

# Green Chemistry

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**F**or the entire chemical industry, operating sustainable businesses that provide value-added products and services with minimal or no environmental impact continues to be a top priority. The adoption of a "green" approach to the manufacture and marketing of chemical products, including paints and coatings, clearly assists companies in attaining this goal. Green chemistry also offers chemical producers a mechanism for connecting chemicals and chemistry to the consumer in a positive way. Of course, green chemistry initiatives must be commercially viable and provide products or services that have enhanced performance qualities and/or cost savings in addition to reducing the environmental footprint of the business.

"Green chemistry is a more eco-friendly green alternative to conventional chemistry practices," says Dr. Louis M. Scarmoutzos, founder and managing partner, MVS Solutions Incorporated. "The green chemistry movement is part of a larger movement ultimately leading to a green economy—namely sustainable development, sustainable business, and sustainable living practices," he explains. Paul Anastas, director of the American Chemical Society Green Chemistry Institute, adds that "Green chemistry is pollution prevention at the molecular level; it is chemistry that is benign by design."

The commitment of the industry to the green chemistry approach was recently apparent when it gave strong support to the green chemistry legislation approved by the U.S. House of Representatives in mid-April of 2004. The bill, which passed with almost unanimous support (402-14) has now moved to the Senate Commerce Committee for review. The new legislation focuses on support of R&D and education and authorizes \$84 million for its activities, which does not include any other additional funding that might be raised from other sources. A green chemistry R&D program within the Environmental Protection Agency (EPA), National Science Foundation

(NSF), National Institute of Standards and Technology (NIST), and the Department of Defense (DOE) would direct these federal agencies to fund R&D for green chemistry initiatives. The bill also promotes green chemistry education and the collection and dissemination of information about green chemistry.

Through its Green Chemistry Program, the EPA has already begun efforts to assist industry with the development and implementation of green chemistry initiatives. The mission of the program is "to promote innovative chemical technologies that reduce or eliminate the use or generation of hazardous substances in the design, manufacture, and use of chemical products." This initiative at the EPA originated with the Pollution Prevention Act of 1990, which established a national policy to prevent or reduce pollution at its source whenever feasible and encourages the use of creative strategies for pollution prevention.

The Green Chemistry Program supports fundamental research in the areas of environmentally benign chemistry as well as a variety of educational activities, international activities, conferences and meetings, and development tools through voluntary partnerships with academia, industry, and other governmental and nongovernmental agencies and organizations. Its Green Chemistry Expert System allows users to build a green chemical process, design green chemicals, or survey the field of green chemistry. A large emphasis is placed on training and education. Short courses for chemical professionals are offered in conjunction with the ACS and its Green Chemistry Institute. The Presidential Green Chemistry Challenge awards recognize industry for successful green chemistry initiatives.

"Our primary message is that green chemistry really does work," says Richard Engler, Ph.D., director of EPA's Green Chemistry Program. "Green chemistry not only helps the environment but also contributes to the bottom line. Environmental and economic considerations are not in conflict. Frequently a solution can be found that benefits both," he continues. According to Dr. Engler, green chemistry utilizes the creativity of chemistry to deliver sustainability.

Other groups around the world are fostering green chemistry initiatives in all segments of the chemical industry. The Green Chemistry Network (GCN) in the U.K. was launched by the Royal Society of Chemistry and is based within the Department of Chemistry at the University of York. The main aim of the GCN is to promote awareness and facilitate education, training, and practice of Green Chemistry in industry, academia, and schools. The GCN aims to help chemical companies and chemists by sharing best practices, promoting green technology transfer, and providing data to show that adoption of green practices can also provide cost benefits for industry.

The Centre for Green Chemistry (CGC) is a Special Research Centre funded by the Australian Research Council and located at Monash University. The mission of the CGC is to become a world leader for research, industrial collaboration, and teaching in the field of green chemistry and to harness this expertise to enhance the international competitiveness of Australian industry. In Japan, the Green & Sustainable Chemistry Network (GSCN) promotes R&D on green and sustainable chemistry through promotion of collaboration, information exchange, communication, education, and relevant proposals to funding agencies, both domestically and internationally.

Getting chemists to look "outside the box" for non-traditional raw materials and processes is one of the major challenges to implementing green chemistry initiatives, according to Dr. Engler. That is why so much effort is focused on education and training of both students and those who are already established professionals. Graduate programs need to place as much emphasis on the development of green chemistry processes (how the products are made) as they do on obtaining the desired target molecule, adds Dr. Scarmoutzos.

"Overcoming an inherent reluctance to change, and particularly to changing existing and established processes and products is another major hurdle," says Dr. Scarmoutzos. In addition, the long timeframes necessary for many green chemistry initiatives to provide a significant return on expenditures or investments are at odds with the relatively short horizon and time span of many senior executives and company shareholders.

## Twelve Principles of Green Chemistry

- 1 Prevent waste
- 2 Design safer chemicals and products
- 3 Design less hazardous chemical syntheses
- 4 Use renewable feedstocks
- 5 Use catalysts, not stoichiometric reagents
- 6 Avoid chemical derivatives
- 7 Maximize atom economy
- 8 Use safer solvents and reaction conditions
- 9 Increase energy efficiency
- 10 Design chemicals and products to degrade after use
- 11 Analyze in real time to prevent pollution
- 12 Minimize the potential for accidents

## Selected Green Chemistry Resources

- EPA Green Chemistry Program .....[www.epa.gov/greenchemistry](http://www.epa.gov/greenchemistry)
- ACS Green Chemistry Institute .....<http://chemistry.org/greenchemistryinstitute>
- Green Chemistry Network (UK) .....[www.chemsoc.org/networks/gcn](http://www.chemsoc.org/networks/gcn)
- Centre for Green Chemistry (Australia) .....<http://web.chem.monash.edu.au/greenchem>
- Green & Sustainable Chemistry Network (Japan) .....[www.gscn.net](http://www.gscn.net)
- Green Chemistry (Journal) .....[www.rsc.org/is/journals/current/green/greenpub.htm](http://www.rsc.org/is/journals/current/green/greenpub.htm)

To be successful, it is important to implement green chemistry thinking and practices up front and early on in the development of new chemical-based products and chemistry-based technologies. "Top to bottom commitment and participation from all aspects of the business enterprise and its activities is also imperative," notes Dr. Scarmoutzos. He recommends that companies keep their first green chemistry programs simple and target obvious changes where the results can be readily observed. Tracking progress, publicizing results, and rewarding employees will also fuel the success of green chemistry initiatives.

Progress can be measured from several viewpoints including economic savings, reduction of specific environmental impacts, and less tangible social aspects of business operations including enhanced company spirit, quality of work life, employee absenteeism or illness, goodwill (customers, vendors, stakeholders) and others, according to Dr. Scarmoutzos. "Notwithstanding the obvious benefits of green chemistry to the environment and to human health, there is growing motivation for businesses and manufacturers to adapt green chemistry processes and to develop or use green products," he says. "Consumer sentiment is increasingly favoring eco-friendly and green alternatives over conventional products and processes. Whenever price and quality are comparable, the environmentally responsible product will have the advantage."

The companies and initiatives that have won EPA's Presidential Green Chemistry Challenge awards clearly underscore how commercially successful green chemistry can be. The paint and coatings industry has received several of these awards and numerous other commendations. PPG Industries received the Presidential Green Chemistry Award in 2001 for developing yttrium as a lead substitute in cationic electrodeposition coatings. Bayer Chemicals received the award in 2000 for waterborne two-component urethanes. Also in 2000, RevTech, Inc. received a Presidential Green Chemistry Award for Envirogluv<sup>®</sup>, a glass decorating technology.

Some other companies from the paint and coatings industry that have submitted products or processes to

the Presidential Green Chemistry Challenge program include BASF (all-acrylic binders for low VOC coatings), Goodyear Tire & Rubber Company (technology for water-based paints and coatings), C.H. Thompson Co. (nonchromate coatings using potassium permanganate), Innovative Formulation (ecological paint that is nontoxic and zero VOC) and Pantheon Chemical (chromate-free conversion coatings PreKote).

In June of 2004, Engelhard received the Presidential Green Chemistry Challenge award for its Rightfit<sup>™</sup> pigments, which are azo pigments that contain calcium, strontium, or sometimes barium instead of the traditional pigments based on heavy metals used to serve the red, orange, and yellow color market. The Rightfit pigments are manufactured in aqueous medium and most have been approved both by the U.S. Food and Drug Administration (FDA) and the Canadian Health Protection Branch (HPB) for indirect food contact applications.

Importantly, Rightfit pigments have good dispersibility, improved dimensional stability, improved heat stability, improved color strength, and cover a wide color range from purple to green-shade yellow. "The Rightfit pigments meet the essential performance characteristics at significantly lower cost than high-performance organic pigments. They provide environmentally friendly, value-added color to packaging used in the food, beverage, petroleum product, detergent, and other household and durable goods markets," says Roland Valin, manager of sales and technical marketing for Engelhard. "Thus, formulators get the right performance properties at the right cost," he adds. In developing its pigments, Engelhard focuses on value and environmental friendliness, because value is a stronger driver than cost for its customers, according to Mr. Valin.

Engelhard's new Synergy<sup>™</sup> line of pigments combines aqueous-based organic pigments and non-heavy metal based inorganic components to provide superior performance with a significantly reduced environmental impact.

RevTech's Envirogluv process directly silk screens radiation-curable inks onto glass, then cures the ink al-

most instantly by exposure to UV light. The result is a crisp, clean label that is environmentally sound and at a unit cost that is approximately half that achieved with traditional labeling techniques. As with Engelhard's pigments, no heavy metals are used. The pigments are biodegradable and the 100% solids formulations contain almost no volatile organic compounds (VOCs). No waste is generated in the Envirogluv process, and high temperature baking is not required.

Applications include tableware, cosmetics containers, beverage containers, and plate glass.

The project was initiated in response to a value analysis effort geared toward reducing the packaging cost for certain cosmetic containers, according to Andrew J. Schlossman, president of RevTech. "Not only does Envirogluv provide coatings that meet ASTM requirements, it permits the use of brilliant reds and yellows for decoration without violating the heavy metal restrictions, eliminates emissions associated with traditional processes, substantially simplifies the labeling process, and significantly reduces overall cost," he notes. The biggest challenge for RevTech was adjusting the Envirogluv process so that customers could use existing application machinery. "We have also designed new machinery to take advantage of the enhanced speed possibilities presented by the utilization of UV curing," says Mr. Schlossman. Currently the company is working to improve the process to enable entry into new markets.

Reduction of VOCs has been a major focus of the paint and coatings industry as regulations have become increasingly stringent. The green chemistry initiatives of many companies have centered on developing products and processes that reduce or eliminate the use of VOCs and the emissions associated with them. "The market for low VOC latexes is growing at an exponential pace, and is significantly larger than it was five years ago," says William Sparks, business manager for BASF's functional polymers business that serves the North American architectural coatings market. Research activities at BASF Functional Polymers have resulted in the introduction of its new acrylic dispersions for low VOC latex paints.

The most significant commercial product to date, Acronal Optive 130, enables low and even zero-VOC architectural coatings with performance exceeding that of premium paints made at much higher, traditional VOC levels. Acronal Optive 330, the latest offering from BASF, is capable of formulating gloss paints at 50 g/l VOC and offers high mar and blush resistance for

clear formulations. "An all-acrylic latex, Acronal Optive 330, was the first high-gloss resin for the North American paint industry to match the high-performance characteristics previously seen only from higher VOC resins," notes Mr. Sparks.

The biggest challenge in developing these emulsion polymers was to invest in a new technology capable of achieving the performance of higher VOC latex paint at significantly lower, even zero VOC levels. Additionally, the aqueous paint formulations may require a different choice of additives—dispersants, surfactants, thickeners, defoamers, biocides, and mildewcides—in order to retain a low VOC level, according to Mr. Sparks. The costs of latex paint formulations can actually be reduced as compared to higher VOC containing products. However, currently higher energy and raw materials costs are driving costs for all emulsion polymers to higher levels.

As paint manufacturers have begun to switch to waterborne systems, Air Products has focused on developing low foam wetting agents and emulsion polymers with positive environmental profiles. EnviroCem<sup>®</sup> AE Surfactants are the latest surfactant products to be introduced to the market. This family of surfactant products is classified as "readily" biodegradable and has acceptable aquatic toxicity profiles, according to Lee Miller, North American coatings marketing manager at Air Products. These products are also solvent-free and therefore do not contribute to final formulation VOC content. In addition, the EnviroCem AE Surfactant series provides customers with three multifunctional high performance additives with performance benefits including improved coating flow and leveling, outstanding foam control, and excellent dynamic wetting.

Airflex<sup>®</sup> EF811 emulsion polymers are water-based dispersions of a vinyl-acetate ethylene (VAE) copolymer which allow coatings manufacturers to formulate architectural coatings with very little, if any co-solvent. Airflex EF811 emulsion polymer is the newest product, designed for high performance, low VOC, architectural coating applications, and possesses high scrub and excellent touch up properties, according to Justine Smith, coatings



Photo courtesy of RevTech.



Photo courtesy of Air Products and Chemicals, Inc.

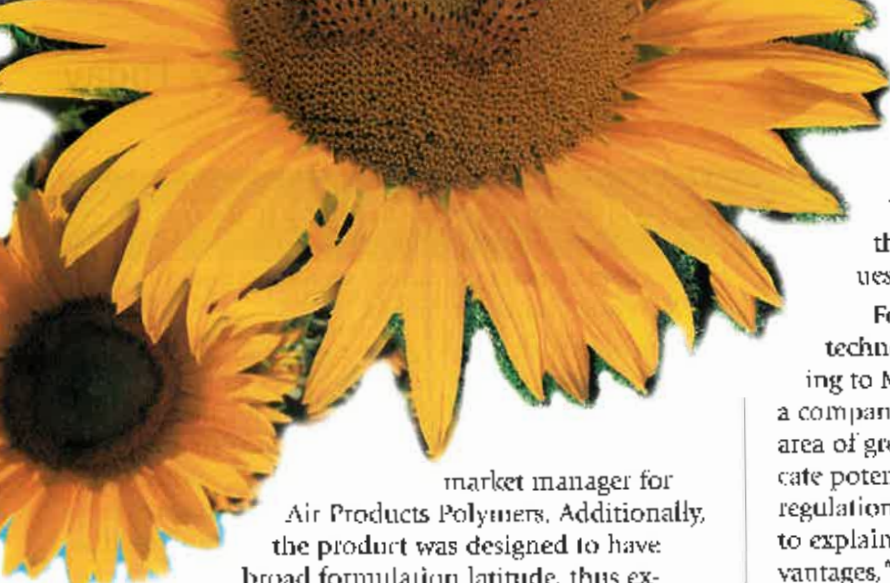


Photo courtesy of Cargill.

market manager for Air Products Polymers. Additionally, the product was designed to have broad formulation latitude, thus expanding the ability for a customer to use the product in a wide variety of formulations.

Mr. Miller attributes the success of green chemistry initiatives at Air Products to the company's philosophy of building environmental, health, and safety criteria into the initial product concept while also focusing on customer needs, industry trends, and maintaining an understanding of environmental regulations. "Our work process helps maximize the ability to identify new molecules that hit environmental, health, and safety targets while minimizing the associated developmental costs and time," he notes. "The need to balance customer and market needs with performance requirements while staying ahead of the global environmental curve is critical to a successful green chemistry initiative." Ms. Smith adds that possessing superior technical capabilities and being able to apply them to customer needs is critical for a company to successfully synthesize new products that meet green requirements.

Air Products believes that one of the main challenges with green chemistry is to overcome the perception held by potential customers that an environmentally friendly product cannot meet the performance of traditional offerings. "The introduction of a new polymer into an industry that has used conventional technologies for many, many years can only be overcome by demonstrating the high performance of the products," says Ms. Smith.

LANXESS Corporation, through its Borchers company, has introduced Baysilone<sup>®</sup> paint additives and Borch<sup>®</sup> Gen dispersing additives that are VOC free or were developed for low-VOC or zero-VOC systems. The company also offers rheology modifiers that help customers to formulate with low-VOC resins that will meet new VOC regulations. The flexibility of these products provides a significant benefit to customers. "Since our products are 100% active, most of the time they can be used in solvent-based or water-based systems," says Karsten Job, marketing manager of Borchers, a LANXESS Company. "That helps to reduce the number of different raw materials that need to be maintained in inventory, ultimately reducing costs. It allows the cus-

tomers to produce low-VOC products that have similar or equal properties compared to their solvent-based predecessors," he continues.

For LANXESS, the introduction of new cleaner technology is an investment in the future, according to Mr. Job. "One of the main factors for success is a company's ability to communicate its efforts in the area of green chemistry. You need to proactively educate potential customers about upcoming changes in regulations. At the same time, you should be prepared to explain your technologies and not just sell their advantages," Mr. Job notes. LANXESS's future green chemistry efforts will focus on additives for water-based coatings, paints, and adhesives. "We will continue to watch the market and try to anticipate certain developments. The company that sees an environmental change coming first and starts its R&D activities quickly will benefit from that once regulations turn into law."

Other companies have taken a green chemistry approach that relies on the use of products for the paint and coatings industry that are based on natural, renewable resources. Palmer International, Inc. offers products based on cashew nutshell liquid, while Cargill Industrial Oils and Lubricants develops materials based on vegetable oils. Both firms have introduced to the marketplace products designed to enable customers to reduce VOC levels in solvent-based systems.

"The mission of Palmer International is to develop products based on cashew nutshell liquid and bring value to the market and for the company based on that molecule," says Kevin Palmer, vice president business development. The company has developed two separate products for the paint and coatings industry—air dry resins for solvent-based systems and nonionic surfactants for dispersion of pigments in waterborne coatings. "Our Cashewthane<sup>™</sup> resins offer better hardening and improved dry times while enabling our customers to reduce the amount of VOCs in their formulations," says Greg Tzap, senior chemist with Palmer. The Aequenol<sup>™</sup> nonionic surfactants offer better color development, enabling the use of less pigment to get the same effect.

Palmer faced two main challenges in implementing this green chemistry initiative. "Internally we had to develop knowledge based on the chemistry of this novel compound," says Mr. Palmer. Once an understanding of the technology was obtained, leadership at the company evaluated different options and selected these two projects to pursue. "We also faced the external challenge of introducing to the marketplace products based on raw materials unknown to most people," notes coatings business manager Andrew Maseloff. "Customer interest has been developing as we have been able to demonstrate the performance of these products," he adds.

R&D efforts at Palmer are focused on finding applications for cashew nutshell liquid derived products in other types of coating systems. In particular, products designed for water-based resins and energy curable resins (both ultraviolet and electron beam) are under investigation.

Cargill Industrial Oils and Lubricants has within the last two years introduced its OxiCure line of reactive diluents based on vegetable oils. The low viscosity diluents are designed to increase the spreadability of solvent-based coatings while reducing the amount of VOCs required. According to Brent Aufdembrink, technology manager with Cargill, the OxiCure 100 series are vegetable oil-based highly reactive diluents that are incorporated into the backbone of the resin. The OxiCure 200 series products are vegetable oil-based ester products with very low viscosity relative to the alkyd resin. The offerings in this series differ in their backbone and fatty acid chains, but all have very low hydroxyl values and act as diluents. Products in the OxiCure 300 series are similar to those in the 200 series except that the high hydroxyl value has been maintained, making these diluents a highly reactive component that is incorporated into the resin, allowing for significant reduction in VOCs.

Dr. Aufdembrink notes that the diluents typically comprise 5–25% of the coating formulation. While the OxiCure products are a little more expensive as components when compared to conventional alkyd polymer chemistry, they enable the customer to continue to offer alkyd-resin based coatings possessing the same performance characteristics that meet lower VOC requirements at just a slightly higher cost. "We have had quite a lot of interest in the OxiCure products and in fact several major coatings manufacturers are scaling up formulations containing Cargill's new green diluents," says Dr. Aufdembrink.

Cargill has faced the same challenge as others trying to introduce novel products to the marketplace. While vegetable oils have been part of the paint and coatings industry for many years, there is a paucity of technological development occurring today, according to Mr. Aufdembrink. "At Cargill, we have inherent knowledge of vegetable oil chemistry and great experience with development of products based on vegetable oils and fatty acid chains for a wide variety of applications," he says. "Cargill Industrial Oils and Lubricants is totally focused on finding new applications for vegetable oils and is able to capitalize on R&D and development efforts completed in other market areas to bring new products to paint and coatings industry," Dr. Aufdembrink continues. R&D efforts concentrate on



Photo courtesy of Air Products.

utilizing these inherently green, natural resources in an appropriate and cost effective manner. For the future, Cargill will be investigating the development of vegetable-oil based products for waterborne coatings.

Rohm and Haas has developed very low, or no odor polymers for paints and coatings and powder coatings that can be cured at

very low temperatures and applied in a manner that yields zero waste. More recently the company introduced special cool roof coatings that are applied to black asphalt roofs for reduction of roof temperature. Energy savings with this technology can be significant. A new Green Chemistry Laboratory, part of Rohm and Haas' Emerging Technologies group, uses the 12 Principles of Green Chemistry as a framework for developing sustainable technologies with clear market applications.

Collaboration is the basis for all of Rohm and Haas' green and sustainable chemistry activities. The company relies on external collaborations between industry, academia, government, and nongovernmental organizations (NGOs) as well as internal collaborations between research, manufacturing, and marketing to address common goals that encourage the invention, manufacture, and marketing of commercially successful green and sustainable products, according to J. Michael Fitzpatrick, Ph.D, president and chief operating officer of Rohm and Haas.

Collaborating with consumer groups to understand buying trends and "green" purchasing triggers is also important. "Green by itself typically is not a compelling selling point. But if we can demonstrate value—whether in product performance, long-term energy savings, or other tangible benefits for the customer—our chances of success increase dramatically," stresses Dr. Fitzpatrick. "For those of us in the chemical industry, we need to understand consumers' ecopurchasing interests and trends around the world, and to match those needs with innovation and thoughtful marketing of Green and Sustainable Chemistries," he adds.

In addition to its yttrium based cationic electrodeposition primer for automotive appli-

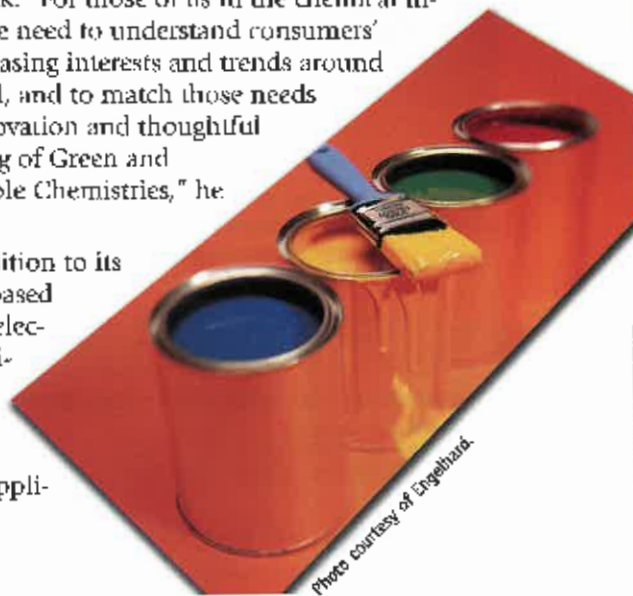


Photo courtesy of Engelhard.

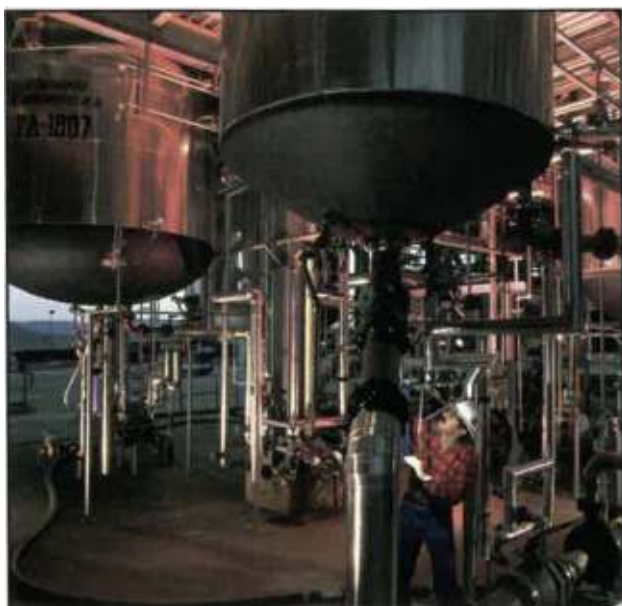


Photo courtesy of Air Products.

cations, PPG has also developed Duramar® SPF coatings for roofs. These coatings are based on a proprietary infrared reflective coating technology that cuts cooling costs, extends roof life expectancy, and aids in reduction of heat-related smog. The coatings, which comply with Energy Star® reflectance limits, are available in a wide selection of colors and are manufactured using a

closed loop batch (Kalaidoscope Work Cells) process that includes recycling and reuse of waste products.

PPG's Pure Performance™ product from Pittsburgh Paints is a high quality, zero-VOC low odor interior latex paint that was introduced in 2002. It earned the Green Seal's Class A Certification and was named one of the top ten "green" building products of 2002 by GreenSpec Director and *Environmental Building News* magazine. Speedhide® Commercial Interior Latex and Pitt-Tech® D™ (direct-to-metal) Industrial Enamel Primer/Finishes are also based on this technology. The company's MegaSeal™ Flooring Systems are zero-VOC industrial floor coatings that contain self-leveling epoxy coating and are available in many different colors.

As these many companies have demonstrated, green chemistry initiatives can indeed be commercially successful. Designing products and processes that reduce consumption and production of hazardous materials can provide opportunities not available using traditional approaches to chemical manufacturing. As protection of the environment and corporate sustainability activities become more and more important to the consumer, the adoption of green chemistry approaches—whether in the paint and coatings industry or other sectors of the chemical marketplace—will be critical for continued success. [G1](#)