Evaluation of Titanium Dioxide as a Catalyst for Removing Air Pollutants

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The Issue

Titanium dioxide (TiO$_2$) photocatalysis is a promising method for removing smog precursors from air. When TiO$_2$ nanoparticles are stimulated by sunlight, they convert air pollutants such as nitrogen oxides (NO$_x$), volatile organic compounds (VOCs), carbon monoxide (CO), and ozone to more environmentally acceptable products such as calcium nitrate and carbon dioxide. TiO$_2$ photocatalysis can be driven by both the ultraviolet and visible components of sunlight, which comprise nearly 50% of ground-level insolation.

![Diagram](image)

Figure 1. Nitrous oxide (NO$_X$) and sulfur oxide (SO$_X$) pollutants adhere to the TiO$_2$ paint coating whether light is available or not. Sunlight then instigates a series of chemical reactions (see Figure 2) that convert the harmful pollutants to carbon dioxide and water vapor. The TiO$_2$ photocatalyst is regenerated by rainfall. (Figure courtesy of Koji Takeuchi, Institute for Environmental Management Technology, Japan.)

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Although carbon dioxide (CO$_2$) is a greenhouse gas, it is nontoxic, and as such represents a net air quality improvement over the precursor pollutants. Moreover, the CO$_2$ production is anticipated to be minimal and would be offset (to an unknown degree) by lower CO$_2$ emissions from power plants due to the reduced cooling load from buildings painted with the highly reflective TiO$_2$ coating.
Researchers have shown that it is technically feasible to coat glass, tiles, and other building materials with a transparent thin film of TiO$_2$ photocatalyst.\textsuperscript{2,3} Hence, TiO$_2$ wall and roof coatings could be used to remove outdoor air pollutants. (As an interesting side benefit, windows coated with a thin, transparent layer of TiO$_2$ can self-clean.)

**Project Description**

This project—funded by PIER’s Environmental Exploratory Grants Program—brought together leading international researchers to evaluate the potential for TiO$_2$ coatings to remove pollutants from urban air. Researchers from Lawrence Berkeley National Laboratory collaborated with the South Coast Air Quality Management District, the California Air Resources Board, and academic and industrial researchers to estimate the efficacy of TiO$_2$ photocatalysis in removing NO$_x$ and VOCs. The project reviewed the laboratory methods and metrics used to measure removal of smog precursors (NO$_x$ and VOCs) and carbon monoxide, and evaluated approaches to extend these methods and metrics to community and regional scales. The project team also worked with the coating industry to assess the commercial readiness of TiO$_2$ photocatalytic coatings. Findings were shared at a workshop with leading researchers and air quality agencies.

![Figure 2. Outline of the pollutant-removal chemical reactions for a TiO$_2$ coating. (Courtesy of Hogan, New Scientist, February 4, 2004, http://www.newscientist.com/article.ns?id=dn4636.)](image-url)


PIER Program Objectives and Anticipated Benefits for California

This project offers numerous benefits and meets the following PIER program objectives:

- **Resolve environmental effects of energy production.** As a result of this work, it is clear that further research and analysis is required for widespread implementation of photocatalytic oxidation technology for cleaning outdoor air in California. With further innovation and development, TiO$_2$ nanoparticles or other photocatalytic coatings may prove a cost-effective means of reducing NO$_X$ and VOCs (compare to SCAQMD’s 2003 plan that cost $2,000–$10,000 per tonne of NO$_X$ removed).

- **Provide affordable energy.** Many TiO$_2$-based coatings have high solar reflectance and can reduce electricity use for summertime cooling by keeping the building roofs and walls cool. Measured data have documented net annual energy savings (summertime cooling savings minus wintertime heating penalty) of 10%–20%.\(^4\),\(^5\),\(^6\) A 10% reduction in annual cooling energy use would save about $50 per household each year, for an annual savings to California of about $50 million.\(^7\)

Results

Following an extensive literature review, the LBNL project team hosted a day-long workshop on Passive Photocatalytic Oxidation of Air Pollution, at which participants discussed the technical state of the art in this field. The efficacy of photocatalytic materials was summarized and tabulated in terms of catalytic activity. Each square meter of high-performance photocatalytic material, exposed to outdoor sunlight, can remove nitrogen oxides from about 200 cubic meters of air per day. The removal rate for volatile organic species is about 60 cubic meters of air per day, while the removal rate for carbon monoxide is negligible. These numbers are rough estimates, but are based on careful quantitative investigations published in references cited by the final report.

Photocatalytic reduction of air pollution using TiO$_2$ nanoparticles is thus technically feasible; however, accomplishing this goal in a cost-effective way will be challenging due to the large volumes of air that must be processed. Apart from cost, choice of the best catalyst from a number of candidates will also depend on which chemical reactions (i.e., which pollutants) are considered most important.

This study makes it clear that further R&D is needed to improve the catalytic activity of available materials and to create novel, more effective catalysts. Before field testing, improved meteorological simulations of smog formation, transport, and destruction will be needed to

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determine how to best deploy and use photocatalytic oxidation technology. In addition, further study is needed to ensure there are no unintended environmental consequences from the use of these catalysts, such as runoff of any undesirable reaction products into the water system.

**Final Report**

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