Building Toward a Cleaner Environment: A New Role for an Existing Product, TiO_2

Smog envelops the City of Los Angeles, an ideal stage for promoting new technologies proven to reduce air pollution.

December 2006, Leslie Katzman

With support from a Sasaki GreenRED grant for the Port of Los Angeles, Wilmington Waterfront Development Program- Buffer Design

SUMMARY

Even though air pollution poses a significant risk to human health and the environment, its negative effects can be reduced by selecting appropriate materials in architecture and landscape architecture. One new class of materials permits the treatment of pollutants close to their source, in the city and on the street. For the last four years, European and Japanese research centers have been investigating the pollution-reducing capability of photocatalytic* compounds. One such compound, titanium dioxide (TiO_2), is widely used in consumer products. In the presence of sun or artificial light, photocatalytic TiO_2 reacts with air pollutants, converting them into molecules that have a relatively benign impact on the environment.

Incorporating cutting-edge technologies such as these “smart” anti-pollution materials is an integral part of Sasaki's approach to sustainable design. However the major drawback of photocatalytic building materials is their premium cost and sparse commercial availability in the United States. At the time of this writing, Essroc (a North American subsidiary of Italcementi Group) and Green Millennium (based in California) are the best sources of TiO_2 products specifically formulated to reduce air pollution. It has yet to be determined whether clients are willing to pay for such innovative products, but the long-term results may well be worth the initial costs.

INTRODUCTION

Air pollution poses a serious threat to human health and the environment. Pollutants from exhaust systems can cause unsightly blackening and costly degradation of walls and building facades. In most urban areas, the main sources of pollutants are automobile emissions, industrial activities, and heating systems. Together they produce a mix of nitrogen oxides (NO_x), volatile organic compounds (VOC's), carbon monoxide (CO), sulfur oxides (SO_x), and particulate matter (PM). The deleterious effects of these pollutants may extend far beyond the original source of emission. NO_2 and VOC's react in the atmosphere to produce secondary pollutants, such as acid rain, smog, and ozone, which may impact sites far from cities and congested streets.

By selecting appropriate building materials, architecture and landscape can reduce the negative impact of air pollution. One solution that has received recent attention involves treating pollutants in close proximity to their source, in the city or on the street. For the past four years, the European Union has supported an international research consortium, PICADA (the Photocatalytic Innovative Coverings Applications for Depollution Assessment), that has investigated the use of building materials to reduce air pollution. Japanese research centers have also been involved, examining the pollution-reducing capability of photocatalytic compounds such as titanium dioxide (TiO_2). In the presence of sun or artificial light, photocatalytic TiO_2 reacts with air pollutants, converting them into small amounts of relatively benign molecules. Both laboratory and field experiments reveal that adding TiO_2 to the surface of pavement and building materials can significantly reduce air pollution, by up to 60% in some applications (Giussani, 2006).

Since incorporating cutting-edge technology is an integral part of Sasaki's dedication to sustainable design, this paper examines the use of "smog-busting" TiO_2 in paving or as a coating on built structures. This analysis is particularly relevant to our current work at the Port of Los Angeles (POLA). The high profile of the site, the project's design, and the environmental context of the Port make it an ideal candidate to showcase the benefits of TiO_2. Furthermore Sasaki, the client, and the surrounding community are all aligned in their desire to create an environmentally sustainable future for this location.

The first part of the paper provides a brief background of TiO_2, the photocatalytic process, and environmental factors influencing this reaction. Relevant research and precedent studies are discussed. This technology is then explored in the context of the design field. How can TiO_2 benefit Sasaki's projects? Which products are commercially available in the United States, and at what cost? The paper concludes with a list of contacts and references for purchasing these products and obtaining additional information.

*Photocatalysis: the acceleration of a chemical reaction involving light due to the presence of a catalyst.

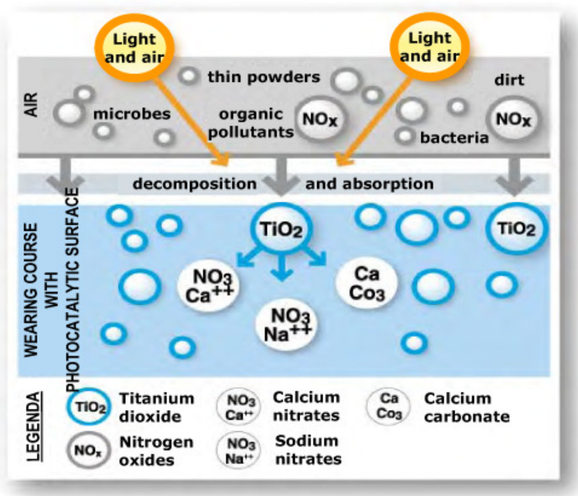
BACKGROUND

Chemical Properties of TiO_2

Titanium dioxide (TiO_2) is a naturally occurring compound widely used in toothpaste, sunscreen, paint, plastics, cosmetics, and a host of other products. Its unique capacity to absorb UV light without being consumed in the reaction is a primary reason for its inclusion in products such as sunscreen. The molecule has several different structures: anatase, rutile, and brookiet. Anatase is the preferred molecular form for breaking down air pollutants due to its higher photocatalytic reactivity (Beeldens, 2006).

The Photocatalytic Process

Activated by the energy of UV light, TiO_2 interacts with water vapor and oxygen to create hydroxyl radicals and superoxide ions which disperse over the surface of the catalyst and react with other substances. Significantly, these radicals and ions oxidize organic compounds such as nitrogen and sulfur oxides, key ingredients of air pollution (Chusid, 2005). The byproducts of the reaction vary depending on what substances are involved, but they are relatively benign. Nitrogen oxides are broken down into nitrates, while organic compounds are turned into carbon dioxide and water. It is this photocatalytic reaction that destroys the molecules of air pollutants, including nitrogen and sulfur oxides, carbon monoxide, and benzene.



In the presence of light and air, titanium dioxide (TiO2) breaks down harmful elements into relatively benign molecules such as calcium carbonate and nitrates. Diagram courtesy of Green Millennium.

Photocatalysis involving TiO_2 is a rapidly developing area in the field of environmental engineering. To improve the efficiency of this process, research has focused on creating nano-sized particles with a different atomic structure than the ordinary pigment used in paint. These nanoparticles, which are approximately seven nanometers wide, offer an optimal surface for the photocatalysis of air pollutants (Frazer, 2001). Research is also being conducted to expand the range of light wavelengths and intensities that stimulate the process, to further its use for both exterior and interior applications.

Environmental Factors Influencing Photocatalysis

Environmental factors, including light wavelength and intensity, relative humidity, temperature, and wind play an important role in the effectiveness of the photocatalytic process. The best photocatalytic results are obtained under higher temperatures and light intensities greater than 300 nm (Beeldens, 2006). An increased relative humidity (over 30%) in the atmosphere reduces the adhesion of pollutants to TiO_2 surfaces. Therefore, a hot summer day with low relative humidity and no wind would provide optimal conditions for reducing air pollution; appropriately, this type of scenario often coincides with high levels of smog. Other factors such as speed of traffic, concentration of air pollutants, and wind direction also influence the reduction rate of pollutants.

APPLICATIONS

The benefits of TiO_2 extend well beyond its ability to purify air; they include a self-cleaning mechanism and anti-bacterial, anti-mold, and deodorizing characteristics. In the presence of UV light, a TiO_2-coated surface reacts with water vapor to produce a super-hydrophilic environment. The thin layer of water that forms on the surface prevents the adhesion of grit and dust as well as particles that contain oil, such as atmospheric pollutants. This protective barrier allows water to slide under and float away surface particles. Surfaces remain clean and bright for an extended period of time, thereby greatly reducing the cost of repairs and maintenance. Self-cleaning products that are readily available on the market include tiles, windows, paints, and bathroom fixtures. Toto Ltd. has several patents for this technology and claims the self-cleaning attributes last throughout the lifetime of the product.

The intermediary products of photocatalysis, hydroxyl radicals and superoxide ions, are strong oxidizers that break down a broad spectrum of organic materials including dirt (soot, grime, oil, and particulate matter) and biological organisms (bacteria, viruses, algae, mold, and fungi), as well as odor-producing chemicals (Chusid, 2005). Many existing applications for TiO_2 are found in self-cleaning tiles for hospitals, roofs, and public restrooms. Japan has started to integrate photocatalytic materials into the interior of buildings to neutralize indoor air contaminants from photocopier toner dust, cleaning chemicals, and odors (Chusid, 2006).

TiO_2 AS A BUILDING MATERIAL

The self-cleaning property of TiO_2, combined with its photocatalytic, pollution-consuming abilities, make it an ideal additive to building surfaces under harsh urban conditions. Depending on the application, TiO_2 can take the form of a coating, concrete or plaster, pavement blocks, or paint. It can be effectively used for paving surfaces or building facades, public restrooms, retaining walls, tunnels, and noise barriers. When TiO_2 is applied in white cement on buildings, the surface remains bright for extended periods of time; dirt is easily washed away after photocatalysis and exposure to a hydrophilic environment.

Photocatalytic materials are particularly effective in areas of concentrated pollution, such as tunnels, indoor parking garages, freeways, or areas of traffic congestion. A key consideration in the ability of TiO_2 to reduce air pollution is its contact with the contaminant. TiO_2 must be present on the surface of the material and exposed to light in order for photocatalysis to occur. Therefore the designer must consider the texture and area of the surface, the time during which the material is exposed to air pollutants, and the concentration of TiO_2 on the surface (Beeldens, 2006). One European design firm, Elegant Embellishments, has developed three-dimensional tiles that increase the surface area coated by TiO_2. These innovative tiles maximize their exposure to sunlight by providing omni-directional reception of light (Schwagg, 2006).

For cement and coating applications, manufacturers often customize the amount of TiO_2 on the surface to meet the needs of the application. Wear-and-tear reduces surface coatings of TiO_2, especially in high traffic areas. To solve this problem, some manufacturers integrate TiO_2 into the wearing layer of cement and tiles. This allows for new TiO_2 particles to be exposed as the surface wears down.

EXPERIMENTS AND PILOT STUDIES

The photocatalytic properties of TiO_2 show great promise in laboratory studies, but translation of these results to real-world situations is critical. The international research consortium PICADA has several ongoing projects in Europe that focus on this goal. One such study, the Canyon Street Pilot project, recorded a 40 to 80% reduction in nitrogen oxide concentrations on TiO_2-treated vertical surfaces as compared to the non-treated control. The relatively wide range of improvements was attributed to different sources of pollution, wind direction, and exposure to sunlight. Another PICADA research project involving a parking garage is underway. The garage's ceiling has been treated with white TiO_2 paint and illuminated with UV lamps. Initial indications of pollution reduction appear promising, but more data is needed. In another study, tests on a 230 meter stretch of road outside Milan showed TX Active (a product developed by the cement-maker Italcementi) cut levels of nitrogen dioxide and carbon monoxide by as much as 60% (Giussani, 2006). A two-acre industrial site near Bergamo, Italy paved with TiO_2 concrete exhibited a 45% reduction of nitrogen oxides (Giussani, 2006).

Additional research must also be conducted on the longevity of photocatalyzing TiO_2 in urban environments. A pilot project using 10,000 m^2 of photocatalytic paving blocks on a major road in Antwerp showed a 20% decrease in photocatalytic efficiency after one year of exposure to vehicular traffic (Beeldens, 2006). Results from a Hong Kong research team revealed a significant deactivation of TiO_2 in concrete paving blocks installed in several high traffic pedestrian walkways over a four month period (Chai-Mei Yu, 2003). This was especially true at two locations near restaurants. It appears that the self-cleaning mechanism may not be strong enough to remove contaminants on a highly impacted, horizontal surface, and this further retards the photocatalytic process. Dirt particles may lodge in porous surfaces, such as cement, and inhibit the self-cleaning mechanism by preventing light from reaching the TiO_2. The Hong Kong researchers also found that washing the concrete blocks with water was not an effective means for regenerating photocatalytic activity; a degreasing agent may be necessary (Chai-Mei Yu, 2003).

These results suggest that applying TiO_2 to less impacted surfaces, such as vertical retaining walls or ceilings, may be a better means of reducing air pollution. Before this material can be used with confidence, additional experiments must to be conducted. Questions still remain regarding TiO_2 dosage rates, compatibility with different ingredients and surfaces, how to apply the product, maintenance, and longevity.

COMMERCIAL AVAILABILITY AND COST ANALYSIS

The major drawbacks of using photocatalytic building materials are the cost and limited commercial availability in the United States. Several types of products are manufactured and used for projects in Europe and Japan. Researchers in the United State appear to have embraced the technology, but it has yet to be incorporated into a large scale project. All of the European representatives contacted for this paper were enthusiastic about the possibility of showcasing their products in the U.S., and were willing to negotiate product costs. Refer to Table 1 for company and product information and Table 2 for pricing information and material coverage.

Table 1. List of companies and brand names for photocatalytic building products.

Company	Brand Name	Photocatalytic Product
Italcementi (Italy), Essroc** (U.S. branch)	TX Active Aria	Additive for white or gray Portland cement concrete mixture.
Green Millennium** (U.S.)	TPX 85 solution	Thin, water-based films that can be used as coating and/or sprayed onto concrete and other surfaces.
Global Engineering* (Italy) and Millennium Chemicals* (England)	Ecorivestimento®	Premixed cement and plaster in powder form for wall coatings or pavement.
	Ecopaint®	Water-based, clear coating for exterior, interior, or tunnel applications.
	Ecostar®	Self-locking concrete pavers.
Elegant Embellishments* (London and Berlin)	3-D Tile	Modular systems of 3-D white tiles that can be assembled into sculptures or wall coverings.
Mitsubishi Materials Corporation* (Japan)	NOxer®	Multi-colored concrete paving blocks. Not yet available in the U.S.
Toto Ltd. Toto Frontier USA	Hydrotect Tile	Ceramic tiles not yet available in the U.S. (Hydrotect costs 10 to 20% more than regular ceramic tiles.)
	Hydrotect Color Coat	Water-based pigmented coating. Not yet available in the U.S.
Eurovia Beton (France)	NOxer® coating process	Coating has been used for highway noise barriers. Not yet available in the U.S.

*Companies will ship their products to the U.S.
** Products are currently available within the U.S.

Two companies with U.S. presences, Essroc and Green Millennium, are the most promising domestic sources of photocatalytic products. Global Engineering, based in Italy, was also easy to contact and has previously shipped products to the U.S. Finally, Elegant Embellishments, a European design firm, deserves special recognition for developing a three-dimensional decorative tile that not only reduces air pollution, but is also aesthetically interesting. These companies, in addition to a few other companies that may be helpful for our international projects, are discussed at greater length below.

Italcementi, the world's fifth largest producer of cement, has opened a branch in Pennsylvania under the name Essroc. This a promising source of photocatalytic pollution-reducing materials for the U.S. market. Their product, TX Active Aria, has both self-cleaning and de-polluting properties. The original formulation of the product, TX Active, was used in several European projects including the Air France headquarters at Charles de Gaulle airport outside Paris, the police headquarters in Bordeaux, and an apartment building in Belgium (Povoledo, 2006). It has also been applied to median barriers and paved surfaced in Italy and France.

In the building industry, Italcementi's primary focus has been precast concrete. Precast provides the quality control necessary to optimize the dosage and distribution of TiO_2 and to achieve the best appearance for the product (Chusid, 2006). To reduce costs, the premium-priced mixture can be applied as a ¾" to 1" cementious layer and backed with conventional concrete (Chusid, 2006). The product cost of TX Active Aria is ($0.60/lb) is about six times the cost of ordinary cement. The manufacturer can also adjust the amount of TiO_2 in the product according to the specific application and to the environmental factors discussed earlier. Paving with pre-cast photocatalytic blocks costs 10 to 20% more than conventional paving (Italcementi product specifications).

The soaring structure of the Jubilee Church in Rome, designed by American architect Richard Meier, is made from precast concrete elements coated with Italcementi's TX Active cement. There is a stark contrast between the brilliant white surfaces of the overall structure and the dirty, gray joints which were not treated with the TiO_2 product. Photo credit Yusheng, Liao. November 2006.

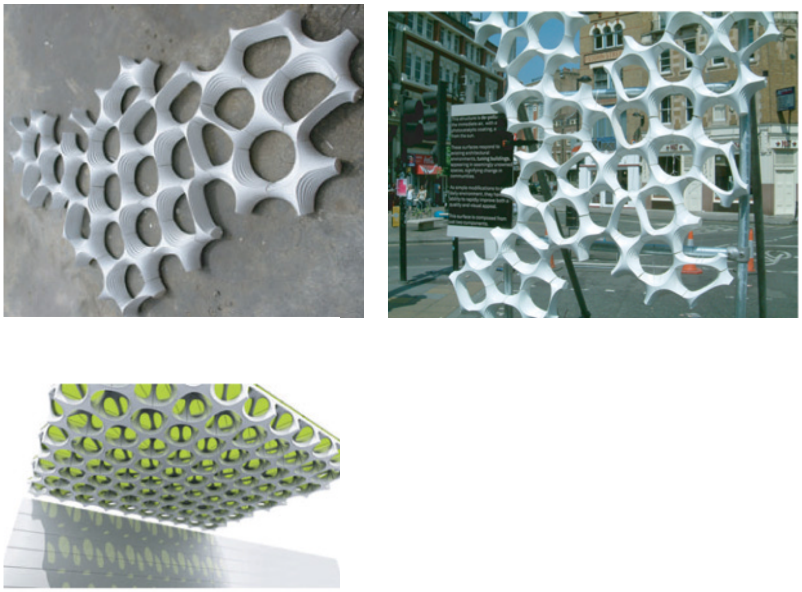
A second company, Green Millennium, produces water-based photocatalytic materials that are currently available in the U.S. Of their numerous photocatalytic coatings, TPX 85 is the best suited for building facades and vertical or horizontal pavement applications. TPX 85 is a transparent solution (99% water, 1% TiO_2) that can be applied as a thin, even coat with an HPLV sprayer to the surface of concrete (Chusid, 2005). The company suggests a 0.5 micron thick layer would be appropriate for a vertical application, and a single application lasts at least ten years. For horizontal surfaces with pedestrian and/or vehicular traffic, a 1.0 micron thick layer may be necessary. Sealed surfaces absorb less of the product than porous surfaces (1 liter / 300-350 ft^2 compared to 1 liter / 200-250 ft^2, respectively). The retail price of TPX 85 is $80 per liter, but the company is willing to negotiate for wholesale and bulk purchases. TPX 85 has been used on concrete surfaces in Japan but has not been formally introduced into the U.S. market.

Global Engineering of Italy is working with Millennium Chemicals of England to produce photocatalytic coating systems (E-coating) and self-locking cement blocks (Ecostar®). Their E-products, Ecorivestimento® and Ecopaint®, can be hardened as paint, plaster, or mortar and applied to vertical and horizontal surfaces. These coatings are applied with a roller, brush, or sprayer and do not alter the appearance of the surface. Ecopaint® is a water-based, clear substance that should be used over a primer. Applications suggested by the company include building facades, interiors, tunnels, and road barriers. The Ecotunnel™ product is specifically designed for coating the inside of tunnels. For interior uses, it is important to remember that photocatalysis requires natural light; it may be necessary to provide supplemental lighting with the appropriate wavelength and intensity.

Ecorivestimento® is a photocatalytic premixed powder that comes in three different forms: a fine plaster, a 2 mm cement coating for paving with light traffic, and Fotofluid®, a fluid-like mortar that can be applied to asphalt and paving with heavy traffic. Ecostar® self-locking paving blocks are available in a wide range of colors and sizes. The company guarantees their trafficable products will last at least three years without losing photocatalytic properties. Global Engineering is based in Europe, but they are willing to ship their product to the U.S. They have done little work in the U.S.; however, as with most of the companies contacted for this study, they were enthusiastic about expanding into the U.S. market.

Elegant Embellishments is a design firm based in London and Berlin that produces three dimensional photocatalytic tiles. These tiles were mentioned earlier for their innovative design which maximizes the surface area of TiO_2 exposed to air pollution and sunlight. The tiles can be assembled into modular, seemingly-random grids which are mounted on bare walls or ceilings, or hung as awnings. Elegant Embellishments hopes this product will become "a recognizable symbol of a safer place to breathe" (Manaugh, 2006).

A representative from the company also offered a glimpse into their future product line, which will include a low-cost, disposable tile as well as "rainscreen" tiles. The low cost tile will have a TiO_2 surface backed with an easily disposable or recyclable material such as certain plastics, packaging, or paper. The firm hopes to introduce this product into developing countries where air pollution problems are extreme and the tiles would have the greatest impact. "Rainscreen" tiles are a more permanent, sculptural tile with a TiO_2 coating that is expected to last 10 to 15 years. These tiles are manufactured from polycarbonates and other plastics. The plastic versions vary in cost depending on the complexity of the design and the difficulties in tooling. Factors influencing price are volume, level of detail, module size, and material; some customers are considering more conventional materials such as concrete and terracotta.



These 3-D photocatalytic tiles by the design firm Elegant Embellishments are installed in an organic, web-like grid. The sculptural design of the tile functions to increase surface area. Elegant Embellishments strives to make a "visually provocative" statement that will become a "recognizable symbol of a safer place to breathe" Manaugh, 2006. Photo credit www.elegantembellishments.net.

Another innovative product, a nitrogen oxide consuming paving block aptly named NOxer®, is readily available in Japan. NOxer® blocks were developed by Mitsubishi Materials Corporation and are manufactured by Marshalls, the largest producer of landscape, building, and drainage materials for the construction industry in the United Kingdom. The block has a one centimeter surface coating containing of a mix of TiO_2, zeolite, sand, and crushed quartz backed by a cement base (Frazer, 2001). Blocks come in a wide range of colors and have been used in sites throughout Japan, but they do not appear to be available in the U.S.

The Mitsubishi Company of Japan created a paving block called NOxer® that removes nitrogen oxides. These multi-color pavers are readily available in Japan and have been used in several large projects, including the one pictured above in Chigasaki City, Japan. Photo credit www.ConcreteDecor.net Aug/Sept 2005.

Table 2. List of brands available in the U.S., product cost (does not include delivery or installation), and coverage of photocatalytic building product.

Brand Name	Cost in US Dollars	Coverage
TX Active Aria (Stucco)	$1.32 per kilogram $28.20 per bag	1 bag covers 1.5 ft^3
TPX 85 solution	$80.00 per liter	1 liter per 200 -250 ft^2 of porous surface. 1 liter per 350 ft^2 of sealed surface.
Ecotunnel® Primer	$17.00 per liter $9.00 per liter	1 liter per 6 m^2 1 liter per 10 m^2
Ecopaint® External Paint Primer	$19.80 per liter $11.33 per liter	1 liter per 6 m^2 1 liter per 10 m^2
Ecopaint® Internal Paint Primer	$10.57 per liter $7.37 per liter	1 liter per 6 m^2 1 liter per 10 m^2
EcoRivestimento® Fine Plaster	$3.97 per kilogram	1.4 kilograms per 1 m^2
EcoRivestimento® 2mm Pavement for Light Traffic	$4.36 per kilogram	3 kilograms per 1 m^2
EcoRivestimento® Fotofluid Pavement for Heavy Traffic	$2.64 per kilogram	6 kilograms per 1 m^2
Elegant Embellishment Disposable Tile "Rainscreen" Tile	 $33.00 – $66.00 per m^2 $330.00 – $529.00 per m^2	
NOXER® pavers	$59.81 per 50 blocks	50 blocks per 1 m^2

CONCLUSION

TiO_2-based products, already well-appreciated for their self-cleaning and antimicrobial properties, also appear to be useful for reducing harmful airborne pollutants. As with all products introduced into the natural and human environment, a cautious approach must be taken. However a growing number of studies and applications have demonstrated a positive impact on our roads and cities, and perhaps on wider-ranging problems such as global warming and acid rain. These benefits make photocatalytic-TiO_2 worthy of attention in the context of Sasaki's approach to sustainable design.

THE PORT OF LOS ANGELES; A CASE STUDY

The Port of Los Angeles (POLA) Wilmington Waterfront Development Program - Buffer is a current Sasaki project that has great potential to showcase TiO_2 in its components. The environmental conditions surrounding the site make it an excellent test bed for this new technology. The project, located adjacent to the community of Wilmington, has been initiated by Mayor Antonio Villaraigosa and is strongly supported by him. This fact, in conjunction with the high-profile nature of the Port, could yield a very visible test application site that could garner interest and support from a manufacturer(s).

The Buffer project site is adjacent to the busiest container shipping port in the nation. In addition to being one of only eleven U.S. ports selected by the Environmental Protection Agency (EPA) to participate in an Environmental Management System, the Port of Los Angeles has adopted serious measures to reduce its environmental impact and increase the efficiency of its operations.

Air pollution is perhaps the biggest environmental concern. In November 2006, the Port joined the South Coast Air Quality Management District, the California Air Resources Board, and the EPA in releasing a five-year comprehensive plan to reduce air pollution by at least 45%. This Clean Air Action Plan proposes hundreds of million of dollars to cut particulate matter, nitrogen oxide emissions, and sulfur oxides by 47, 45, and 52%, respectively (Port of Los Angeles News Release, 2006). The goal is to make the Port the greenest, most environmentally friendly seaport in the world. This sets an ideal stage for promoting new technologies proven to reduce air pollution.

The attention being paid to lowering air pollution is well deserved. The topography of Los Angeles lends itself to temperature inversions which increase smog by reducing atmospheric mixing. The Los Angeles-Long Beach-Riverside region is ranked by the American Lung Association as the worst metropolitan area in the nation with respect to ozone air pollution and both short-term and year-round particle pollution (http://www.lungusa.org). Wilmington is exposed to particularly high levels of pollutants from nearby Port industry and busy streets. The Port's diesel-powered equipment, ships, trucks, and trains significantly contribute to the unhealthy air quality (San Pedro Bay Ports Clean Air Action Plan Fact Sheet, 2006).

One feature of the Buffer project is particularly suitable for a TiO_2 application. The site will have a +/-55,000 square face-foot, stepped, pre-cast concrete retaining system abutting Harry Bridges Boulevard on the south edge of the property. The proposed system will be in close proximity to four lanes of heavy container truck traffic (to be expanded in the future to six lanes) and will have a southwest exposure. As was discussed earlier, high light intensity, high concentration of pollution, minimum wind disturbance, and a large surface area on which TiO_2 has direct contact with air pollutants are all factors that greatly enhance photocatalysis. The southern California climate, with its long hours of sunshine, an average annual temperature of 75 °F, and little rain seems to be an ideal setting for a large-scale application of TiO_2.

Because graffiti is prevalent in this area, the Port expects to periodically repaint the surface of the pre-cast panels. A paint and TiO_2 combination is therefore the appropriate application for this location. There are two options: mixing a TiO_2 product directly into the paint, or painting the panels and then covering the surface with a clear coat of TiO_2.

The first option requires sending the TiO_2 product to a paint manufacturer to test its compatibility with the paint's properties. This test must be competed before the manufacturer can customize the paint, and it must account for several considerations. Paint particles are larger than the TiO_2 nanoparticles and tend to hinder the photocatalytic process. Furthermore TiO_2 breaks down organic ingredients, including pigments, which may discolor the paint.

To avoid this an oil-based paint is preferable. Interestingly, the strong binding properties of TiO_2 will increase the longevity of the paint and its adhesion to the panels. The second option, painting the wall and then applying the TiO_2 product, requires more labor but optimizes the pollution-reducing capacity of the TiO_2. An oil-based paint is again preferable for use as the base coat. Green Millennium's TPX 85 is a good TiO_2 product for either option, and it is readily available in the United States.

CONTACTS

Throughout this research, numerous contacts were made with researchers, consultants, and sales representatives from companies in Japan, Europe, and the United States. They are listed below.

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