Transformational Thinking: Innovating for the Future

By **George R. Pilcher**
The ChemQuest Group, Inc.

First things first. I would like to remind my readers of the dictum of PPG's late, great director of research, Dr. Marco Wismer, who stated on numerous occasions during the last 30 years of the past century, that the Six Strategic Goals of the coatings industry could be easily and quickly enumerated[1]:

1. Corrosion Protection
2. Elimination of Solvents
3. Conservation of Energy
4. Reduction of Toxic Wastes
5. Cost Reduction
6. Improved Durability

The French critic, journalist, and novelist, Jean-Baptiste Alphonse Karr, is famed for his aphorism, "plus ça change, plus c'est la même chose,"[2] which is generally translated into English as, "the more things change, the more they stay the same." Those words are as true today as they were when Karr wrote them in 1849. There have been many, many changes in the global paint and coatings industry over the past 40 years, including the fact that, "More and more companies from the coatings industry have been shifting production from mature markets to developing countries of late. The majority are turning to Asia-Pacific, which is currently the largest paint market in the world."[3] In spite of many technological, processing, application, and geographical changes that have occurred in the coatings industry over these years, however, *nothing has changed in the coatings industry in the past 40 years* with respect to "Wismer's Six Strategic Goals." The challenges that we face today are the same challenges that we faced 40 years ago, when I first joined the coatings industry, and they will continue to be challenges long after I retire. Even today, "it is clear that the various global coatings marketplaces, both industrial and consumer, are seeking (in some case, *struggling*) to provide positive, proactive, and economically viable realizations for each of these goals."[4]

The only way in which we can deal with them—the only way in which we can make continuous strides toward these six strategic goals—is through a process that I refer to as "transformational thinking."

What, then, is "transformational thinking"? As I define it, transformational thinking is a subtle, but very real, change in the way in which we view familiar objects, people, and—most especially, for the purposes of this article—materials and concepts. It is a way of viewing "what is," and trying to imagine "what it could be," without the need for radically changing either the basic nature of the material or the intrinsic content of the concept. It is a process by which we attempt to innovate not by creating entirely new concepts or materials, because—while completely new concepts and materials are wonderful—they are few and far between and generally come at a high price in terms of both human and monetary resources. Instead, transformational thinking is a way of looking at the familiar, and viewing it "in a different light," or from a "different angle," and asking the questions: "If I were to use this material or concept in a different way or for a different purpose—or if I were to manufacture this material via a different production or synthesis route—what would I have?" "What new properties might it be able to confer, in our case, to a paint or coating?" "How could I use this material in a different way from how it has previously been used, and what properties could be improved upon were I to do so?" "What value could I add to existing products in the marketplace or what value could I add by introducing a new product based upon the use of transformational thinking?" Looked at in this way, transformational thinking is a precursor to innovation, and innovation is the heart and soul of any successful industry.

In 2004, Mark Brockaert emphasized that "innovation is key in driving profitability for customers,"[5] and his words are as true in 2012 and they were in 2004. In my view, however, there are three types or degrees of innovation[6]:

Presented as the Plenary Lecture at PaintIstanbul, September 13-15, 2012 in Istanbul, Turkey.

1. **True Innovation—**
   - Game-changing for the industry/market
   - Almost always involves both basic and applied research
   - Generally originates in academia, government laboratories, and—to a much lesser extent—within the ranks of industry.
   - Infrequent in the coatings industry
   - Historic examples in coatings: waterborne latex consumer paints; powder coatings; cathodic electrodeposition coatings ("e-coat"); radiation-curing coatings
   - Recent example: The service life predictions for coatings undertaken by Dr. Jonathan W. Martin and co-workers at the U.S. National Institute of Standards and Technology (NIST), which have resulted in not only appropriate predictive methodology, but also the construction of a weathering sphere that is able to predict the performance of a coating exposed under any set of weathering conditions.[7-9]
2. **Incremental Innovation—**
   - Generally accomplished at the *applied,* rather than at the basic, R&D level
   - Often accomplished as a result of cooperation between coatings companies and their suppliers, and generally—but not exclusively—performed under confidentiality/nondisclosure agreements. This is the type of innovation to which Brockaert was referring, and which I strongly support
   - Is often fostered and/or initiated through casual conversation at major coatings conferences.

Yes, it costs money to send technical personnel to such meetings, but as Anthony J. O'Lenick Jr., president of Siltech LLC, so notably stated, "As new products and processes are added to a firm's assets, intellectual property is created. Although they do not generally appear on the balance sheet, product management and commercial exploitation of such property has a dramatic effect upon a company's profitability."[10]

3. **Innovative Thinking—**
   - This is a cultural issue within coatings firms, and involves the way in which, and the *degree to which,* a producer encourages its employees to "think outside of the box"—to see products and situations from a different angle or in a "different light," to use coatings industry imagery, that will create value-added opportunities.
   - This approach involves teamwork throughout the organization—technical personnel must work closely with sales, marketing, and production personnel in multidisciplinary teams to create new products, services, and situations that will be received by a grateful marketplace.
   - This approach requires that a coatings employer offer its employees, in all departments, the opportunity to seek educational opportunities outside of the organization—to attend industry events such as the biennial European Coatings Show; ChinaCoat 2012; the American Coatings Association's biennial American Coatings Conference; and this PaintIstanbul 2012 meeting.

Creating a culture of innovative thinking also requires that the interdisciplinary employee teams spend as much time as possible with customers and potential customers, attempting to discover not only what they *think* that they need in terms of new or improved products or services, but also to discover what their *unarticulated* needs are—those things that they do not even realize that they need, but will be grateful for when they are presented with them. Once again, to quote the words of Dr. Marco Wismer, "A product has to be developed before it's needed, because by the time it's needed, it's too late."[11] The coatings producer that creates a culture of innovative thinking will bolster its market position and growth by developing a strong pipeline of new products that are positioned to meet the needs of the evolving market well ahead of its competitors.

Where, then, do we stand today with regard to Wismer's Six Strategic Goals in the year 2012, and how has our progress been affected by transformational thinking, leading to innovating thinking?

1. **Corrosion Protection—**May or may not be *better* today, but the unique performance of traditional hexavalent chromium anti-corrosive pigments is being approached, depending upon end-use requirements, with a variety of more environmentally friendly materials:
   - Phosphates
   - Pyrophosphates
   - Polyphosphates
   - Phospho- and borosilicates
   - Metaborates
   - Mercaptobenzothiazoles
   - Trivalent chromium compounds
   - Molybdenum compounds
   - Magnesium metal
   - Ion exchange compounds
   - Nanoparticles that increase barrier properties—packing so tightly that water cannot permeate the film, leading to better barrier properties
   - Platy nanoparticles—do not pack, but orient in a laminar fashion and increase the path length that water must travel, leading to better barrier properties
   - Superhydrophobic coatings, containing polymer-modified nanosilica, creating

superhydrophobic surfaces that cause water to run off (the so-called "lotus leaf" effect)
- Silanes and organo-functional silanes—form SiO bonds with metallic substrates, increasing adhesion and decreasing corrosion
- Various organic compounds, including zinc salts of aminocarboxylates and cyanuric acid, benzothiazols, and others.
- Inherently conductive polymers (ICPs—polyaniline, polypyrrole, polyphenolene, etc.)
- Conductive, fullerene (carbon) nanotubes (CNTs)
- Addition of magnesium to the zinc pot for galvanized steel
- Many others.

Of these various approaches to corrosion inhibition, while either eliminating hexavalent chromium ion or improving the corrosion resistance of other materials, one stands out as an example of true innovation, driven by transformational thinking—the use of conductive, fullerene carbon nanotubes in two-part (2K) epoxy "zinc-rich" primers, enabling the reduction of the zinc particles by approximately 50%. This, in turn, improves the overall physical properties of heavy-duty industrial maintenance/marine/protective coatings systems, since lowering the zinc level improves adhesion, strengthens the coating film, and decreases permeability, yet allows the zinc particles to remain in electrical contact, providing equal corrosion protection. Since a polyurethane or polyurea/polyaspartic topcoat can be applied directly to the basecoat, resulting in a two-coat system, this enables the elimination of the traditional epoxy intermediate coat, while exhibiting equal corrosion-inhibiting performance. This invention, pioneered by joint work with a private company, Tesla NanoCoatings Ltd., and the U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL), received a prestigious R&D 100 award in 2011.[12] Writing in *Corr**Defense** Online Magazine,* Susan Drozdz added that, "The strong and conductive network of carbon nanotube ropes strengthens and stiffens the film while building an electron path though the binder system."[13] The U.S. Army already has been testing the coating for six years—and is recommending that it be used to replace the coatings now in use by the military on steel structures."[14]

Every bit as interesting, and also driven by transformational thinking, are corrosion-resistant coatings products for protective, heavy-duty maintenance applications, developed by this same team, which also incorporate inherently conductive polymers (ICPs), such as polyaniline. According to Drozdz, "The ICP facilitates the transfer of electrons by creating an electron path through the binder and between the cathodic substrate and anodic zinc dust particles."[15]

2. **Elimination of Solvents—**Globally intense effort has been expended in reducing the amount of organic solvents used in coatings. Although not yet universally eliminated, great strides in VOC reduction have been made in consumer coatings and in many industrial coatings as well. There are some areas where solventborne coatings simply must be used, such as in the majority of heavy-duty protective/industrial maintenance applications, where waterborne coatings have not yet proven to be as effective. Another is coil coatings, where virtually all of the solvent is captured by thermal oxidizing units and burned to create heat, not only for the ovens but for other parts of the factory facility as well, such as offices. In cases such as this, the overall performance and energy equations, while not especially well-defined, are nonetheless very likely to favor the continued use of solventborne coatings, which are likely to generate a lower carbon footprint than using waterborne coatings, which would require considerable additional use of fossil fuels to heat the ovens and the facilities. Moreover, greater energy is required to drive off water than is required to drive off organic solvents in thermosetting coatings systems.

   There are, of course, many other examples of solventborne systems that continue to be used, either because they give superior performance characteristics that cannot yet be achieved by waterborne systems, or because they actually generate lower carbon footprints. One example of this is Ford Motor Company's decision, after very detailed and exhaustive study, to abandon the waterborne coatings route, and return to the use of solventborne coatings exclusively. While their work is proprietary, it was sufficiently detailed to suggest that Ford has arrived at the correct conclusion that using solventborne coatings ultimately results in a lower carbon footprint and the generation of fewer greenhouse gases than waterborne coatings.

3. **Conservation of Energy—**This strategic goal is probably the least well-defined and the most difficult to achieve, insofar as it could involve not only every aspect of the paint-making process (including the carbon footprint generated by the polymers, pigments, and additives used in the composition of the paint), but also the results of applying and curing the paint and even the energy-saving effects of the paint itself once it has been applied. While progress has certainly been made in this area, it is difficult to quantify,

and I cannot help but suspect that there is much more to be done in this area.

Because of various national health and environmental regulations, there are fewer new monomers being developed which might have lower carbon footprints than common, currently used monomers. It has been estimated, for example, that the familiar monomer adipic acid generates N_2O (nitrous oxide) during its synthesis, which is considered to be a "carbon dioxide equivalent" (CO_{2e}), along with methane. Nitrous oxide is considered to have approximately 300 times the amount of CO_{2e} than carbon dioxide, so adipic acid adds very significantly to the carbon footprint of any polymers that contain it. In fact, in my specialty field of coil coatings, approximately 90% of the carbon dioxide equivalents that are generated by polymer production (polyesters and silicone polyesters) come from the monomers; only ~7% are generated by the polymer synthesis process itself, and ~3% are generated by the transportation of the monomers and the finished polymers.

With regard to paint and coatings that have been applied, perhaps the most interesting from a "conservation of energy" point of view are so-called "cool roof coatings," which rely principally on the use of infrared (IR)-reflective pigments that keep buildings cooler on the inside in hot areas of the world, thus reducing the need for air conditioning, and subsequently the need for energy. An interesting and important side effect of the ability to reflect IR radiation is that the coatings themselves do not become as hot as coatings that do not contain infrared-reflective pigments, and the lower temperature of the coatings typically enhances their performance life span with regard to both color retention and overall film durability.

4. **Reduction of Toxic Wastes—**
    - On-going reduction of lead-containing pigments, even in OEM industrial coatings
    - Global reduction in the use of hexavalent chromium for corrosion resistance
    - Significant decrease in the use of cadmium pigments
    - Elimination of perfluoronated surfactants
    - Ongoing elimination of alkyl phenol ethoxylate surfactants in latex synthesis
    - Re-use, rather than disposal—e.g., recycled supersacks; wash solvent reclamation and re-use; scrap material used as fuel; using heat from incineration to heat ovens and buildings
    - Recycling of reclaimed consumer paint into new products
    - Many other approaches

There is no question that great strides have been made in the area of reduction of toxic waste, but there is still a long way to go. Many companies, both paint producers and paint consumers, in many parts of the world still fail to practice routine forms of toxic waste reduction.

5. **Cost Reduction—**Anyone reading this article who has worked in the coatings industry for at least five years already knows the answer to this one."Cost down" programs have affected not just the automotive industry over the past decade—they have affected virtually all industrial OEM segments, and have even cut into the profits of the architectural (consumer) coatings segment, although not with the same intensity. Fortunately, soaring raw material prices over the years 2009–2011, and—to some extent—in 2012 as well, have enabled most coatings companies to "pass along" all or part of the increased raw material costs and, in many cases, pass them along with an additional increase in the cost of the coatings to help improve the bottom line of the coatings manufacturers.

6. **Improved Durability—**Dramatic improvements are available in consumer and industrial products:
    - UV-absorbers and HALS (hindered amine light stabilizers)-containing automotive basecoats/clearcoats have dramatically improved the long-term appearance of automobiles
    - Very significantly improved polyester technology, both aromatic-based and aliphatic-based, has enabled extended life expectancies and enhanced appearance for metal building products, such as aluminum and steel siding and roofing for both residential and commercial applications
    - Polyurethane dispersions (PUDs) and acrylic/polyurethane "hybrids" have enabled superior performance in waterborne technology for a variety of substrates, from wood flooring to leather goods
    - Significant improvements have been made in radiation-curing technology, although there is still considerable room for more advances, including improved UV-cured powder coating technology
    - Increased use of colored complex inorganic pigments (CCIPs, "calcined colored pigments," "ceramic pigments," and other common names) have dramatically improved the lightfastness of highly-warranted building panel systems and

plastics and other applications where color stability and overall durability are expected for 20+ years.
- The use of inherently conductive polymers and fullerene carbon nanotubes to improve the durability of heavy-duty protective coatings, as well as to reduce the amount of toxic waste associated with those coatings.
- Many others.

THE PROCESS AND GOALS OF TRANSFORMATIONAL THINKING

We are living through a transformational period of history—a period that will alter not just individual behavior, but which will affect society at large, and industry as a whole. Emerging from global recession, much looks the same—but don't be fooled. . .

- For the past several years, governments around the globe have been in the process of spending untold amounts of money on infrastructure improvements, alternative energy generation, programs that will reward the development of advanced manufacturing strategies, etc.
- The past two decades have largely been years of creative stagnation for chemical-based manufacturing industries, and certainly for the coatings industry. Yes, we've seen our share of new products and processes, but—take a second look—and it becomes clear that what we have mostly been practicing is "incremental improvement," not transformational product design.

The global recession of late 2007 through mid-2009 was the worst economic disaster in decades, and—although the United States and several other countries are in "recovery mode"—there is still danger, particularly in Europe, of a so-called "double-dip" recession. In fact, the United Kingdom, Greece, Italy, Portugal, and Spain are currently considered to have entered a recessionary period, and France is in stagnation, and may not be far behind. This is not good news, of course, and will place increasing stress on the coatings industry, as well as many others. Whether a coatings business is in a country that is in recovery mode from the 2007–2009 recession or is entering into a new recession, there are certain questions that need to be asked:

- If your company is operating in a post-recessionary economy or if it is operating in an economy which is currently in—or about to slip into—recession, is it hanging on by its fingernails, hoping to get back to "business as usual," once the overall economic situation improves?
- Is your company breathing a sigh of relief that it made it through the recent recession in reasonable style, and is now faced with the problem of how to produce enough product fast enough to "fill the pipeline" and address all of those decimated customer inventories?
- Is your company pawing the ground so that it can get "back to business" faster than competitors because—during the recession—it made some incremental improvements to its products, which it now feels are "better" than its competitors?
- Or are you calmly working with both your marketing colleagues and your customers, polishing and releasing your new literature telling the world about the new products that you developed during the recession, and successfully trialed on your customers' lines while their business was slow, and they had the time to work with you to optimize your new products on their equipment?

The truth is that—given the choice between incremental improvement focused on value-maintenance, and strategic creation of value-added platform technologies and new products—there truly is no choice, although incremental improvement is preferable to doing nothing at all.

Transformational thinking is not about making a new and improved mousetrap to replace the last mousetrap that did not live up to its advertised performance. It is harnessing our creative energies to look at both processes and products in a different way, to see potential opportunities that we have missed in the past—so that we can see beyond "what is" to "what might be," and how "what might be" can add value to our products and processes, and to our customers' products and processes, as well. No better examples of transformational *processes* can be offered than the ways in which Dell, Toyota, and Wal-Mart all rose to the top of their respective industries by creating stunningly efficient ways of getting products into consumers' hands more inexpensively than their rivals.

As an example of transformational thinking applied to a *product,* Frito-Lay (a PepsiCo subsidiary) created a new scoop-shaped corn chip.

- *Practical effect:* More salsa in the consumer's mouth, and less on his Persian rug
- *Bottom line:* Frito-Lay saw significant improvement in its sales and profits—and both the function and the efficacy of the lowly corn chip were forever transformed.

These companies—Dell (computers), Toyota (automobiles), Wal-Mart (discount department stores), and PepsiCo/Frito-Lay (consumer snack foods) have nothing in common except the ability to use transformational thinking to enable them to be innovative with regard to their products and processes

TRANSFORMATIONAL THINKING IN THE PAINT AND COATINGS INDUSTRY

Ten years ago, less than 5% of residential homes in the U.S. had a metal roof, even though they typically last for 30–40 years compared to an asphalt shingle roof which typically lasts 12–15 years, and constitutes hazardous waste when it is removed.

Why was this? Because metal roofing (principally painted galvanized steel, Galfan® or Galvalume®—the latter two are types of zinc/aluminum coated steel) was expensive, it had an "industrial" look, and it brought nothing exciting to the game—it basically kept the rain out. Today, the number of residential homes with metal roofing has nearly doubled. Why? Because the industry has *transformed* the way in which the homeowner views these roofs:

- Design changes have turned their look from "industrial" to "designer"
- New "cool roofing coatings" have made them more energy efficient[16-18]
- The California wildfires over the past 8–10 years have demonstrated that a metal roof can make the difference between a house unharmed and a house destroyed
- Metal roofing basically lasts "forever"
- Steel is infinitely recyclable

As a result, metal roofing will continue to grow and flourish, in spite of its initial cost, because it has been transformed from a product that had nominal aesthetic and functional appeal to being both a product and a concept that have highly aesthetic and very clear—and very "green" (environmentally friendly)—functional appeal.

Another example of transformational thinking—this time of European origin—involves the metal packaging industry. Twist-off caps have had plastisol (PVC) gaskets for as long as anyone can remember—but an increasingly tough series of European Union regulations regarding the amounts and types of "migrating molecules" that can be used in the lids of certain types of foods may force the PVCs (which contain up to 40% plasticizers) out.

There may be many companies that make these PVC gaskets that are each working on replacement products, but at least one—Actega DS, an operating company of Altana—has approached the problem in an extremely strategic manner:

- They worked with a polymer supplier to identify a material with the necessary physical and performance properties, safety, and application characteristics.
- They formulated this polymer into a finished gasket compound that met the end-use requirements
- They worked with an equipment supplier to design application equipment to apply the new compliant gasket compound to twist-off closures.

This is a first-rate example of transformational thinking—not just a better mousetrap—but any entirely new, highly-innovative, user-friendly "turnkey" system.

My final example of transformational thinking is one with which paint and coating technologists can identify more closely—the development of the basecoat/clearcoat concept in the automotive industry. For decades, even the finest monocoats had distinctly limited durability characteristics, and made a car look old, even when it was still in good running condition. The highly innovative concept of placing a clearcoat over a colored basecoat protected the finish and reduced fading and loss of gloss to such an extent that now even a very old car can still look brand new:

- The clearcoat provides aesthetic properties and is intrinsically resistant to environmental degradation—UV-resistant resin composition + UV absorbers + HALS
- And—it shields the colored basecoat, primer, and E/D coating from being damaged by UV radiation, followed by subsequent hydrolysis-induced chain scission and decomposition
- Thus—the colored basecoat, at the very least, can be formulated with less expensive materials.

TRANFORMING THE 'INTERESTING' INTO THE 'ESSENTIAL'

Even prior to the onset of the global recession, paint and coatings companies, in an effort to maximize their bottom lines, were cutting their R&D and marketing staffs to the bare bone, and the recession only compounded this problem. R&D spending has declined year-on-year to the point that as a percentage of industry sales, R&D spending today is no more than 60–70% of what it was 10–15 years ago, and what has been funded is largely tactical in nature—incremental improvement focused on value-maintenance and raw material substitution, rather than the strategic creation of value-added platform technologies and truly new products. This is equally true with regard to the suppliers to the paint and coatings industry. In 2009, the eminent R&D manager for the Decorative and Industrial Resins business in EMEA for Nuplex Resins BV, Dr. Dirk Mestach, had this to say:

> *During the last decade, most resin manufacturing companies have focused their R&D resources to make sure that they could offer binders that allowed their customers to formulate coatings that were meeting the requirements of the European 2010 VOC directive. Even though real innovation continued both in academia and industry, for example the development of controlled free radical polymerization techniques or the use of nano-technology in polymer synthesis, the time and financial constraints put onto the European resin manufacturing industry has been an obstacle to actually implement these innovations in commercially available binders.*[19]

Unfortunately, there never seems to be a good time for coatings producers to team up their R&D and marketing people with their raw material producers and direct them toward the future. Either business is good, and all hands must be on deck to take care of current business, or things are slow, reductions in force are enacted, and all available R&D and marketing resources are deployed toward producing results for the current quarter. Slow times, however, are the perfect time to engage the best marketing and R&D people in strategic planning, and to act to assure a more secure and profitable tomorrow.[20]

In 2012, therefore, we have an industry which simply does not have sufficient R&D and marketing personnel to bring about transformational change in its paint and coatings products to meet the needs of the changes that are taking place in its customer base. True marketing people are the antennae of an organization—they are equipped by both training and temperament to:

- Look farther down the road than the rest of us
- Seek new segments for the company's products and platform technologies
- Sense product changes that will need to come about to keep satisfying current customers and regulatory requirements
- Identify areas in which new products will need to be developed for sustainable growth
- Uncover and give voice to unarticulated customer needs
- Determine future, longer-term trends.

While the ideal is for "everyone to work together as a team" in every company, this rarely happens. The two groups that absolutely *must* work together, however, are R&D and marketing—this is the combination that really creates the opportunity for strategic, transformational product development to happen. Add to this technical/marketing partnership an independent unbiased third party—a consultant knowledgeable in coatings and also markets and technology in adjacent industries—and magical things can begin to happen, because the team has a greater potential to see and develop programs to:

- Extend existing products into new market areas not previously known or explored
- Extend existing technology to new products
- Identify technology from other market areas that can be applied within your own markets
- Identify market areas for future technology development
- The list goes on.

None of this can happen, however, as long as the R&D and marketing people are confined to the box in which almost all companies and corporate cultures tend to place them. The coatings industry needs to "get out of the box." It is a box in which we imprison ourselves, and it contains the resins, additives, pigments, solvents, and all the rest of the tools and materials with which we are familiar. Especially with regard to the R&D community, it attempts to develop new products and/or concepts, by automatically reaching for the materials and tools on the shelves in its box—a box which is kept deliberately limited because of the perceived need to keep both the number and the amounts of raw materials to an absolutely minimum to control costs. While both practical and admirable, there is a balance between familiar raw materials and new raw materials that must be achieved for truly transformational product formulation to take place.

A classic example of being "in a box," is to think of alkyd resins as materials that "... were first described by Kienle 80 years ago... it can be stated with relative certainty that more has been known and forgotten about alkyds than is currently known about other polymeric binders. This is because most of the research was performed by industrial scientists and not in academic laboratories."[21] In fact, when I first entered the paint and coatings industry in 1970, the perceived wisdom was that alkyd technology was old and would soon vanish from the industry entirely. In 2012, however, we are seeing "a significant change of this trend...[and that] alkyds in many applications with special demands perform superior to other systems...[and they also benefit from the fact that they] are partly based on a readily available renewable feedstock—fatty acids and glycerol from vegetable oils or other natural sources. This has an impact not only on environmental issues but also on the cost performance of these systems."[22] In his recent paper, "Alkyd Resins: From Down and Out to Alive and Kicking,"[23] DSM's Ad Hofland has described a very broad array of both commercial and pre-commercial concepts, all of which are based on "old" alkyd technology, and all of which are likely to play a significant role in the coatings of the future, whether they are alkyd emulsions, high-solids alkyds, hybrid alkyd-acrylic and alkyd-urethanes, fatty acid modified polyurethane dispersions (FAPUDs), and even so-called "tribrids"—alkyd, acrylic, urethanes. Purely from an environmental view, many of the alkyd components are not only bio-renewable, but do not even compete with food crops for their components—tall-oil fatty acid, a by-product of the pulp and paper industry was cited by Hofland as a good example.[24] Another example is castor oil, which is used so effectively by companies like Alberdingk Boley GmbH in their waterborne polymers. We are even seeing examples of new materials based on sustainable bio-based oils being used as reactive diluents in hydroxyl-bearing coatings. For example, in traditional oil-free, saturated polyester resins, such as those used in coil coatings, work has been reported using rape seed methyl ester (RME) that has been successfully used as a reactive diluent to replace part of the petrochemical-based organic solvent in polyester coil coatings.[25]

Be honest—if you are in industrial coatings, how often do you read the house paint literature? How often do you talk to sales representatives from the leading suppliers of waterborne latex resins for house paints? How often do you read the literature from *outside* the coatings area? When was the last time you had a conversation with an adhesives chemist? Do you even know any adhesives chemists? It is an unfortunate, but very true, fact of life that adhesives formulators rarely read the paint & coatings literature, and paint & coatings formulators rarely read the adhesives literature. This is a shame, because coatings and adhesives have a lot in common—what, after all, is a coating but an adhesive that must "stick like glue," to a single surface, but that could, under many sets of conditions, bond two surfaces together?[26]

Several years ago, a coating with really quite remarkable properties was introduced into one segment of the coatings market, and—try though they might—the inventing company's competitors could not replicate the performance of the product. The secret? The inventing company was thinking outside of the box, had read the adhesive literature, and incorporated a polymer normally used exclusively in adhesives into its coating. The result was a unique product which could not be matched, no matter how hard the competition tried, because they were not able to think out of the box—and because they were clearly not familiar with the adhesives literature.[27] This is a classic example of transformational thinking.

There is, for instance, a very interesting class of structural acrylic adhesives in which polymerization is initiated in a mixture of acrylates by a blocked organoborane catalyst such as triethylborane/3-diamino-propane. Such materials exhibit amazing adhesion to low energy surfaces. The trick? Organoborane catalysts are activated by abstracting oxygen from the low-energy surface. Has this approach ever been tried in coatings for low-energy surfaces? If so, what were the results? If not, why not?

Have coatings researchers in non-packaging fields ever taken a look at vapor deposition coatings which are used so effectively to impart barrier properties to both rigid and flexible packaging? They are basically made out of silica and alumina, and—while they sound pretty removed from the realm of traditional coatings—what if they could impart a truly damage-resistant surface by applying a thin, invisible layer of glassy-hard, yet flexible silica?

Increasingly, paints and coatings are being called upon to be multi-functional:

- Aesthetic appeal coupled with anti-bacterial properties
- Durability coupled with anti-corrosive properties
- Corrosion-resistance coupled with aesthetic properties
- Chemical resistance coupled with ductility
- Ductility coupled with hardness and damage resistance
- Durability coupled with self-cleaning properties
- Aesthetic appeal coupled with anti-mold characteristics
- Corrosion-resistance coupled with thermal properties
- Many, many others.

The combinations are endless. . . .but they all spell "value," they do not come about by accident, and they all involve creating a world of new opportunities and possibilities by using transformational thinking—by transforming the "interesting" into the "essential."

TRANSFORMATIONAL THINKING: 'GREEN AND SUSTAINABLE'

Paints and Coatings

There are many ongoing technological approaches to making coatings more environmentally compliant:

- Powder
- High solids
- Radiation-curable—ultraviolet (UV), electron beam (EB), visible light
- Waterborne—lower VOC or no VOC
- 100% solids
- etc.

At the end of the day, however, all of these technologies still have petrochemical antecedents.

What about truly renewable materials? Twenty years ago, we had symposia *ad nauseam* on the subject, but I'm not sure that the times were really right for people to get serious about the subject. Things are different now, however, and the concept of materials derived from renewable resources ". . . is not only familiar territory (the coatings industry has used oils and fatty acids from bio-sources for decades to make alkyd polymers and other materials), but there are vast resources dedicated to turning wishes and hopes into commercial reality."[28]

What about coatings based on materials that are based on "green polymers" or coatings that use green, sustainable, bio-renewable solvents? "Green" is the topic of the day—it is everywhere, and this is unlikely to change in the years ahead.[29]

While neither I, The ChemQuest Group, Inc., nor the publishers of *CoatingsTech* are recommending or endorsing the following products, they nonetheless embody a necessarily limited number of interesting materials that are representative of this group of sustainable coatings components, and are cited strictly for informational purposes and to stimulate the reader's interest in these types of materials:

Table 1—Building Blocks for New Monomers

Building Blocks
1,4 succinic, fumaric and malic acids
2,5 furan dicarboxylic acid
3 hydroxy propionic acid
aspartic acid
glucaric acid
glutamic acid
itaconic acid
levulinic acid
3-hydroxybutyrolactone
glycerol
sorbitol
xylitol/arabinitol

- Palmer International's Cashewthane™ reactive diluents and resins, derived from cashew nutshell liquid, a non-food source[30]
- BASF/Cognis Sovermol®—linear and branched hydrophobic branched polyether/polyester polyols made from renewable resources[31]
- EcoSynthetix EcoSphere® dry biopolymer nanoparticle agglomerate powders made from annual crops—claimed as alternatives to petroleum-based latexes[32]
- Alberdingk Boley's polyurethane dispersions based on castor oil and linseed oil[33]
- VertecBio EL™, ethyl lactate solvent derived from corn—non-HAPS, non-VOC, and, in certain systems, can affect rheological properties in very interesting and useful ways; supplied in a variety of blends to replace common paint, coating, and ink solvents such as methyl ethyl ketone (MEK), xylene, ethylene glycol monobutyl ether (2-butoxyethanol, "Butyl Cellosolve™," etc.), isophorone, tetrahydrofuran (THF), cyclohexanone, and many other solvents[34]
- Dow Corning's ECOSURF™ SA7 and SA9 low-foam, anionic surfactants derived from seed oils[35]
- Lignol Innovations Ltd. (subsidiary of Lignol Energy Corporation)—sulfur-free lignin in dry powder form; can serve as raw material for production of surfactants and other wetting agents, as a result of it hydrophilic and hydrophobic groups; many other lignin-based derivatives with potential for use in coatings.[36]
- Many, many others.

In fact, bio-renewable materials, while currently only used at approximately a 5% level in the paint and coatings industry, are without question going to play a major role in the future of not only this industry, but many industries. How many paint and coatings chemists are aware that the University of California-Davis did major work on the use of whey from milk[37] for a variety of potential uses, including: oxygen barrier coatings for foods; oxygen-barrier coatings for plastics—may make plastic bottles recyclable; grease-barrier coatings for paper and paperboard.

The research team was using transformational thinking to look at a substance that has been used in cheese-making and painting prior to recorded history,

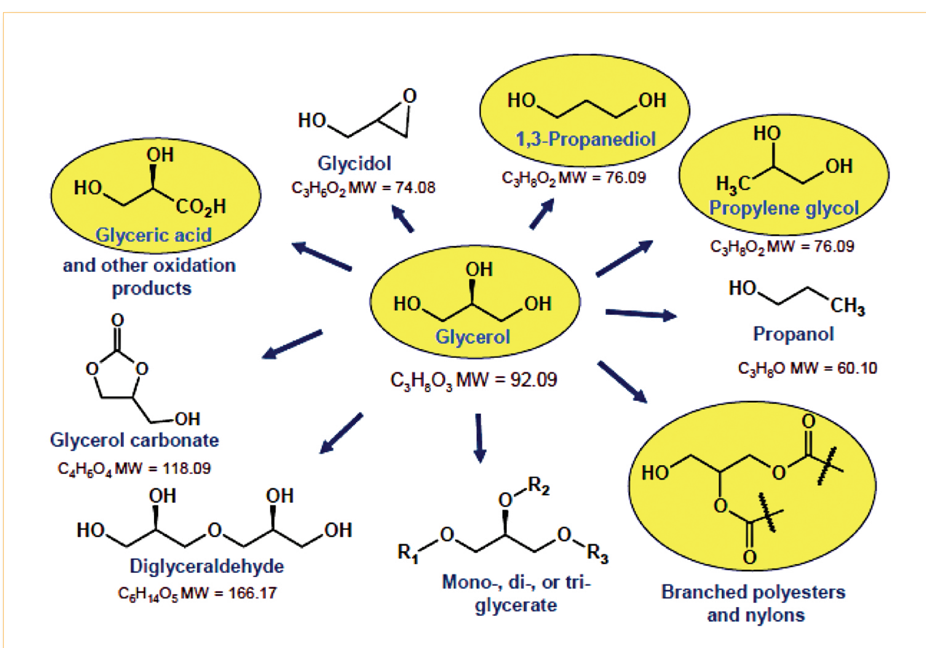

Figure 1—Major chemicals that can be derived from glycerol.

yet we have only begun to tap its full potential. (Based on work performed by the University of Vermont, there is even an American paint company, Vermont Natural Coatings, which has introduced whey-based PolyWhey® floor and furniture finishes—using the clever slogan, "There's a Better Whey."[38])

We are just beginning to tap the potential for generating vitally important starting materials that will yield not only bio-based versions of important starting materials that we currently obtain from fossil fuels, but which will also yield new monomers upon which to build new, value-added, higher-performance polymers for use in paints and coatings. Some of the most studied monomers, all of which can be produced from sugar cane,[39] can be seen in *Table* 1.

Taking just a two examples from the list in *Table* 1, glycerol and 3-hydroxypropionic acid, it can be seen how many important chemical streams can be obtained from each. Glycerol[40] ("glycerine," "propane-1,2,3-triol," etc.) can serve as a starting material for a broad variety of organic molecules, including branched polymers and nylons, and especially as a starting material for the synthesis of propylene glycol, which is currently produced from propylene, which is obtained from fossil fuels (*Figure* 1):

If we turn to 3-hydroxypropionic acid,[41] we see that a number of monomers that are vitally important not only to paints and coatings, but to a number of other fields as well, can be derived from this bio-based material, including acrylic acid, methyl acrylate, acrylamide, 1,3-propanediol, and acrylonitrile (*Figure* 2).

While it will certainly take several years to make some of these monomers on a sufficient scale so that they can be economically feasible, the day will come. In the meantime, the paint and coatings industry should be investing in long-term development programs to determine what types of unique, value-added properties can be derived from some of the new monomers that are being generated by the biomass research community.

A FEW FINAL THOUGHTS ON 'WHAT'S NEW' IN THE PAINT AND COATINGS INDUSTRY

According to the recently published *U.S. Paint and Coatings Industry Market Analysis,* "The majority of basic research is done at universities or government-supported laboratories, rather than companies participating in the paint and coatings industry today. (In fact, a Science Coalition Report[42] stated that in 2008, 55% of all basic research was done in universities versus less than 20% in companies.) However, while most of the announcements are from these institutions, when one digs further it becomes apparent that, in many cases, paint/coatings companies and raw material suppliers are partners in research programs, providing financial support and expertise to the programs. This is particularly true in Europe, but also occurs, to a slightly lesser degree, in both North America and Asia Pacific, and constitutes a very valuable activity. University research provides a good option for companies as they face the challenges of the economic climate and focus on applied research projects with more immediate sales potential. Industry participation provides practical input to research programs as researchers without industry experience struggle to evaluate the viability of technological breakthroughs."[43]

As a result, the report continues: "Technological developments have been made in nearly all component categories of paint and coatings during the last several years despite the economic climate. Some of these developments are in the areas of:

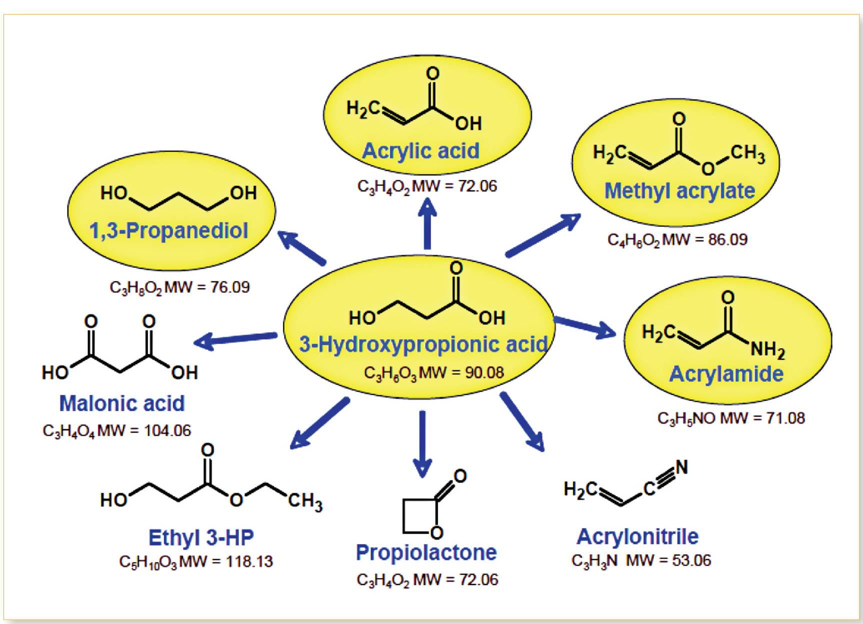

Figure 2—Major chemicals that can be derived from 3-hydroxypropionic acid.

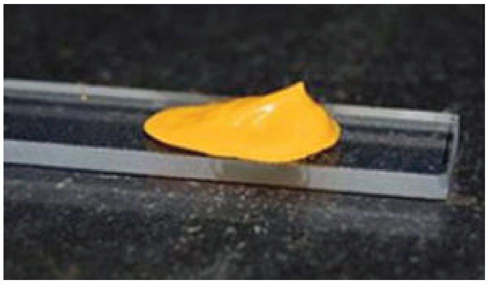

Figure 3—Paste of cadmium sulfide/selenide-coated TiO_2 quantum dots.

- Nanotechnology/nanoparticles/nanofibers
- Biogenerated monomers and polymers
- Resins
- Additives and crosslinkers
- Pigments
- Inorganic anti-microbial additives

It is notable that most new material product announcements are related to new particles, polymers, processes, or coatings rather than new molecules or monomers. Tightened regulations and difficulty in registering new monomers have dampened new monomer commercialization in the mature industrial regions such as North America."[44] Nonetheless, there is work, in various stages, being done by research institutes, raw material suppliers, and paint producers to design coatings that:

- Are more insulative
- Improve energy efficiency through less "drag" for aircraft, marine vessels, and automobiles
- Enable paint films to generate electricity via solar conversion
- Exhibit "self-healing" properties via several different chemical and physical mechanisms
- Utilize sol-gel chemistry to create coatings based on ceramers, which have the potential to alter not only coatings properties, but also pretreatments for metal, to improve their resistance to corrosion
- Provide anti-microbial properties to coatings applied on various substrates
- Are "self-cleaning"
- The list goes on and on.

We are living in very exciting times, but this interesting work can only be extended from the realm of the "interesting" to the realm of the "essential" if technical and marketing personnel at the paint companies are aware of the research being done and are willing to engage in a transformational thinking process that can convert the potential of this work into a marketplace reality.

Unfortunately, virtually no technical personnel in the coatings industry have the time or the resources to work with every new raw material that comes to market, and—as has been alluded to earlier—the industry has been enduring a period of time during which relatively few new raw materials have been brought to market. This seems to be changing, however, driven partly by regulatory issues on the horizon as well as by the gradually increasing growth in the global coatings industry as it emerges, albeit very slowly and tentatively, from recession. The economic recovery is certainly very fragile, and—as has also been previously mentioned—certain parts of Europe are either in—or heading into—recession once again. Nonetheless, many raw material suppliers have begun to spend less time and fewer precious R&D dollars looking for substitute materials and/or additional sources for their starting-point materials, and are beginning to look toward new materials to meet future needs.

Unfortunately, many paint and adhesive formulators, are still spending the majority of their time and monetary resources looking at alternative raw materials, at additional sources of those materials, and at reducing formulation costs, trying to recover margins depleted by the soaring raw material costs of the past four years.

It is in the spirit of engaging the attention of such formulators that I would like to mention a necessarily limited, random sampling of materials that I have read or heard about that, with only one exception, have come to market within the past 6–18 months. Although I have no personal knowledge of their value, I have listed these materials in an Appendix to this paper simply so that they will receive greater exposure and perhaps stimulate the creative impulses in paint and coatings formulators who are reading this paper. Neither the publishers of *CoatingsTech*, The ChemQuest Group, Inc., nor I are recommending or endorsing any of these products—this listing is offered strictly in the spirit of being helpful to the reader. All information in the Appendix has been obtained from supplier literature and/or conversations with a supplier representative. (*See Appendix*.)

Finally, I would like to discuss an example of truly transformational thinking, insofar as it involves the humble paint component, titanium dioxide, and two materials that were common pigments in paints and coatings until the relatively recent past: cadmium sulfide and cadmium selenide. These pigments have been in use for decades around the world, but—looked at "from a different angle" or "in a different light"—hold the long-term promise of the possibility that someday the paint on our roofs may be able to generate the electricity for use in our homes and businesses (*Figure* 3).

A team of researchers at the University of Notre Dame, in South Bend, IN, has made a major advance toward this vision by creating an inexpensive "solar paint" that uses semiconducting nanoparticles to produce energy.

"We want to do something transformative, to move beyond current silicon-based solar technology," says Prashant Kamat, John A. Zahm Professor of Science in Chemistry and Biochemistry and an investigator in Notre Dame's Center for Nano Science and Technology (NDnano), who leads the research. By incorporating power-producing nanoparticles, called quantum dots, into a spreadable compound, we've made a one-coat solar paint that can be applied to any conductive surface without special equipment."

The team's search for the new material, described in the journal *ACS Nano*, centered on nano-sized particles of titanium dioxide, which were coated with either cadmium sulfide or cadmium selenide. The particles were then suspended in a water-alcohol mixture to create a paste. (*Note:* Similar work in this area is also being conducted at the University of Toronto, Ontario, Canada, incorporating quantum dots of solar cells.)

When the paste was brushed onto a transparent conducting material and exposed to light, it created electricity.[45]

Whether the subject is "green" coatings made from sustainable, bio-renewable raw materials, or the potential to make paints and coatings from substances like whey protein, or lowering VOCs via the use of non-VOC coalescents or new latex resins that do not require coalescing aids, the global coatings industry will only be able to take advantage of new approaches by being open to the concept of transformation thinking, which automatically leads to innovation.

At this very moment, the metal container coatings industry is dealing with the so-called "BPA" (bisphenol A) and "BADGE" (bisphenol A diglycidyl ether) issues, which are not going to go away—and it will be quite interesting to see if/how epoxy acrylates and epoxy phenolics can be replaced in these critically important applications, because doing so will require truly transformational thinking—there is no other way.

Applying transformation thinking to coatings products and processes is the key to the industry's future, and has the power to change how we think about coatings forever.

Appendix

- King Industries: Solvent-based, tin-free 2K polyurethanes, XK-635 and XK-639; Waterborne Blocked Isocyanate XK-635; 100% active polyester polyols XM-360 and XM-366.[46]
- Grace Material Technologies: SYLOWHITE® titanium dioxide extender. *Note:* This particular example does not represent new technology, but it is my understanding that it has not been broadly available, and is likely, therefore, to be unfamiliar to many of the readers of this article.[47]
- Essential Industries: 40 g/l hydroxyl-functional urethane/acrylic hybrid, R4400.[48]
- Patcham (FZC): Zero-VOC, anionic, APE-free polymeric wetting agent for use in dispersion paints and colorants, Pat-Add DA 202; polymeric, mineral oil-, polysiloxane- and fluorocarbon-free defoamer based on green chemistry for both solventborne and waterborne paints, Pat-Add AF 5210; No-VOC coalescing agent for waterborne dispersion systems, claimed to be similar in performance to 2,2,4-trimethyl-1,3-pentanediol mono(2-methylpropanoate), Pat-Add COAT 77.[49]
- HALOX: Low odor, water-soluble organic-based, tannic-, phosphoric- and gallic acid-free paint additive which converts red rust to black iron oxide, Halox® RC-980.[50]
- The Dow Chemical Company: Waterborne series epoxy hardeners with very low odor, increased water-vapor permeability, rapid drying and curing and processing ability at lower temperatures, Dow D.E.H.™ Series 800 polyamine adducts.[51]
- Solvay Rhodia: Biodegradable vegetable oil defoamer for low/zero VOC for flat-to-semi-gloss waterborne coatings, Rhodoline® 621; APE-free, zero VOC additive that promotes extended open time, Rhodoline® OTE-500.[52]
- Cytec Industries Inc.: Ultra-low (<0.1%) free formaldehyde, high-solids (98%, minimum) melamine crosslinker for ambient and low temperature cure coating applications, for solventborne and cationic waterborne coatings, CYMEL® XW 3106 Resin.[53]
- Alberdingk Boley GmbH: Water-based UV-curable, hard elastic PU-dispersion with short flash-off time, high scratch- and chemical-resistance, high gloss, good pigment and extender wetting, LUX 255; Self-crosslinking, multiphase emulsion with superior water barrier, excellent adhesion properties and superior corrosion resistance, very low MFFT, and good blocking resistance, AC 2403; and Lignin-reactive hydrosol for wood protection, that significantly increases the weathering resistance in comparison to conventional primers, Lignocure 2010.[54]
- Emerald Performance Materials (Emerald Kalama Chemical LLC): Low VOC, superior wet edge (flat), increased scrub resistance proprietary blend of three dibenzoates, K-Flex® 975P Coalescent for Coatings.[55]
- Dow Corning Corporation: New acrylic slip aids for waterborne systems, 401LS, 402LS, and 205SL.[56]
- Troy Technology Corporation, Inc.: VOC-free, formaldehyde-free, broad-spectrum wet-state preservative, Mergal® 758.[57]
- Arkema: Associative neutralizing and co-dispersing agent for ultra-low or zero VOC aqueous coatings, also said to contribute anti-corrosion performance and reduce the amount of anti-flash rusting agents required, Reverlink® NoVOC.[58]
- Croda International Plc: New bio-based dimer diamine functional building block designed for use in epoxy systems, Curing Agent Priamine™ 1071.[59]
- BYK Additives and Instruments (Altana): New Inorganic additive based on surface modified silica nanoparticles (20 nm) for solvent, solvent-free and radiation curable coatings for wood, furniture and industrial coatings to improve scratch and abrasion resistance, NANOBYK® 3605; new water dispersion of multi-wall carbon nanotubes to impart conductivity and antistatic behavior to waterborne coatings, CARBOBYK® 9810.[60]
- Cardolite Corporation: A novel class of epoxy curing agents called phenalkamides has been developed to fill a gap between polyamide and phenalkamine chemistries that are said to offer the benefits of both while mitigating their limitations; coatings formulations based on phenalkamides are said to have the desired color stability, overcoat window, and flexibility of polyamides, but with the outstanding corrosion protection and fast low temperature cure of phenalkamines, Lite 3000 series.[61]
- Falcon Technologies: A polysaccharide-based sustainable colloid technology that is able to replace HEC at 100% with similar viscosity at a lower average particle size distribution, enabling improved mechanical properties, LPC100.[62]

References

1. Wismer, M., *Amer. Paint Coat. J.,* 68, No. 49, p.12, 1984.
2. Karr, A., Les Guêpes, January, 1849.
3. Abraztova, N., "Identifying and Exploiting Europe's Potential," *Eur. Coat. J.,* H1571, 07/08, p. 9 (2012).
4. Pilcher, G.R., "Meeting the Challenge of Radical Change: Coatings R&D as We Enter the 21st Century," *J. Coat. Technol.,* 73, No. 921, p. 135 (2001).
5. Brockaert, M., "Innovation is Key," *Eur. Coat. J.,* 03/04, p. 21 (2004).
6. Pilcher, G.R., "Challenge 2005 and Beyond: Recognition, Transformation and Profitable Use of Innovative Thinking," *JCT Research,* 2, No. 5, pp. 343-348 (2005).
7. Bauer, D.R. and Martin, J.W. (Eds.), *Service Life Prediction of Organic Coatings: A Systems Approach,* American Chemical Society Symposium Series 722, Oxford Press, 1999.
8. Martin, J.W. and Bauer, D.R. (Eds.), *Service Life Prediction Methodology and Metrologies,* Oxford Press, New York, 2001.
9. Martin, J.W., Ryntz, R.A., Chin, J., and Dickie, R. (Eds.), *Service Life Prediction of Polymeric Materials: Global Perspectives,* Springer, 2008.
10. O'Lenick, A.J. Jr., "Managing Intellectual Property or Getting More than a Penny for Your Thoughts," *The Chemist,* March-April, p. 17 (2001).
11. Wismer, M., "Learning to Leap: Rising to the Technical Challenge of Today's Coatings Industry," *J. Coat. Technol.,* 62, No. 780, 86 (1990).
12. www.rdmag.com/Awards/Rd-100-Awards/2011/08/Nano-tubes-Join-Zinc-To-Fight-Corrosion/R&D Magazine E-Newsletter, 15 August, 2011.

13. Drozdz, S., "Nanotechnology Helps Army Usher in Coatings Evolution," *CorrDefense Online Magazine,* 6, No. 2, p.2 (2010). http://corrdefense.nace.org/corrdefense_summer_2010/PDF/project_news1.pdf
14. www.crainscleveland.com/article/20120305/NORTECH12/120309954 Nortech Innovation Awards 2012. "Tesla NanoCoatings LTD.: Teslan® Carbon Nanocoating," Crain's Cleveland Business, 5 March, 2012.
15. Drozdz, S., "Supporting the Troops: Complex Strategy Worked for Repainting Ft. Lewis Water Tank," *J. Protective Coatings and Linings,* 27, No. 8, p. 26 (2010).
16. Cocuzzi, D.A. and Pilcher, G.R., "Cool Roofing," Part I, *Polymers Paint Colour Journal (PPCJ),* 194, No. 4482, pp. 42-46 (2004).
17. Cocuzzi, D.A. and Pilcher, G.R., "Cool Roofing," Part II, *PPCJ,* 194, No. 4483, pp. 28-36 (2004).
18. Cocuzzi, D.A. and Pilcher, G.R., "Cool Roofing: A Really Hot Topic," *CoatingsTech,* 1, No.4, pp.22-29 (2004).
19. Mestach, D.E.P., "Resin Technology Challenges Beyond 2010," Proc. European Coatings Congress, 2009.
20. Pilcher, G.R., "Where Will You Be When the Recession Ends?," *Adhesives & Sealants Industry (ASI),* 16, No. 5, p. 12 (2009).
21. Soucek, M. and Johansson, K.G., (Eds.), *Prog. Org. Coat.,* 73, No. 4, Guest Editorial, (2012).
22. *Ibid*.
23. Hofland, A., "Alkyd Resins: From Down and Out to Alive and Kicking," *ibid*., pp.274-282.
24. *Ibid*., p 279.
25. Ohlssan, K., Bergman, T., Sundell, P-E., Deltin, T., Tran, I., Svensson, M., and Johansson, M., *ibid*., pp. 291-293.
26. Pilcher, G.R., "Adhesives and Coatings—More Similar than Different," to be published in *Adhesives & Sealants Industry (ASI),* in September 2012.
27. *Ibid*.
28. Pilcher, G.R. "Sustainability and 'Greening' Issues: Meaning and Trends," in Chapter 7 of the *U.S. Paint & Coatings Industry Market Analysis (2010-2015),* p. 11, The American Coatings Association, Inc. (2012).
29. Pilcher, G.R., "Chemical Management Services: Industry Report 2009, Trust for Conservation Innovation/Chemical Strategies Partnership (2009).
30. www.palmerint.com.
31. www.specialchem4coatings.com/tds/sovermol-1005/cognis-part-of-basf/24500/index.aspx.
32. www.ecosynthetix.com.
33. www.alberdingkusa.com.
34. www.vertecbiosolvents.com/tour-home.htm.
35. http://msdssearch.dow.com/PublishedLiteratureDOWCOM/dh_088e/0901b8038088e257.pdf?filepath=surfactants/pdfs/noreg/119-02221.pdf&fromPage=GetDoc and www.dow.com/products/market/oil-and-gas/product-line/ecosurf/product/ecosurf-sa-9/
36. www.lignol.ca/
37. Hutchinson, F.M., Balagtas, J.V., Krochta, J.M., and Sumner, D. A., "Potential Gains to Producers from New Uses for Whey," *AIC Issues Brief,* No. 20, February 2003, University of California.
38. www.vermontnaturalcoatings.com/
39. www1.eere.energy.gov/biomass/pdfs/35523.pdf
40. *Ibid.*
41. *Ibid.*
42. www.sciencecoalition.org/sucessstories/
43. Anderson, S.M. "New Technology Developments and Market Opportunities," in Chapter 6 of the *U.S. Paint & Coatings Industry Market Analysis (2010-2015),* p. 1, The American Coatings Association, Inc. (2012).
44. Anderson, S.M., *ibid*., p. 2.
45. www.sciencedaily.com/releases/2011/12/111221211324.htm
46. www.kingindustries.com
47. www.grace.com/engineeredmaterials/productsandapplications/coatings/TiO2Extenders.aspx
48. www.essentialrmd.com
49. www.patchamltd.com
50. Multiple suppliers in all major global regions. Website in Turkey: www.kemiropa.com.tr/index.php; In the U.S., www.halox.com
51. www.dowepoxy.com
52. www.rhodia.com
53. www.cytec.com/
54. www.alberdingk-boley.de
55. www.emeraldmaterials.com/cms/epm/home.html
56. www.dowcorning.com
57. www.troycorp.com
58. arkema.com
59. www.crodacoatingsandpolymers.com
60. www.byk.com
61. www.cardolite.com
62. www.faltech.net

AUTHOR

George R. Pilcher, vice president, The ChemQuest Group, Inc., 8150 Corporate Dr., Ste. 250, Cincinnati, OH; gpilcher@chemquest.com.