GREEN COATINGS

A Trend That Is Becoming the Rule Rather Than the Exception

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In recent years, many leading paint and coatings manufacturers have been trying to meet the growing consumer demand for safer and healthier products enabled by strict environmental regulations and government legislations. As a result, there is a growing need in the coatings industry for what is referred to as "green coatings." Several independent certifying agencies[1-7] have evolved over the last 10 years to support this task. These organizations have established their own environmental performance standards and evaluation criteria. Based upon those, these organizations certify a consumer product as eco-friendly or "green." In further support of this movement, in November 2006, the Green Chemistry Research and Development Act of 2005 (H.R. 1215) was passed by the U.S. House of Representatives.[8-11] The bill has been referred to the Committee on Commerce, Science, and Transportation and must be now approved by the U.S. Senate.[8-11] This bill will certainly foster an increasing recognition of green chemistry practices when passed into law. All of the above indicate that the trend towards developing "green" coatings will soon become the rule rather than the exception. This significant need for innovation is mainly driven by continuing regulatory requirements and increasing consumer eco-consciousness.

The goal of this article is to review the impact of government regulations as innovative drivers for a paradigm shift in the paint and coatings market. This analysis is divided into six parts. Subsequent to the introduction, in order to put green coatings in appropriate perspective, a sequential historical overview of the development of coatings technology with respect to environmental regulations is provided. The next section describes how paint and coatings companies responded to the implemented government regulations. This is followed by a section which provides an overview of independent organizations that certify a coating as "green." The following section summarizes current initiatives by the government for a green revolution and discusses the international scenario and sustainability issues of green coatings. Lastly, the final section focuses on the future of green technology.

HISTORICAL OVERVIEW

Paint and coatings technology can be classified as one of the oldest technologies in the history of mankind.[12,13] A historical review[12-13] shows that the Egyptians and many of the ancient Asian and European cultures used to mix raw natural pigments (for example, turmeric) with plant oil or egg-yolk for decorative as well as protective purposes.

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Extensive literature reviews[12-16] show that the business of paint manufacturing began in the U.S. in early 1900s. In general, a paint formulation incorporates (1) pigments and/or extenders to impart color, opacity, and sometimes a few other properties such as corrosion resistance; (2) binders (to disperse pigments or extenders), considered as the "engine" of coatings mainly contributing to physical, mechanical, and chemical properties; (3) additives, added in a relatively small amount of the total formulation, which significantly affects the final performance properties; and (4) solvent, which makes a paint or a coating flow over a substrate and once the paint film is formed, evaporates; thus, may contribute towards volatile organic compounds (VOCs).[12-16]

Prior to 1960, there were few regulations or laws that specified or restricted the use of toxic substances or the amount of volatile organic solvents in formulating paints. For example, lead pigments that are toxic in nature and hazardous to human health, were used without any regulations or mandated limits in commercial paint manufacturing until 1960.[17] Another example involves VOC levels: when a gallon of paint was used to coat a surface, approximately 900 grams of VOCs were released into the atmosphere. [18] When exposed to sunlight, these VOCs contributed to the formation of smog. These compounds have been defined by the Environmental Protection Agency (EPA)[18] to include "any compound of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate, which participates in atmospheric photochemical reactions."[19]

The above and many more similar examples started to raise concerns about product safety, health, and environmental friendliness. Those fears generated a need to develop regulatory standards for consumer paints. In 1978, the Consumer Product Safety Commission (CPSC)[17] came into action and issued a regulation to restrict the use of lead pigment in commercial paint manufacturing. Prior to this in 1966, Rule 66 was promulgated by the Los Angeles Air Pollution Control Department (LAAPC) regarding VOC emissions.[20] Rule 66 was among the first regulations in the country regarding VOC emissions.[20] Since the passing of Rule 66, the federal government enacted the Clean Air Act in 1967 and established the Environmental Protection Agency (EPA).[19] The purpose of the law was to regulate the use of "toxic air pollutants which were hazardous to human health or the environment."[19] The Clean Air Act was amended in 1977 and again in 1990.[17] From the coatings industry perspective, by enacting the Clean Air Act, the government tightened the limits on the use of VOCs in paint formulations. In the second major amendment to the Clean Air Act, the Federal government "included a list of 189 toxic air pollutants for which emissions must be reduced."[19] Further, the law stated that the EPA had to publish a list of source categories within a year after the law was passed. The list of source categories[19] was based upon the source's emission levels of the toxic air pollutants. The list included "the major sources emitting 10 tons/year of any pollutant or 25 tons/year of any combination of those pollutants."[19] This directory also included geographical area sources. Any area source, whether large or small (such as a dry cleaning business), was included in the list. The EPA also issued "Maximum Achievable Control Technology"(MACT) standards for each listed source category according to a prescribed schedule.[19] These standards were based on the "best demonstrated control technology or practices within the regulated industry." The law also mandated that all controls had to be achieved within 10 years of its enactment. The law granted an extension of six years for meeting MACT requirements to "companies that voluntarily reduced emission according to certain conditions."[19] The EPA also classified a list of compounds that were exempted from the Clean Air Act or VOC regulations.[17] These compounds, even though they are carbon-based, have been exempted based upon their "negligible reactivity" towards smog or ozone formation. This list is known as the "VOC-exempt list" and can be found on the EPA website.[17]

In addition to the nationwide law, states were also asked to develop State Implementation Plans (SIPs), "a collection of regulations a state will use to clean up polluted areas"[19] mandated by the 1990 Clean Air Act. According to the law, each state's SIP had to be approved by the EPA and if it was unacceptable the EPA could take over enforcement of the Clean Air Act in that state.[19] As a result, state regulatory programs were developed through public participation and comment. "The California Air Toxics Hot Spot Information and Assessment Act of 1987" or "The Ozone Transport

Figure 1—Historical progression of key environmental legislations.

- 1955—The Consumer Product Safety Commission (CPSC) lowered the limit of lead in paint to 1.0 %
- 1966—Rule 66 promulgated by the Los Angeles Air Pollution Control Department (LAAPC) regarding VOC emissions
- 1967—EPA established the Clean Air Act (CAA)
- 1977—Clean Air Act amended
- 1978—CPSC bans white lead paint (limit of lead in paint below 0.06%)
- 1987—The California Air Toxics Hot Spot Information and Assessment Act
- 1990—Second major amendment in CAA: development of MACT standards. Ozone Transport Committee (OTC) established. State Implementation Plan (SIP)'s required

Committee (OTC)," created in 1990 as a part of the Clean Air Act amendment, are examples of state regulatory programs.[19] The OTC has many member states and has been involved in developing model rules to reduce VOCs in consumer paint products such as architectural coatings, maintenance coatings, or automotive refinish coatings. The 1990 Clean Air Act also developed a "permit" program for larger sources that release pollutants in the air.[19] The law also covered the interstate pollution and international pollution issues.[19] Indeed, these regulations were not only a major initiative to restrict or control the use of hazardous or toxic substances in consumer products, but they could be viewed as significant steps towards beneficence and betterment of human health, safety, and the surrounding environment.

THE GREEN SHIFT

The introduction of the federal and state regulations motivated raw material suppliers and paint manufacturers to think "outside the box." The researchers in industries as well as in academics started exploring new strategies to meet the mandated limits. Some of these plans could be characterized as "(1) switch to an alternative technology, (2) reformulate, or (3) install control or recovery technology."[21] As a result of industry research efforts, four main environmentally friendly or "green" technologies evolved. These four technologies included waterborne coatings, powder coatings, high-solid coatings, and radiation-curable coatings.

Water-based coatings have remained the prime choice for manufacturers as well as end-users. The Glidden Company was the first one to introduce VOC-free paints and primers for architectural coatings into the market, in 1992.[18] They were the first generation of VOC-free coatings. These paints, however, did not attract consumer purchases because of their higher cost than conventional waterborne paints and marketing approach.[18] Subsequently, companies successfully invested their resources in developing low to zero VOC paints. According to a market report,[9] waterborne coatings in the U.S. market are the largest type of eco-friendly coatings, with 2005 sales of $8.3 billion. They contribute 60% of all sales, mainly in the architectural coatings market. High-solids coatings were the second largest type of eco-friendly coatings at $2.6 billion in sales. The third largest and the fastest growing coatings market was powder coatings with U.S. sales of $1.4 billion in 2005. In 2001, Jones[22] overviewed the above three technologies. According to Jones,[22] "these three alternatives could serve as answers to federal regulations." Furthermore, commenting on powder coating technology, Jones[22] cited M. Wismer's (PPG) thought: "breakthroughs in coatings technology often stem from breakthroughs in application technology." According to him, powder coatings served as an example of an innovative application method which was a result of joint efforts among formulators, chemists, and application engineers.

In addition, many researchers have also been exploring the possibilities of using renewable resources in coatings technology.[21] The need has arisen due to the increasing raw material costs of petroleum-based products. Some renewable resource materials are used as monomers in manufacturing water-based coatings. The use of castor oil-based monomers[23,24] or soya oil-based monomers[23,25] as partial substitution of petroleum-based acrylic monomers has been explored by many researchers. In addition, the use of epoxidized soy bean oil in radiation cure coatings also has been explored.[26] Jones[22] also emphasized that despite certain shortcomings such as yellowing or poor weatherability, vegetable oils are relatively inexpensive abundant resources. According to Jones,[22] the use of vegetable oils as reactive diluents or as monomers has potential commercial viability.

Thus, since 1970 the federal government regulations primarily initiated the "green revolution" in the paint and coatings industry. Also, "renewed social awareness" provided momentum. These two factors greatly pushed the raw material suppliers and paint manufacturers to adopt green technologies and to consider the benefits and advantages provided by practicing green chemistries.

STANDARDS AND CERTIFICATIONS FOR GREEN COATINGS

In the last decade, many different independent organizations have been developed that certify a consumer product as "green." Their standards are based on various criteria that are developed from their assessment and evaluation of a product's environmental attributes. Some of the organizations established in recent years include Green Seal, U.S. Green Building Council, Master Painter Institute, Green Guard Environmental Institute, BuildingGreen, GreenHomeGuide, Environmental Home Center (EHC), and McDonough Braungart Design Chemistry (MBDC)'s "Cradle to Cradle certification."[1-7]

Green Seal[1] is one of the leading non-profit certification organizations. Green Seal has developed many scientific environmental standards for several major product categories, three of which are for paint and coatings. These three standards are GS-03 for anticorrosive paints, GS-11 for general paints, and GS-43 for recycled-content latex paint. These standards are developed based upon various criteria—for example, restricting the use of toxic compounds in paint as well as in packaging materials, or determining the limits on VOC levels and aromatic (or carbon) compounds. The evaluation criteria mainly assess the overall environmental performance of the entire product life-cycle. In the course of developing a standard, whenever possible, Green Seal also follows international standards to evaluate the performance of a product in terms of its eco-characteristics. For example, Green Seal follows the Guiding Principles and Procedures for Type I Environmental Labeling Standard of International Organization for Standardization (ISO 14024).

The U.S Green Building Council (USGBC)[2] has been recognized and accepted both in the U.S. and in Canada. The USGBC has developed a Leadership in Energy and Environmental Design (LEED) Green Building Rating System. According to the organization, this system works as a "national consensus-based, market-driven building rating system designed to accelerate the development and implementation of green building practices." There are five key areas in LEED: (1) sustainable site development, (2) water conservation, (3) energy efficiency, (4) materials selection, and (5) indoor environmental quality. Each area has specific performance points and based upon the total earned points LEED provides different levels of certifications.

The Master Painters Institute[3] is another independent organization with green performance standards for paint and coatings. These standards are based on different criteria such as VOC quantities used in a paint formulation, its durability, and physical performance. The Green Guard[4] Environmental Institute is also an independent non-profit organization. They have developed standards for "indoor products, environments, and buildings." Their standards incorporate acceptable levels of VOCs, formaldehyde, and other emissive compounds used in indoor products.

Further, many organizations are involved in supplying information and providing on-line directories of green building materials. Building Green Inc.[6] has developed a subscription based on-line directory, "Green Spec," which includes lists of green products and materials, articles, news, case studies, and reviews of several consumer products. To consider any product as "green," Green Spec uses various criteria for evaluations. GreenHomeGuide[5] is another example of a community-centered online resource directory that supplies information, case studies, expert opinions, and tips for "green" options available to conventional building and consumer products.

Founded in 1995, MBDC[7] is a product and process design firm which claims to transform its client organizations through an innovative eco-effective design approach known as "Cradle to Cradle" certification. As defined by the firm, the "cradle to cradle certificate" is conceptually about "using environmentally safe and healthy materials; design for material reutilization, such as recycling or composting; the use of renewable energy and energy efficiency; efficient use of water, and maximum water quality associated with production; and instituting strategies for social responsibility."[7] The firm also claims that upon achieving the required criteria, "a product is certified using various terms such as Silver, Gold, or Platinum product or as a Technical/Biological Nutrient and it can be branded as Cradle to Cradle."[7]

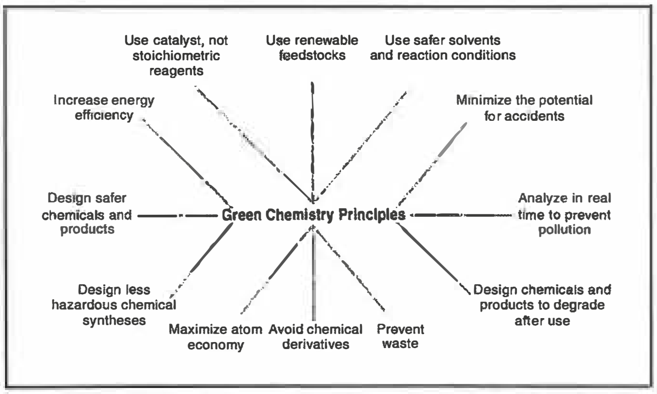
GOVERNMENT'S INITIATIVES FOR GREEN

Recent passage of the Green Chemistry Research and Development Act of 2005 (H.R. 1215) by the U.S. House of Representatives indicates that the government has recognized and supports the green revolution.[8] The goal is to develop an interagency program involving the National Science Foundation (NSF), the Environmental Protection Agency (EPA), the Department of Energy (DOE), and the National Institute of Standards and Technology (NIST).[8] Further, these organizations would work together to promote green research and development by providing research grants to individual researchers, and establish university-industry corporate research centers through education and training of undergraduate and graduate students in green technology and many more activities.[8-11]

Shortly after the passage of the Pollution Prevention Act of 1990, the Environmental Protection Agency (EPA) also developed a Green Chemistry Program to promote "innovative chemical technologies that reduce or eliminate the use or generation of hazardous substance in the design, manufacture, and use of chemical products."[27] The EPA is currently building an Internet-based Expert System, comprised of literature and many practical examples, to help and promote green strategies among manufacturers.[27]

After 1990, to prevent pollution and to encourage green chemistry practices,[27] the EPA adopted "12 Principles of Green Chemistry," originally published by Anastas and Warner.[27] These rules serve as a guiding map for researchers to apply green chemistry practices.

Figure 2—12 Principles of Green Chemistry.[27]



Also, as part of the Green Chemistry Program,[27] to encourage organizations, the EPA gives yearly awards in various categories of green practices. Currently, there are five categories: "(1) alternative solvent pathways, (2) alternative solvent and reaction conditions, (3) designing safer chemicals, (4) academics, and (5) small business."[27] Incorporated in 1997, the Green Chemistry Institute (GCI), is a corporation which claims to be "devoted to promoting and advancing green chemistry principles and practices into all aspects of the chemical enterprise."[28] GCI's mission is "to be the premier change agent that has the knowledge, expertise, and capabilities to catalyze the movement of the chemical enterprise toward sustainability through the application of green chemistry principles."[28] According to GCI, it accomplishes its mission by "supporting research, works to integrate green chemistry into all levels of chemical education, aides companies with industrial implementation, hosts conferences, and coordinates efforts with an international network of green chemistry advocates."[28] Every year, GCI recognizes and honors researchers from industry and academia for their valuable contribution towards designing and developing innovative pollution prevention strategies.[29]

INTERNATIONAL SCENARIO

In today's global economy the coating industry has faced challenges because of burgeoning globalization, outsourcing, and the changing business climate of the U.S. market. The initiatives to implement strict regulations from Europe and the price-cost squeeze from fast developing Asian economies are two prime sources of pressure from the global market.

European VOC (EU VOC) policies take volatility into account, not reactivity.[30,31] According to EU VOC regulations, "any material with a boiling point above 250°C is considered exempt."[31] Thus, for solvent-based paints, VOC content limits in Europe can generally be considered more stringent than in U.S. In other words, a coating/paint formulator in Europe designing a solventborne paint is restricted from using fast-evaporating solvents under current EU VOC policy. However, in the U.S., the coating/paint formulator does have more latitude in terms of using fast-evaporating solvents—for example, tert-Butyl acetate (TBAC)—to design a paint formulation. Recently, the European Union passed new legislation known as REACH (Registration, Evaluation, and Authorization of Chemicals).[30,31] According to this new regulation, "companies producing chemicals above 10 tons per year would have to provide safety data for the chemicals." There is a provision of substitution of safer alternatives to hazardous chemicals. Also, the public can request information about the presence of a limited number of hazardous chemicals in products."[31] The EU's regulatory initiatives such as REACH will certainly put pressure on U.S. legislators and policy makers to adapt a similar regulation plan.

The current high man-power costs, increased raw material expenses, rising energy costs, tighter regulatory requirements, and escalating insurance premiums contribute to greater pressure on U.S. manufacturers. Currently, global competitors in Asia do not face the same challenges and magnitude of such operating costs.[32-33]

SUSTAINABILITY ISSUES: COST AND RECYCLABILITY ARE IMPORTANT

Although the green chemistry practices incorporate critical concepts such as environment, human health, and safety into product design and development, many argue that cost is not recognized as a key factor.[34] As a result, major companies including Akzo Nobel, BASF, Bayer, DSM, Rohm and Haas, Shell Chemicals, and many more are pushing an alternative term, "sustainable chemistry."[34,36] The proponents of sustainable chemistry claim that besides the economic element, another difference between green and sustainable chemistry is its lifecycle end analysis.[34] The green chemistry principles say that "products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment."[27] On the other hand, sustainable chemistry puts forward the concepts of recyclability and reusability.[34,36] According to recent research reports,[34,36,37] today several companies—for example, Bayer MaterialScience, BASF, ACC Plastic Division, and major retailers such as Wal-Mart are using life cycle—a technique to compare the environmental impact of competing processes and products—as a way to define greenness. The reports further quoted that leading companies—for example, BASF and Rohm and Haas—are spending heavily on sustainable green R&D, which includes activities relating to- "energy efficiency, resource conservation, and climate protection."[34]

Recently, the Synthetic Organic Chemical Manufacturers Association (SOCMA) launched an International Center for Sustainable Chemistry in partnership with the EPA.[34,35] The center aims to "develop and establish consistent methods for analyzing alternatives that can achieve a similar function, without disrupting the marketplace."[35] According to a report,[34] this center also plans to include corporations, academic institutions, and environmental groups to form a governing body which would primarily focus on defining what is and what is not green. Also, according to another news report,[38] recently American Chemical Society's Green Chemistry Institute (GCI), led by Paul T. Anastas, a green chemistry pioneer, announced that "green and sustainable chemistry" will be their main focus at upcoming and future ACS national meetings.

GREEN FUTURE

The future of green technology is bright because its ultimate goal is to strengthen our eco-system by producing environmentally friendly products. However, like any other technology, green technology holds many opportunities and challenges for its stakeholders. Consumers want a product that is not only eco-friendly but must also produce better, or at least equivalent, performance at the same cost. Recyclability, reusability, and cost are also critical factors in product design and development from the manufacturer's standpoint. Also, the manufacturers view the major obstacle to be overcome is the natural resistance to change—specifically, the modifying of existing processes and products.

It is true that the green innovation in the paint and coatings industry has been mainly driven by federal regulations. However, today a large number of raw material suppliers and manufacturers are voluntarily adapting the green trend for their products. According to a recent news report,[39] a Brazilian-based company named Braskem claimed that they have encountered success in producing trial quantities of the world's first bio-based high density green polyethylene (PE), made from sugar cane-based ethanol. In the future, they aim to build a green PE plant in Brazil and invest $60 million–$100 million, depending on whether it is built at an existing facility or a Greenfield location. In addition, according to recent reports,[39,40] the other companies involved in such green activities as developing bio-based plastics include DuPont, which claims that it has recently developed high performance polyol ("Cerenol") based bio-materials; Archer Daniels Midland and Metabolix, which aim to jointly produce polyhydroxyalkanoate (PHA) based renewable materials; and Cereplast, which is a producer of bio-based polyactic acid.

The concept coming to the forefront of the public is that "green is not only good for business, but also for the betterment of mankind."[41] Government initiatives may eventually encourage or even mandate that all manufacturers shift towards implementing green technologies. Thus, in the not too distant future, the green trend would become the rule rather than the exception. CT

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