Reducing Titanium Dioxide in Paints for a More Sustainable Future

Scientific advancement often begins with foundational questions, such as “Why?” or “How?” For example, Galileo’s astronomical investigations expanded our understanding of the universe, while Marie Curie’s research on radioactivity significantly contributed to both physics and medicine. Studies on DNA structure have furthered knowledge of biological processes. The scientific method encompasses exploring unknowns, formulating hypotheses, conducting experiments, and refining approaches based on outcomes. This process is often shaped by external factors, including regulatory requirements and consumer influence. Regulations can prompt scientists and innovators to reassess established methodologies, pursue alternative solutions, and explore emerging areas of knowledge. These compliance efforts have driven advancements in technologies such as architectural coatings and sustainable materials across various consumer markets.

Scientific curiosity-combined with evolving regulatory requirements and environmental concerns-drives innovation in architectural paints. The market, projected to reach USD 110 billion by 2032 (according to dataintelo.com), is fueled by urbanization, consumer interest in aesthetics, and growth in emerging regions. Key innovation drivers include increased awareness of indoor air quality, efforts to reduce environmental and health impacts, elimination of hazardous chemicals, and the pursuit of sustainability certifications. Stricter guidelines are pushing suppliers and manufacturers to adapt and collaborate, ensuring compliance while overcoming new challenges.

Modern paint makers are working to reduce or remove chemical groups such as per-and polyfluoroalkyl substances (PFAS), volatile organic compounds (VOCs), and biocides from their formulations. Titanium dioxide (TiO_2) has faced scrutiny for its potential health inhalation concerns and environmental footprint, particularly due to energy-intensive mining that contributes to pollution and habitat loss. In 2020, European Chemicals Agency (ECHA) classified the powder form of TiO_2 as a suspected carcinogen by inhalation; however, the European Court of Justice recently annulled this classification[1]. Regulatory bodies have set exposure limits for TiO_2. While it is safer in liquid paints, spraying or sanding can still release harmful particles, and skin or eye contact may cause irritation. Proper ventilation, respiratory protection, and thorough cleanup help minimize risks. Sustainability efforts now focus on both the climate impact and health concerns associated with TiO_2[2,3,4].

TiO_2 is prized in architectural coatings for its exceptional light-scattering ability properties, granting impressive opacity and coverage with fewer coats. In 2023, the global TiO_2 market reached approximately 6.6 million metric tons[5], with the paint industry accounting for 55% of worldwide TiO_2 consumption[6]—a testament to its pivotal role in achieving high-performance finishes. TiO_2 bolsters UV resistance, color stability, durability, and overall weatherability, while also enabling smooth, glossy surfaces and, in some cases, self-cleaning properties through photocatalytic mechanisms[7]. Despite these advantages, TiO_2 has limitations. At high concentrations, or due to pigment flocculation, overlapping light-scattering domains can reduce its efficiency and ability to effectively mask surfaces.

Dow has pioneered advancements in hiding technologies since the 1950s, beginning with the introduction of TAMOL™ Dispersants to enhance pigment dispersion stability. Continued innovation throughout the 1980s and beyond led to the creation of **ROPAQUE™ Opaque Polymer** - a polymeric pigment capable of efficiently scattering light in a manner like TiO_2-enabling formulators to substitute up to 5% of TiO_2 without sacrificing hiding effectiveness. Dow’s latest development in TiO_2 technology emerged in the 2000s with **EVOQUE™ Pre-Composite Polymer**, which utilizes latex particle stabilization of titanium dioxide particles to optimize pigment spacing for maximum TiO_2 light scattering efficiency. This enables a reduction of TiO_2 content by up to 20%. All of Dow’s hiding enhancement tools work seamlessly to deliver an optimized coating performance. For example, if a paint contains 2.5 lb/gallon of TiO_2, incorporating **ROPAQUE™ Opaque Polymer** and **EVOQUE™ Pre-composite Polymer** can reduce TiO_2 content by 15–25%, which equals a reduction of approximately 0.38–0.63 lb/gallon.

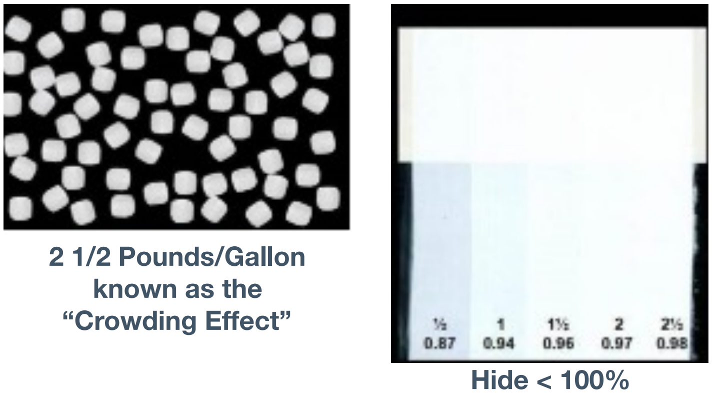

Figure 1. Illustrations showing the diminished hiding when TiO_2 particles become overcrowded.

Dow's **ROPAQUE™ Opaque Polymer** and **EVOQUE™ Pre-Composite Polymer** are technologies designed for pigment applications in architectural paints. Paints optimized with pigment spacing technology and the use synthetic hollow-sphere opacifiers, will enable effective hiding power with reduced TiO_2 content of up to 25% in a formulation. This adjustment maintains paint quality and reduces the environmental impact associated with TiO_2 production. For each share point of TiO_2 replaced globally, about 186,000 metric tons of CO_2 emissions can be lowered[8].

A cradle-to-grave life cycle analysis (LCA) demonstrated that using TiO_2-efficient binders and opacifying additives in flat to semigloss paints can reduce greenhouse gas emissions by up to 12%*, without compromising performance or significantly increasing other environmental impacts. The LCA measured the amount of paint needed for one square meter over a 60-year building lifespan. These innovations illustrate how regulatory, and sustainability goals drive technical improvements and help lower environmental impact.

Opaque Polymer Technology

TiO_2 positively influences paint quality but negatively impacts formulation cost and user health and safety due to potential inhalation concerns. In practice, increasing TiO_2 content yields diminishing returns; its contribution to opacity eventually reaches a limit. As illustrated in Figure 3, the film's scattering coefficient plateaus with increasing TiO_2 levels because particle crowding leads to overlapping light-scattering spheres, reducing incremental light-scattering efficiency.

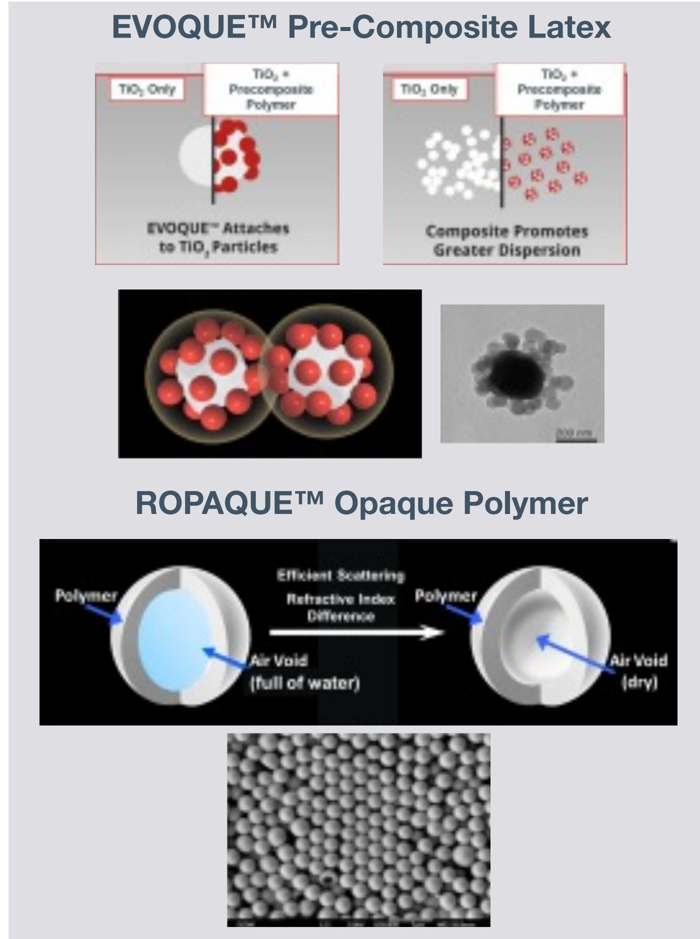

Figure 2. Two hiding technologies that reduce the use level of titanium dioxide in paint.

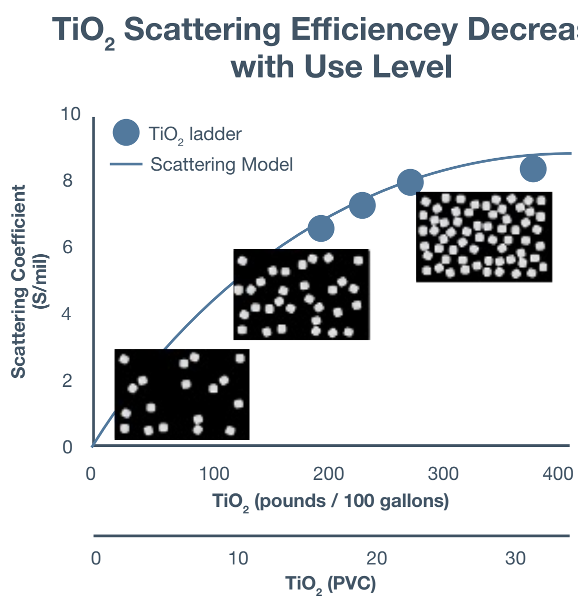

Figure 3. Titanium dioxide light scattering efficiency decreases with increased use level.

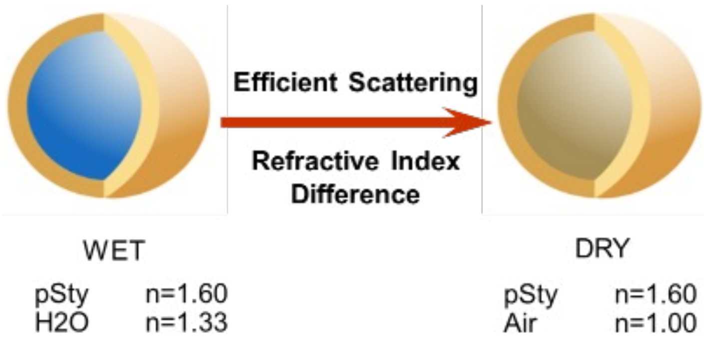

Figure 4. A cartoon image of a ROPQUE™ Opaque Polymer particle with and without water, before and after drying. The difference in the refractive index between the styrene shell and air void provides efficient light scattering.

ROPAQUE™ Opaque Polymer is a synthetic hollow-sphere pigment that scatters light, allowing up to 5% replacement of TiO_2 in formulations. Composed of a styrene shell and a water-filled center, the polymer drains water as coatings dry, leaving a hollow core that reflects light efficiently without crowding (see Figure 4).

The styrene shell maintains air voids in the opaque polymer (OP), ensuring consistent opacity even at higher concentrations. This enables paint formulators to substitute TiO_2 with OP without loss of dried opacity. ROPAQUE™ Opaque Polymer is recommended when TiO_2 exceeds 1.5 pounds per gallon. Using OP instead of TiO_2 reduces particle crowding and preserves coating opacity, with a replacement guideline of 1:3% PVC for formulations containing more than 1.5 lb/gallon of TiO_2.

Dow continues to advance ROPAQUE™ Opaque Polymer chemistry. Figure 5 illustrates this progress, highlighting upcoming developments aimed at further reducing TiO_2 use and enhanced paint safety.

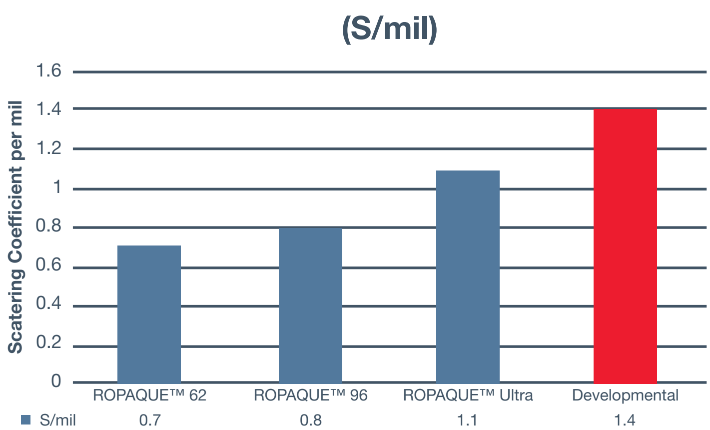

Figure 5. ROPAQUE™ Opaque Polymer evolution and the incremental S/mil increase with each iteration. The numbers above each bar in the graph is the year of development.

EVOQUE™ Pre-Composite Polymer

Dow's EVOQUE™ Pre-Composite Polymer Technology improves the efficiency of TiO_2 in architectural coatings. As mentioned above, TiO_2 creates opacity through its high refractive index, but its cost, crowding, and environmental concerns require better efficiency.

EVOQUE™ Pre-Composite Polymer enhances TiO_2 performance by facilitating the formation of polymer-pigment composites that improve dispersion efficiency. In traditional formulations, TiO_2 particles often agglomerate, resulting in overlapping scattering domains and reduced optical effectiveness. EVOQUE™ Polymers associate with the TiO_2 surface to form a structured composite, optimizing inter-particle spacing, reducing crowding, and ensuring uniform distribution across the film matrix. Figure 6 shows the enhanced TiO_2 distribution within paint film with EVOQUE™ Pre-Composite Polymer compared to conventional paint, as observed via SEM.

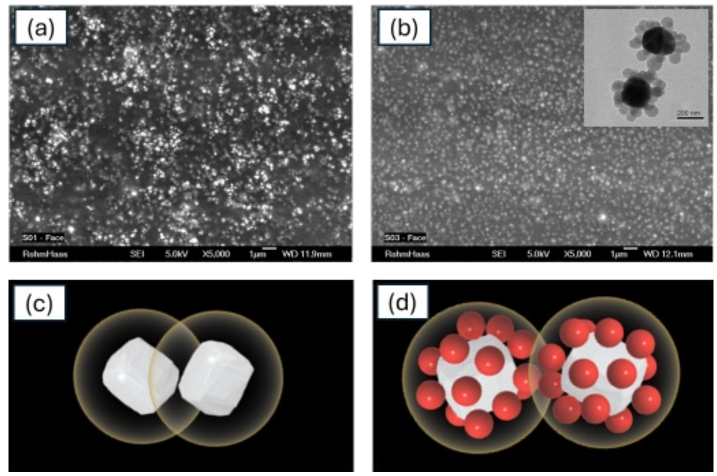

Figure 6. SEM image of (a) regular paint (b) paint with EVOQUE™ Pre-Composite Polymer. Inset in (b) shows TEM image of a TiO_2 composite with EVOQUE™ Polymer. Corresponding schematic of TiO_2 in (c) regular paint and (d) paint with EVOQUE™ Pre-Composite Polymer.

This spatial refinement increases the effective scattering cross-section of individual TiO_2 particles, significantly improving light-scattering efficiency. As a result, formulators can achieve superior hiding power at equivalent TiO_2 loadings or reduce TiO_2 content by up to 20% without compromising opacity or overall film integrity. Figure 7 presents the elevated scattering coefficient per unit thickness for an EVOQUE™ Binder compared to a standard acrylic binder.

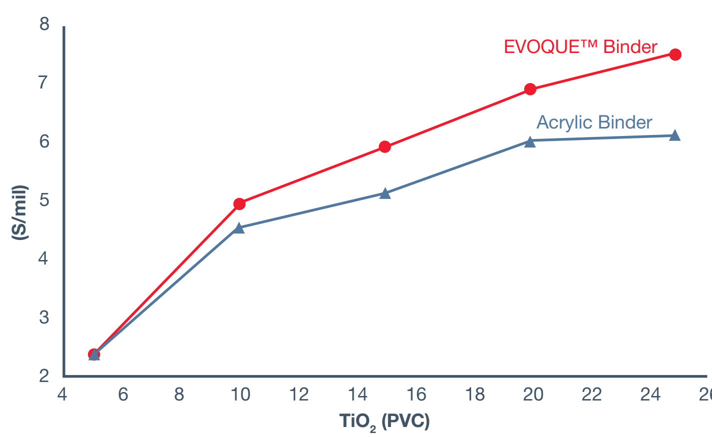

Figure 7. Scattering coefficient per mil as a function of TiO_2 PVC for a standard acrylic binder and EVOQUE™ Binder.

EVOQUE™ Binder enhances both interior and exterior paints by improving pigment distribution, which strengthens film structure and boosts stain resistance, cleanability, tannin blocking, corrosion resistance, and durability (Figure 8 and 9). Successive EVOQUE™ generations of binders have continually improved these attributes across various coatings.

The architectural paint industry is at a pivotal moment where sustainability and innovation must go hand in hand. Innovations such as **ROPAQUE™ Opaque Polymer** and **EVOQUE™ Pre-Composite Polymer** have revolutionized TiO_2 optimization, offering significant environmental benefits without compromising performance. A cradle-to-grave life cycle assessment (LCA) study found that in high-quality flat to semigloss paints, TiO_2-efficient binders combined with opacifying polymeric additives can reduce greenhouse gas emissions by up to 12%*, without sacrificing performance or significantly increasing other environmental impact categories. This finding underscores the potential for innovative materials to drive the industry towards a more sustainable future-balancing environmental responsibility with the high standards of quality and durability that consumers expect. As we move forward, continued research and collaboration will be essential in achieving these goals and ensuring a greener, more sustainable world.

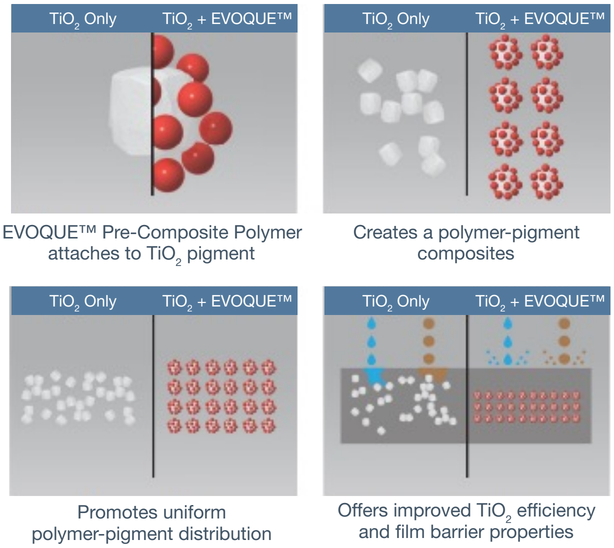

Figure 8. Overview schematic of EVOQUE™ Pre-Composite Polymer Technology and film structure.

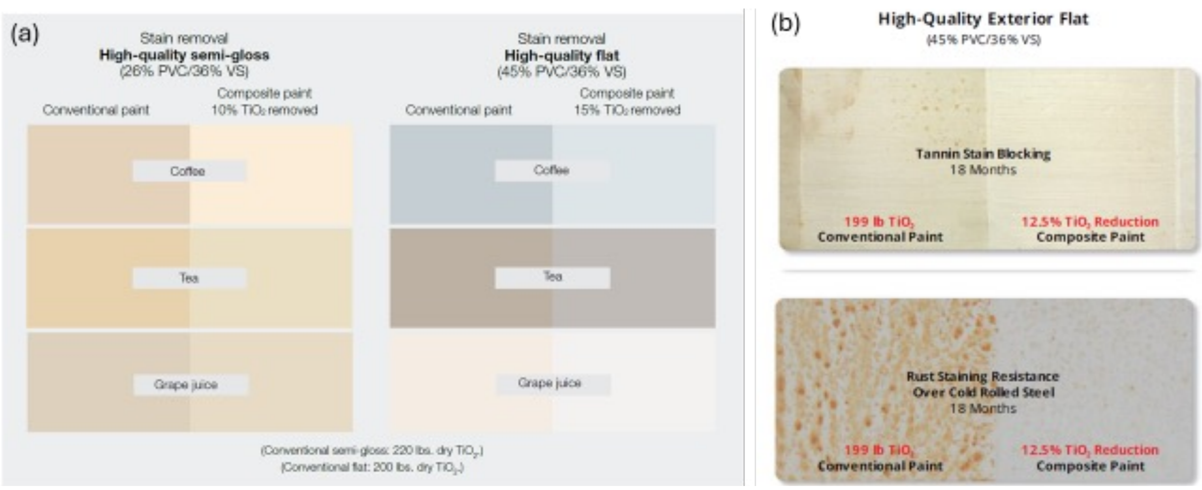

Figure 9. (a) Household stain removal of conventional vs composite interior paints and (b) Exterior durability of conventional vs composite paints.

*This information is formulation dependent and came from a Dow internal lifecycle assessment and has not been critically reviewed externally and as such is subject to revisions.

1.ECHA website: https://echa.europa.eu/-/new-guide-available-on-classifying-and-labelling-titanium-dioxide

2. Savastano, D. (2025). EU's Titanium Dioxide Ruling Sparks Concern. Coatings World. Retrieved September 9, 2025, from https://www.coatingsworld.com

3. National Institute for Occupational Safety and Health (NIOSH). (2011). Current Intelligence Bulletin 63: Occupational Exposure to Titanium Dioxide (DHHS Publication No. 2011-160). Centers for Disease Control and Prevention. Retrieved from https://www.cdc.gov/niosh/docs/2011-160/

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7. Mohamadpour, F., & Amani, A. M. (2024). Insights into TiO_2-based photocatalytic systems. Catalysts, 9(8), 680. https://www.mdpi.com/2073-4344/9/8/680

8. Based on Dow estimates for PCF for titanium dioxide from TDMA.

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