White Paper

NASA's Potential Contributions for Using Solar Ultraviolet Radiation in Conjunction with Photocatalysis for Urban Air Pollution Mitigation

Robert E. Ryan and Lauren W. Underwood
Science Systems and Applications, Inc., John C. Stennis Space Center

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Abstract

More than 75 percent of the U.S. population lives in urban communities where people are exposed to levels of smog or pollution that exceed the EPA (U.S. Environmental Protection Agency) safety standards. Urban air quality presents a unique problem because of a number of complex variables, including traffic congestion, energy production, and energy consumption activities, all of which can contribute to and affect air pollution and air quality in this environment.

In environmental engineering, photocatalysis is an area of research whose potential for environmental clean-up is rapidly developing popularity and success. Photocatalysis, a natural chemical process, is the acceleration of a photoreaction in the presence of a catalyst. Photocatalytic agents are activated when exposed to near UV (ultraviolet) light (320–400 nm) and water. In recent years, surfaces coated with photocatalytic materials have been extensively studied because pollutants on these surfaces will degrade when the surfaces are exposed to near UV light. Building materials, such as tiles, cement, glass, and aluminum sidings, can be coated with a thin film of a photocatalyst. These coated materials can then break down organic molecules, like air pollutants and smog precursors, into environmentally friendly compounds. These surfaces also exhibit a high affinity for water when exposed to UV light. Therefore, not only are the pollutants decomposed, but this superhydrophilic nature makes the surface self-cleaning, which helps to further increase the degradation rate by allowing rain and/or water to wash byproducts away.

According to the Clean Air Act, each individual state is responsible for implementing prevention and regulatory programs to control air pollution. To operate an air quality program, states must adopt and/or develop a plan and obtain approval from the EPA. Federal approval provides a means for the EPA to maintain consistency among different state programs and ensures that they comply with the requirements of the Clean Air Act.

Currently, the EPA is working with DOE's (Department of Energy) LBNL (Lawrence Berkeley National Laboratory) to estimate the efficacy of titanium dioxide photocatalysis for removing air pollutants on community and regional scales. This research is being conducted under a Public Interest Energy Research Program Energy-Related Environmental Research grant titled *Evaluation of Titanium Dioxide as a Catalyst for Removing Air Pollutants* (PIER, 2006). The goal of this project is to establish the research, development, and implementation of a statewide program in California that uses surfaces coated with photocatalytic materials as a method for air pollution removal. This project is primarily exploratory; they

are surveying the current research that exists, and they are looking at the potential of photocatalytic materials so that the potential they hold for futures areas of research is understood.

By partnering with NASA, the EPA, in conjunction with LBNL, could incorporate Earth science research on atmospheric ozone and aerosols into a testbed project that looks at understanding and evaluating UV radiation effects on titanium dioxide (TiO_2) surfaces for air purification applications. NASA data could be integrated as a means to predict and evaluate the effectiveness of photocatalytically coated surfaces for solar UV radiation pollution mitigation purposes.

1.0 Project Purpose/Scope

This project proposes examining the use of NASA-derived atmospheric aerosol and ozone data to monitor UV dosage levels on the Earth's surface and evaluates whether this information would enhance the ability of decision makers to predict the efficiency of photocatalytically coated surfaces as a method for removing pollutants from urban air.

Within the framework of this project, the functional strategy is to look at novel methods for remediating environmental air pollution through the use of building construction materials made with photocatalytic materials, such as TiO_2. NASA UV irradiance data is then used to estimate the photocatalytic activity of these materials, which is important because the amount of UV can drive the photocatalysis process.

In recent years, researchers have expanded the applications of photocatalysis, and it has become more attractive for use because it is a non-invasive, non-toxic, and cost-effective method to address a wide variety of technologies related to purification and degradation processes (Choi, 2006; Cassar, 2004). Researchers have shown that building materials, such as glass, tile, and cement, can be coated with heterogeneous photocatalytic materials, such as TiO_2 (Bonafous, 2006). Once coated, these sidings, roofs, or roads could remove outdoor air pollutants, such as nitrogen oxides, volatile organic compounds, carbon monoxide, and ozone. These pollutants are converted into non-toxic compounds, such as carbon dioxide and water vapor. Large-scale deployment of these materials (e.g., by coating roadway systems) is being considered for air pollution mitigation (Wang, 2002) and has already been used on several building structures in Italy (Giussani, 2006; Povoledo, 2006).

The Clean Air Act, established by Congress in 1972 and amended in 1990 (EPA, 2007), is intended to protect the quality of our Nation's air. Congress also directed the EPA to develop the NAAQS (National Ambient Air Quality Standards) to regulate pollutants considered harmful to public health and the environment. Even though these pollutants have been regulated since the Clean Air Act was passed, many urban areas still have air pollution levels that exceed the NAAQS levels.

To resolve this situation, alternative measures to abate persistent air pollution problems that exist in urban environments need to be explored. Such measures include examining cost-effective approaches to evaluate and address the environmental effects of energy production, use, and emissions as sources of pollution. For decades, human-induced air pollution (in particular smog) has been strongly associated with California. LBNL, the EPA, and the State of California are exploring the use of technical innovations that involve photocatalytic degradation of organic air pollutants. Working together, these groups are looking at creating and using construction materials that innately destroy pollutants in the air and that prevent build-up of pollutants on surfaces; such materials also keep the building clean and help to preserve the structure's appearance over time (PIER, 2006). Preliminary testing among other groups using photocatalytic coatings on surfaces in urban settings have shown that some pollutants can be reduced anywhere from 20–70 percent (TXActive®, 2007).

The EPA works with state and local government to identify requirements and to develop appropriate measures to ensure that air pollution programs meet requirements of the Clean Air Act. As mentioned above, the EPA is currently collaborating with LBNL to examine the use of photocatalysts in construction materials as an innovative way to minimize pollution in an urban environment. California is one of the world's largest economies and is the tenth largest energy consumer in the world (PIER, 2006). This process of generating and distributing energy has had detrimental impacts on air quality in California. As a result, smog, which is a combination of nitrogen oxides and hydrocarbons, has become one of California's biggest air quality problems.

Researchers at LBNL conduct the type of science that enables public policy-makers to make informed decisions about the most effective ways of reducing hazardous air pollutants. In 2005, the DOE LBNL was awarded a grant through the Environmental Exploratory Grant Program, which funds research on the relationship between energy use and air quality and on the health benefits of removing pollutants from urban air (PIER, 2006). The goal of this funded grant is to find new solutions to pollution problems that are not being resolved by emission reduction alone. This project incorporates multiple partners and researchers working together to evaluate the potential of photocatalytically coated building materials, such as walls and roofs, to remove pollutants from urban air. The findings will ultimately be shared with leading researchers and air quality agencies across the state, and future results could involve the establishment of statewide and/or nationwide programs for the research, development, and implementation of urban photocatalysis for urban air pollution control.

By partnering with NASA, historical and real-time UV data could be incorporated into LBNL's urban pollution mitigation project; this data would enhance the ability to assess the photocatalytic potential activity of these surfaces so that additional useful support could be provided to state and local decision makers. Further research on the UV photocatalytic degradation of building materials, as well as UV dosage in an urban canyon, are not fully understood and would require further investigation.

2.0 NASA Earth-Science Research

Heritage data from the TOMS (Total Ozone Mapping Spectrometer) sensor on the Nimbus 7, Meteor 3, and Earth Probe Mission satellites, all specializing in ozone retrieval, could be used to develop long-term UV irradiance averages. This sensor, in conjunction with radiative transfer models, predicts daily global coverage of UV exposure that would result in skin irritation (erythmal response), total column ozone, aerosol index, and reflectivity (GSFC, 2006). The latest TOMS sensor is currently out of commission. Ozone and aerosol data is currently being provided by the OMI (Ozone Monitoring Instrument) sensor on the Aura satellite that was launched in July 2004 into a near-polar, sun-synchronous orbit with a period of approximately 100 minutes. Aura repeats its ground track every 16 days to provide atmospheric measurements over virtually every point on the Earth in a repeatable pattern, permitting assessment of atmospheric phenomena changes in the same geographic locations throughout the life of the mission. The mission is designed for a 6-year lifetime. OMI observes Earth's backscatter solar radiation in the visible and UV with a wide-field telescope feeding two hyperspectral imaging systems. This sensor will add to the TOMS record of total ozone and other atmospheric parameters related to ozone chemistry and climate.

3.0 NASA Earth-Science Models

NASA-funded radiative transfer codes, such as the as the OMI Surface UV algorithm (Stammes, 2002), are used to estimate UV irradiance on the ground (Tanskanen et al., 2006a; 2006b) from satellite observations. These algorithms are relatively accurate for unobstructed surfaces. To predict the UV dosage within an urban environment and in urban canyons in particular, these NASA Earth science results will have to be integrated into the Monte Carlo or another ray trace radiative transfer approach to propagate the unobstructed radiation field to the Earth's surface.

4.0 NASA Proposed Configuration's Measurements and Models

NASA historical and current UV, ozone, and aerosols datasets, along with radiative transfer models and additional biological activity functions, could be integrated into the assessment of the overall effectiveness of photocatalytic degradation on biological and chemical compounds. This integration would include the use of UV maps that would have activity response information pertaining to photocatalytic materials such as TiO_2; this information would be used to help understand and assess UV effects on photocatalytic activity.

By partnering with the EPA and with the DOE's LBNL, NASA could provide historic and real-time UV data to help assess and evaluate whether these photocatalytically coated surfaces significantly reduce pollutants in urban environments, both at local and regional scales.

Further research is necessary, such as studying the interaction between TiO_2 and assorted building materials as well understanding the effects of varying UV dosing. Urban canyon radiative transfer analysis will need to be incorporated. Additionally, time-dependent measurements require consideration, and large-scale/canyon effects warrant evaluation.

5.0 Societal Benefits

Using NASA UV data to assist research on photocatalytic coatings would benefit the air quality programs nationwide. By partnering with the EPA and the DOE LBNL, NASA could help facilitate research and implement a process that would enable the photocatalytic removal of urban air pollution to improve air quality. This approach could shift the fundamental basis of new building construction on a nationwide level. A test application designed as a proof of concept experiment would help determine whether photocatalytically coated surfaces could be assessed for efficiency and effectiveness if additional UV data were considered during evaluation of this photocatalytic process.

6.0 References

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