify surfaces; they simply expand the performance of coatings into a new realm of functionality.

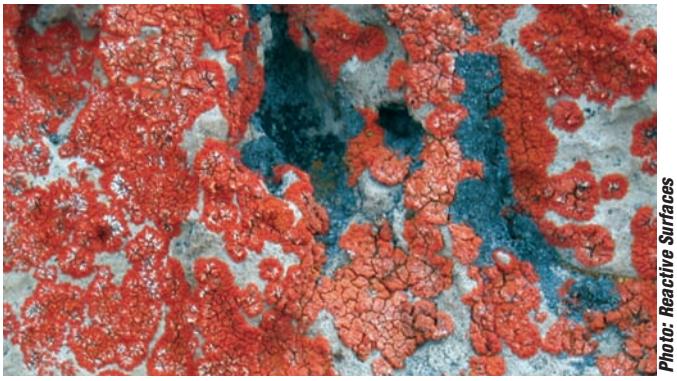


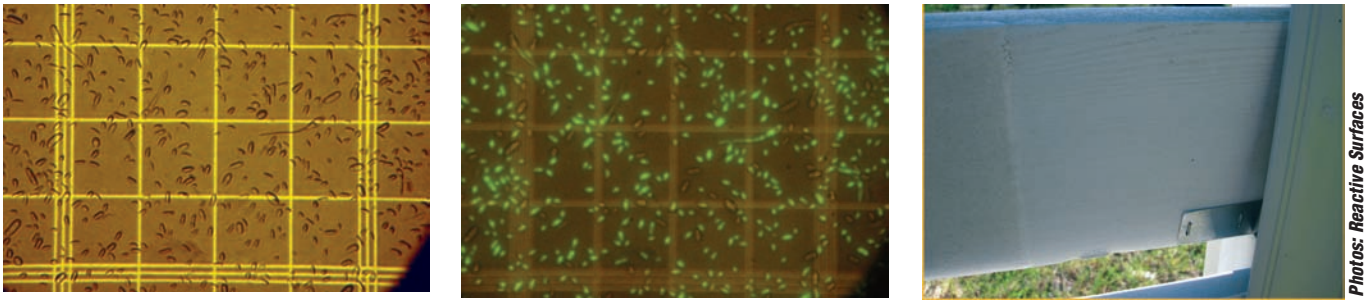
Photo: Reactive Surfaces

Brilliantly-colored red-orange lichen biofilms on Arctic frozen rocks, Devon Island, Nunavut Territory, Canada.

There is a vast number of different types of naturally occurring biomolecules that can be manipulated, providing researchers with an almost limitless potential for creating coatings that possess practically any functionality desirable. As our understanding of the capabilities of this technology grows, the industry will be able to create a whole host of innovative, bioengineered "smart" additives for functional coatings. When the coating innovator decides she wants a new functionality, chances are the bioengineers can "dial in" the natural resource, modify it as necessary and deliver it formulation-ready.

The opportunities really are endless. For instance, biomolecules can be used to create a self-cleaning coating reduce the amount of cleaning chemicals and work effort required to

Photo 1: ProteCoat in action under photomicroscopy and in exterior tests



Photos: Reactive Surfaces

The first two images show photomicroscopy using fluorescent light to view fungal spores and vegetative cells. Untreated cells in a solution containing a dye that fluoresces green—Sytox Green—if the cell membrane is ruptured (left panel), versus cells fluorescing green after being immediately ruptured in presence of small amounts of ProteCoat (middle panel). The rightmost image shows results in exterior tests during an 18-month comparison of fence panels conducted by the University of Southern Mississippi. The right portion of the cedar fence panel painted in Navy Haze Gray containes ProteCoat while the left portion does not.

maintain them while also decreasing wear and extending the life of the paint. Surfaces that stay free of grease and other food-sources are much more hygienic and odor-free. Bio-based additives that catalytically repair polymeric linkages allow for preparation of self-healing coatings that also reduce repair and maintenance costs. Bioengineered additives that are naturally hygienic reduce the need for toxic biocides. Naturally-hygienic coatings also provide for the first time a means for safely reducing the amount of microbial contamination on interior surfaces with minimal risk of increasing antibiotic resistance. Other possibilities include antiviral, anti-allergenic, anti-fouling, deodorizing, desulfurizing, dechlorinating and pH-adjusting coatings, to name a few.

Several different products are already being developed and their utility in various coating applications are being investigated. Reactive Surfaces is commercializing bioengineered additives for use in paint formulations including broad-spectrum antimicrobial peptides, enzymes that benignly break down phosphate-based chemical warfare agents and pesticides, enzymes that catalyze the synthesis or hydrolysis of esters for self-repair and keep surfaces free of grease, and enzymes-peptide combinations that prevent the growth of algae and fungi on architectural surfaces.[3]

Other companies have focused their efforts on one or two specific products with end-uses in a single targeted market. MariCal and BioLocus are developing marine anti-fouling paints, while MiniMed, Inc. is focused on medical device applications and the Swedish Institute for Food and Biotechnology (SIFB) and VTT Technical Research Centre of Finland (VTT) are exploring biomolecules for coatings used in the food packaging industry.[4]

All of these products address a serious unmet need in the markets they are targeting. In the case of antimicrobial and antifouling actives, concern over the negative environmental and safety profiles of many older additives has led to their strict regulation and/or elimination from use in paints and coatings.[5] The regulatory climate has also reduced corporate investment in the development of new products, as testing costs can be prohibitive. Antimicrobial peptides, enzymes and biomodulators, are non-persistent, meet the more stringent regulatory requirements and have been shown to maintain activity over extended periods while presenting no problems with resistance adaptation. Environmentally-benign bio-based additives should significantly reduce the impact of regulatory oversight and allow a wide-range of new actives to be used by formulators.

ProteCoat from Reactive Surfaces is based on antimicrobial peptide (AMP) technology.[6] AMPs are found in many different species of microorganisms, plants and animals and have evolved specifically to protect living things from harmful pathogens, while causing no harm to the host organism. The additive selectively targets these harmful bacteria, mold, yeast and fungi and kills them rapidly by disrupting the cell membrane, avoiding the issue of resistance development, and does so without adverse impact on the host organism whether human, animal or plant. ProteCoat can be easily incorporated into various paint formulations and selectively targets harmful bacteria, mold, yeast and fungi, killing them rapidly by disrupting the cell membrane while chiefly avoiding the issue of resistance development *(see Photo 1 on the previous page)*.

The effectiveness of AMPs has been demonstrated in-process, in-can and in-film and they have been shown to work synergistically with traditional biocides, extending the product lifecycle for such traditional biocides. These naturally occurring amino acid polymers can be readily produced at commercial scale using existing fermentation technology.

With a substantial library of antimicrobial peptides and enzymes, Reactive Surfaces designs functional additives that are tailored to target particular contaminants of interest for any given formulation. As an example, in response to a request from a formulator, Reactive Surfaces investigated the activity of AMPs against common algal contaminants in exterior architectural surfaces and found them to be highly effective *(see Photo 2 below)*.

Marical and BioLocus have taken different approaches to developing bioengineered additives designed to prevent fouling on vessels, oil platforms and other marine surfaces. Many antifoulant additives in use today are based on heavy metals like copper, which presents environmental concerns. Marical has identified calcium sensing receptor (CaSR) proteins that it has incorporated into coatings.[7] These proteins interfere with the ability of marine invertebrates to settle,

Photo 2: ProteCoat's effect on algae contamination

Photos: Reactive Surfaces

Typical algae-contaminated architectural surface (left panel) and a plate of typical algal contaminant (Chlorella vulgaris) showing effect of 3% ProteCoat in acrylic latex coated paper discs (middle panel) versus control lacking ProteCoat (right panel).

attach or metamorphose on marine surfaces.

BioLocus, on the other hand, has identified enzymes that degrade the glue that barnacles use to attach themselves to surfaces.[8] Coatings containing the BioLocus additive are undergoing both static and in-motion tests. There have, in fact, been numerous studies of enzymes for antifouling applications and a review of this work was published in 2007.[9]

A third company, I-Tech, is developing a small molecule anti-fouling agent that, while not a biological macromolecule itself, has a biological mode of action and is thus of interest.[10] Medetomidine (catemine 1) binds to certain protein receptors on the cell surface of the fouling organisms, creating a specific response. In this case, the result is increased motility of the larvae, which prevents them from being able to explore the surface and ultimately prohibits attachment.

Enzymes are also being investigated in coatings designed for food packaging applications. Glucoside oxidase (GOx) has been investigated by both the SIFB and VTT. SIFB has prepared carboxylated styrene acrylate latex coatings with GOx that have been shown to be effective as oxygen scavengers in food packaging.[11] The enzyme can be immobilized on the surface of the film as well as entrapped within the polymer matrix. VTT, meanwhile, immobilized GOx onto plasma-activated biooriented polypropylene films.[12]

Enzymes have also been a target of research at Reactive Surfaces. OPDTox and DeGreez are enzyme-based additives designed for use in paints. Each presents a new functionality for coatings not previously available.

OPDTox contains organophosphorous hydrolases (OPH) that cleave specific bonds in the phosphoryl centers of organophosphorous compounds, which include common insecticides (malathion, parathion and coumaphos) and chemical warfare agents (soman, sarin and VX).[13] The byproducts of the reaction are not toxic, and Reactive Surfaces can tailor the enzymes for specific applications. This method of decontamination is much more attractive than current processes, which typically involve the use of harsh chemicals or foams, high heat or caustic oxides. Preliminary testing of OPDTox-containing CARC-painted (Chemical Agent Resistant Coating) panels against actual nerve agents delivered as neat droplets to painted panel surfaces by a working group of NATO member countries has shown encouraging results.[14]

DeGreez also provides a way for reducing the use of chemicals. When added to paint formulations, the lipase enzyme degreases surfaces exposed to natural greases and oils. Because of the catalytic nature of the enzyme, it will perform continuously over extended periods of time. Not only is the need for cleaning chemicals reduced, but odor and microbe contamination concerns are eliminated.

As with OPDTox, the byproducts of the self-cleaning action are harmless to humans and the environment, and easily removed with only water *(see Photo 3 below).*

BRINGING VALUE TO THE MARKET

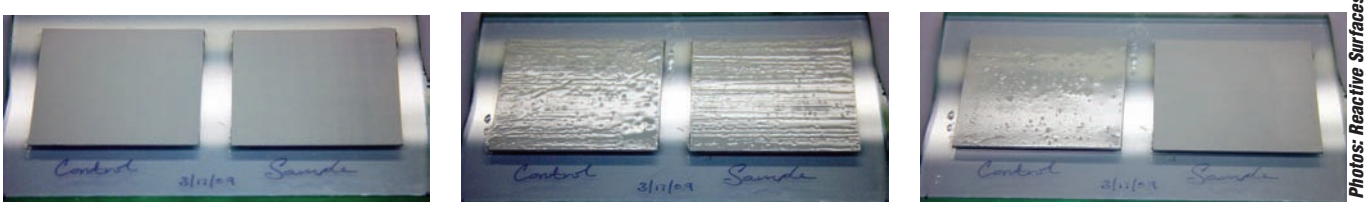
These products are just the tip of the functional additive iceberg. Ongoing R&D efforts at Reactive Surfaces and other companies as well as in a number of academic labs are leading to the introduction of many more bioengineered additives for adding functionality to paints and coatings. Combinations of bio-based additives each delivering differing functionalities, are providing additional novel solutions to real-world coatings problems.

A critical part of these research activities involves preparation of additives that are suitable for incorporation into paints and coatings. Specialized technologies for stabilization and distribution of the bioactive materials into a formulation ensure that the peptides, enzymes or other components perform at the desired level throughout the lifecycle of the coating, including during production, while in storage in the can and of course in the applied film. Reactive Surfaces has established a team of scientists including formulation experts from the University of Southern Mississippi and leading microbiologists and genetic engineers from Texas A&M University and the University of Georgia to focus on these issues.

When developing new products, this group first considers the target application for the functional coating and the specific ways in which a bioengineered additive can add unique value. The conditions under which the additive must perform (temperature, humidity, weather, microbes, chemicals, UV radiation, etc.), the possible application methods for the coating, compatibility with other ingredients, and the means of incorporating the additive all have to be taken in to consideration. The advanced tools of biotechnology make it possible to create additives with specific capabilities and physical characteristics most suitable for the production and application conditions required for a certain end use application. In many cases, both the functionality and other properties of the additive can be adjusted to meet the specific needs of individual customers or market segment.

This easy functional "dial-ability" increases the value add that bioengineered materials can contribute to paints and coatings, as does the vast array of possible biomolecules and

Photo 3: DeGreez 72-hour decontamination



Photos: Reactive Surfaces

The first image at left shows an uncontaminated surface; image two shows a surface heavily contaminated with vegetable oil; the third image shows the effect of DeGreez after 72-hour decontamination.

functionalities that researchers can tap for further study. Bio-based additives specifically designed for incorporation into architectural, special purpose or OEM coatings will have performance characteristics tailored to help solve unique problems faced by many different market sectors that traditional technology has not yet been able to address.

Because bioengineered additives can be designed to perform under a variety of conditions, market opportunities are expanded to non-traditional applications as well. Some possibilities for antimicrobial additives may include consumer electronics, as well as seed, paper and roof coatings. Bio-based marine antifoulants, because they present no danger to the environment, could lead to increased used of antifoulant coatings and displacement of other non-coating technologies. Hospitals, clinics, schools, child care centers, airports and many other public service locations where use of toxic biocides is prohibited would be ideal end users for coatings with natural, safe antimicrobial and antiviral capabilities.

These end-use markets, plus others such as the automotive, furniture and appliance, textile and restaurant industries, would also be ideal targets for self-cleaning and self-deodorizing coatings. Decontamination coatings have endless potential in military applications, from uniforms to sensitive equipment, as well as for the protection of first responders and other emergency personnel. Self-repairing coatings provide numerous possibilities in high performance applications, particularly where a substandard protective coating can lead to serious surface damage and possible structural failure (aerospace, automotive, process industries, etc.). There are also applications for functional coatings in the pharmaceutical (tablet/capsule coatings, disposable production equipment, clean rooms), medical device, and food packaging industries.

CAN THE PAINT & COATINGS INDUSTRY REVITALIZE & REPOSITION ITSELF?

The tremendous opportunities presented by functional bioengineered additives open the door for the paint and coatings industry to reposition itself as a provider of high performance specialty materials. Paints will no longer be seen as inactive surface coverings, but as novel and efficient tools for preventing or solving problems facing consumers and industrial users of coatings. Acceptance of this concept will take some time. But perhaps much less time than might otherwise be anticipated in a consumer environment where rapidly changing product capability is wholly-embraced. Eventually purchasers of paints and coatings will turn to functional formulations as they turn to cell phones, hand-held calculators and laptop computers today for increasingly novel solutions to problems encountered in day-to-day living.

If history is any guide, perhaps we should look at other step changes that decommoditized an industry, and none is better than pre-digital electronics. Mechanical calculators—adding machines—were used throughout the first half of the twentieth century.[15] By 1948 models existed that could do multiplication division and square roots as well as addition and subtraction.[16] The first handheld electronic calculator was introduced by Texas Instruments in 1967, and was shortly followed by truly portable "pocket" calculators in wide use by the late 1970s, when they became affordable.[17]

Magnetic recording and integrated circuits led to the digital revolution and its profound implications on the daily lives of most people. Further advances and their repercussions continue today. Instant global communication via cell phone, e-mail or Skype, immediate access to information on the Internet, conferencing, tremendous computing power in your PDA, Facebook, Twitter and LinkedIn networking systems are all capabilities that could not have been anticipated back in the 1970s. While many initially resisted the use of these new technologies, life without them now is hard to imagine. Historic commercialization timing to market is no longer acceptable to the end-user. Prior to just three to five years ago, innovation and adoption into commercial reality was at a speed acceptable to the suppliers of goods and services. Today, innovation and speed of adoption is at the speed of thought-acceptance of the consumers of the goods and services.

Bioengineered additives will have an impact on the coatings industry similar to the one the development of magnetic recording and integrated circuits had on the electronics industry, and ultimately on society as a whole. Unlike the digital revolution, which took place over several decades, however, the adoption of innovative functional additive technology will rapidly de-commoditize the paint and coatings industry. Formulators only need recognize the value proposition and begin developing novel products that will be highly attractive to their customers. No additional technological discoveries are required before bioengineered additives can begin meeting critical needs in the marketplace and making a difference to the profitability of the paint and coatings industry. And, by virtue of their natural sources, these types of additives are not likely to raise the environmental concerns.

The incorporation of tailored biological compounds with non-persistent, non-accumulating and non-toxic profiles will enable the creation of unique, highly-functionalized surface coatings that will address unresolved issues faced by consumers and businesses. The time to revitalize the coatings industry is now and bioengineered additives provide a way to do so. ***CW***

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Coming next month in Part II

"Formulating with Bioengineered Additives: Increasing the Performance and Functionality of Paints and Coatings"

Abstract: Carefully engineered, high performance bio-based additives with highly specific activities can add unique functionality to paints and coatings and dramatically increase their value. All of these additives are biodegradable, produced via green manufacturing processes, work under mild conditions and do not create harmful by-products. In addition, extensive research and testing has been conducted to ensure that bioengineered materials specifically targeted for use in paints and coatings can be readily incorporated into a variety of formulations and will perform as expected in applied films.