AN INTRODUCTION TO COATINGS Sustainability

by **Clifford K. Schoff**,
Schoff Associates

Sustainability is a way of doing business that supports and maintains the enterprise involved, yet also protects the environment and promotes health and safety. There are three interconnected aspects: economic, environmental, and social. In addition, the word "sustainability" means the ability to maintain, support, endure, and survive—implying long-term effects and preparing for the future. This fits in with the United Nations Brundtland Commission definition of sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."[1,2]

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SUSTAINABILITY AND COATINGS

What does sustainability mean for coatings and the coatings industry? Let us begin with the economic aspect, the idea of sustaining or maintaining the business of a paint manufacturer or supplier. The company must have or develop products that meet market needs and must be able to make a profit on the sales of these products. Economic sustainability literature stresses efficiency in every part of a business, from management to production, conservation of energy and raw materials, maintenance of equipment, and minimization of waste. The ultimate efficiency would be to optimize all of these processes and activities. Optimization saves money, increases profits, and can provide additional jobs. A logical conclusion is that putting effort into sustainability makes excellent sense for coatings-related businesses. Also, we must not forget that coatings promote sustainability for other industries, through improved durability of coated products such as automobiles, bridges, beverage cans, oil tanks, furniture, houses, commercial buildings, etc. Coatings protect against moisture, corrosion, thermal and UV degradation, abrasion, chemical attack, and other threats, thereby extending the lives of the coated objects and they accomplish this with thin films at low cost.

WHAT MAKES A COATING OR COATING SYSTEM SUSTAINABLE?

A sustainable coating needs to have the following properties:

- Low solvent emission (low VOC)
- Minimal hazardous air pollutants (HAPs)
- Inclusion of renewable materials where possible
- Use of low cost raw materials where possible
- Straightforward, efficient, low energy manufacturing, efficient pigment dispersion, excellent batch control, and low waste

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- Relatively low energy needed for cure
- Good application properties with a low tendency for surface defects
- Long service life

Let us take a closer look at service life. The service life of a coating is the period of time over which it has acceptable appearance and supplies adequate protection while in its service environment. It is important because the price of paint may not tell us very much about the cost of using it. A cheap coating with a short service life may well be far more expensive environmentally and economically than a coating that lasts a long time. When the coatings industry made the same or similar coatings for years at a time, service life information was known through field experience and/or long-term testing. Now we have new chemistries and alternative technologies such as high (and higher) solids solventborne, waterborne, powder, and radiation cure. Unfortunately, we rarely have the experience or data to tell how these new coatings will hold up and what sorts of failure modes will occur.

A number of investigators have been working on identifying key failure modes in specific coatings and developing ways of making meaningful service life predictions.[3-10] Many of the techniques that are being used involve analysis of coating surfaces (often on a nanoscale) to follow chemical and physical degradation with weathering (natural, accelerated, or just UV). Other methods follow changes in electrical properties with exposure to corrosive environments. The tools used are considerably more sophisticated than fences and weathering cabinets. They include various types of microscopy (light, scanning electron, infrared, confocal, etc.); electrochemical impedance spectroscopy (EIS); nanoindentation; and measurement of gloss/surface roughness, surface wettability, and fracture toughness. Computerized databases make it possible to compare coatings, identify failure modes, determine the most meaningful tests and, ultimately, to decide on the best formulations from a durability standpoint.

However, service life is only one part of a comprehensive analysis of the life of a coating called Life Cycle Assessment (LCA), which is the process by which the cumulative environmental and economic impacts of a product over its lifetime are measured.[11-14] A complete analysis covers everything from raw material acquisition to disposal of the coating when the painted object is scrapped or recycled. The results of assessments can be used to compare products and processes in order to determine which ones have less overall cost, environmental impact, and/or energy use. For example, LCA can and is being used to compare the overall impact of waterborne coatings compared to high solids coatings. Partial assessments such as that of paint manufacturing alone or paint shop operations can be useful. Once an LCA is completed for a given product, changes in raw materials, processes, VOC requirements, energy costs or sources, etc. readily can be factored in and new LCA numbers calculated. LCA also can be used as a marketing tool or defensive tactic. It is likely that more and more customers, including do-it-yourself (DIY) consumers, will ask paint suppliers for LCA data on their products.

RAW MATERIAL ASPECTS

The mix of raw materials used in coatings has evolved over the years in response to a greater understanding of the health and safety aspects of materials and of their finite availability. There used to be little or no restriction on the use of solvents and other raw materials in coatings. We now know that many of the materials that were industry favorites are toxic, have odors that no longer are acceptable, are photochemically reactive, and/or may cause cancer. Continuing to use them would be against major aspects of sustainability -the need for sustaining the health and safety of workers and customers and the need for ensuring that neighborhoods around paint and customer plants are acceptable places to live. Public health and the environment are important parts of the sustainability equation.

Besides the effects on solvent usage, government regulations regarding solvent emissions have had a secondary effect of driving the development of new polymers and oligomers, crosslinkers, catalysts, and reactive diluents. A good example is the development of latexes with a hard core and a soft shell where the continuous phase is composed of the shell polymer in which the hard cores form ordered structures. There is no need for a coalescing solvent and it is possible to develop a very low or zero-VOC coating. In addition, more attention is being paid to the effects of pigments and the quality of dispersions to reduce viscosity and allow higher solids. Low density, low oil absorption pigments, and the use of wetting agents provide advantages.

PAINT FORMULATION

There also has been an evolution, perhaps even a revolution, in paint formulas and formulation practices—all driven by one aspect or another of sustainability (although it was not called that at first). Due to poor and worsening air quality in many countries, government regulations designed to reduce solvent emissions from coatings were instituted. Guidelines were established restricting the content of volatile organic compounds (VOCs) in terms of mass/volume, and the allowable levels have been reduced every few years. Initially, many VOCs were calculated based on formulas (ASTM D5201, "Calculation of Formulation Physical Constants of Paints and Coatings," is useful for doing this). The results showed how much solvent would have to be removed from a formulation for it to come in below the VOC limit for that type of product. Often it helped to replace a solvent with a lower density one (a consequence of VOC being in mass of solvent per unit volume). The regulations have led to the development of higher and higher solids coatings and greater use of alternative technologies, such as powder coatings and radiation-cure products.

One of the difficulties with achieving low VOC via high solids coatings is viscosity. Low solvent levels give high viscosities and some high solids coatings are barely sprayable. The viscosities of solvents become important; the lower the better. The solvents that give the lowest viscosities in solutions of specific resins need to be identified. It is important for low molecular weight polymers and oligomers to have narrow molecular weight (MW) distributions and to minimize groups that give hydrogen bonding in order to minimize viscosity. Reactive diluents that can act like solvents and then react into films can be useful. Beware of another viscosity problem, sagging—especially in the oven. Low molecular weight resins and oligomers keep right on flowing and flowing even after all of the solvent is gone. Materials are needed that flatten out viscosity temperature behavior so that the normal deep viscosity minimum on baking does not occur. A number of thixotropes accomplish this. However, controlling hot sag and orange peel at the same time is difficult.

More recent government regulations have tended to place emphasis on hazardous air pollutants (HAPs, also called air toxics), and most countries now have lists of solvents and other chemicals, the use of which they wish to minimize. For some time, industrial hygiene and product safety people had been directing the removal or limiting of a number of these chemicals and others of concern because of toxicity, possible carcinogenicity, objectionable odor, or other negative aspects. However, other chemicals on these lists still are used in paints. This has led to more work on reducing solvent content and developing solvent replacements. It also has made alternative technologies, particularly powder coatings, more attractive.

MANUFACTURING

Let us look at sustainability with regard to the manufacture of coatings. What about production practices? Historically, paints have been produced on the basis of "make it wrong and fix it." Formulas were designed to need adjustment for color, viscosity, and, sometimes, other properties. After testing, more pigment paste was added to bring the color to the specification (tinting). More solvent or more of the resin-solvent letdown was added to lower the viscosity to the shipping specification. The viscosity usually was further adjusted at the customer to fit the application equipment and conditions. The color sometimes was further adjusted as well. Primers and other products with wide color latitude could be made right the first time (first run), but not most others. This scenario may be changing, but it appears that a lot of paint is still made the old-fashioned

way. Improved sustainability requires more efficient manufacturing.

There is a better way. Some manufacturers in Europe and the United States have been manufacturing coatings, especially small- to medium-sized batches, using dispense technology similar to that of tinting machines, but on a larger scale. In this process, all components are fluids—solutions, dispersions, and solvents. The fluid materials are piped to a dispensing head that has a series of nozzles and carefully metered amounts are squirted into a pail, drum, tank, or tote. Before actual production, a very small specimen batch is made, tested, and adjusted to meet requirements. The formula then is adjusted, and production batches are made based on the new formula and shipped. There is much better batch-to-batch consistency than with conventional production (each batch should be exactly the same) and much less waste.

Sustainable paint manufacturing practices provide environmental benefits as well as economic. For example, AkzoNobel recently built a new paint plant in Ashington in northeast England that is expected to produce 100 million liters of paint per year with reuse of 100% of water (helped along by rainwater harvesting) and 90% of solvent. Beyond that, it is expected to reduce VOC emissions by 75%, cut waste by 50%, and cut energy use per liter by 60%. All of this will reduce production costs and provide jobs at the same time that it will reduce air pollution and impact on the climate.[15]

CONSERVATION AND RECYCLING

We also have begun to realize that because most materials used in coatings are based on petroleum or natural gas, they are not going to be available forever. This has led to much interest in renewable materials, including biobased resins and intermediates based on sucrose and other sugars, soybean oil, tall oil, castor oil, and other natural oils. Biocomponents such as sucrose polyols, soy polyols, biobased acrylic acid and methyl methacrylate, succinic acid, dimer fatty acids, 3-hydroxy propionic acid, caprolactone lactides, epoxidized sucrose esters, epoxidized soybean oil and acrylated derivatives are commercially available or will be soon.[18,19] However, just because a material is biobased, it does not necessarily mean that it or products made from it are sustainable. That depends on the biomass source, how the product is made, how much energy is needed to make it, and what happens to it at the end of its life.[20]

There have been disappointments with a number of biobased materials because properties of coatings produced from them were inferior to conventionally produced coatings. However, Chisholm and coworkers have synthesized vinyl ether monomers from soybean oil triglycerides and have followed this with reactions with other monomers.[21-23] The resultant polymers and copolymers have greatly increased functionality, which allows the development of materials with excellent hardness and mechanical properties. The "living" polymerization process used provides control of polymer structure and molecular weight and gives a narrow MW distribution. All of this means that new biobased materials with much better properties are possible.

There also is interest in the conserving and recycling of coatings, their components, and waste from their application, particularly overspray. Reuse of solvents recovered from resin and paint manufacture is relatively straightforward, but other recycling has been much more difficult. A successful approach has been the collecting of leftover latex paint from homeowners at special hazardous waste disposal days (usually held in a local school parking lot) and having it eventually turned into a usable product. The process is labor intensive, but at least one company in the United States appears to be making a success of it.[21] Every container that is received is opened and inspected to determine if the paint is usable. Good quality paints are hand sorted by color for processing into recycled content paint. Non-reusable paints are manufactured into other products, including one that can be used in Portland cement.

The most unified approach has been with PaintCare™ Inc., a non-profit organization established by the American Coatings Association to ensure effective operation and efficient administration of paint product stewardship programs, on behalf of all architectural paint manufacturers in the United States. PaintCare is developing and implementing strategies regarding post-consumer architectural paint: reducing its generation, promoting reuse of what is generated and collecting, transporting, and processing whatever is left. PaintCare's objectives can be summarized as "reduce, reuse, recycle." Seven states and the District of Columbia have passed paint stewardship laws and similar legislation is expected to be introduced in several other states over the next few years.

Another area with potential is the recycling of automotive factory paint sludge that comes mainly from paint overspray. A company in India has used dried paint sludge in industrial primers and has blended it with asphalt (bitumen) for use on roads.[25] There also has been a pilot project in the United States to use paint sludge as filler for automotive sealants. Anything that reduces the large amount of sludge that goes to waste would be beneficial.

ENERGY

Energy certainly is a key factor in sustainability, particularly electric power generation and use. Power is expensive, but we have never had so many power sources, so many opportunities for more efficient use of power, or so many tools for monitoring and controlling use of power. For generations, we have depended mostly on coal and oil for power generation. Natural gas now is catching up and biobased fuels are becoming more available. Fuels derived from plant material (biomass) have the advantage of coming from renewable sources. Then, there are alternative means of generating power such as wind and solar, both of which can provide on-site power as well as feed the grid. The heat from incineration of waste is being used at a number of companies (including a few paint producers) to heat water to make steam and/or electricity. The U.S. armed forces even are trying direct gasification of waste.

However, it matters less where you get your power or other energy than it does how efficiently you use it. Considerable energy is wasted in nearly all factories and offices, 20–60% by most accounts. Saving energy saves money. Hardware and software are available to monitor energy usage and to control processes so that they use less electric power or other energy and/or use it at off-peak times. They normally pay for themselves in a few months.

Another area of high use of energy related to paint is at customer factories, particularly when coatings are baked. One way to reduce energy use in auto factories is to simplify the painting process so it is more compact with fewer bakes, which means fewer of the very expensive, high energy use ovens. Most automotive coating systems consist of four coatings: electrodeposition (ED) primer, a second primer, basecoat, and clearcoat. Normally, there are bakes after the ED primer and the second primer, but the basecoat and clearcoat are applied wet on wet (more like wet on tacky) and then baked. The two main compact painting systems are designed to remove the primer oven. After the E-coat is applied and baked, the three wet system involves the wet on wet on wet application of solventborne primer, basecoat, and clearcoat, without any heated flash zones in between, followed by a final bake. There also is a type of waterborne system that eliminates the need for a primer. Following E-coat, two basecoat layers are applied wet on wet. Basecoat layer 1 acts as a primer, filler, and anti-chip and provides durability. Basecoat 2 provides color and additional durability. The clearcoat is then applied and the basecoat and clear layers are baked together. In addition to reducing customer energy use, compact systems also cut customer investment costs and increase productivity.

WASTE

Waste disposal costs a lot of money. Labs used to receive gallon cans of paint for testing even though only a few milliliters were needed to run most tests. Architectural paints could be taken home and used, but other paints were a waste and had to be disposed of. Formulation labs made gallons at a time and ended up disposing of at least part of it. Many labs had high waste disposal bills. That had to change and it eventually did. Now, labs make smaller test batches and many labs in the industry do their screening via high throughput technology where they make and test very small coating specimens. Promising formulas are then scaled up for further testing. Far more important is the need to reduce waste in paint plants. Bad batches mean double losses—the cost of making the batch and the one for burning or otherwise disposing of it. The paint manufacturing system similar to tinting, discussed earlier, makes bad batches very unlikely.

Wasting of paint also occurs in customer factories. Excess overspray is one example. Another example is repainting to repair surface defects and dirt, which lowers productivity and may lead to field defects and failures in the repaired areas. The Japanese changed our attitudes toward such waste with their concept of "no touch," the principle of achieving such quality that repairs are unnecessary. For both the paint producer and user, "no touch" really means making the best quality paint possible and applying it under such conditions that there are no defects, no dirt. That is a lofty goal, but it can be done.

FUTURE SUSTAINABILITY TRENDS

- More efficient development and manufacturing of paints (greater use of computer-based aids)
- Further reduction of VOCs and HAPs
- Higher solids, more waterborne, more powder, more radiation cure
- More biomaterials used (renewable resources)
- Coatings with greater durability
- More wet on wet processes
- Lower cure temperatures
- Better energy conservation
- Closer cooperation with users to prevent surface defects and avoid repainting
- More customers who want to know your sustainability record.

CONCLUSIONS

Sustainability is vital for our industry if we hope to survive and prosper. We are improving our degree of sustainability on average, but with great variation from company to company. There is much more to do in order to increase manufacturing efficiency and decrease environmental impact (reduce VOC and HAPs). There is a need for suppliers to develop materials that are more sustainable, yet competitively priced. Where practical, more of these should be based on renewable resources. Improvements in energy conservation must be made and waste must be reduced. All of these things are good business and should result in greater profits and more jobs.

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AUTHOR

Clifford K. Schoff, Schoff Associates, Allison Park, PA 15101, USA; c_schoff40@msn.com.