TiO$_2$: A Key Ingredient to a Long-Lasting Reflective Roof

By Brian J. Whelan and Ramen Chiu

Cool roofs: Although some believe them to be a relatively new phenomenon, the truth is, they have been around for a long time—decades for sure, and perhaps for centuries. In many warm-weather countries such as Greece, Spain, and Bermuda, folks have long been painting their roofs white and have understood the benefits of reflecting the sun's energy back into the atmosphere rather than heating the house or building.

In the United States, cool roofs started to surface in the mid-1970s with polyvinyl chloride (PVC) single-ply roof membranes and, later in the late 1990s, with thermoplastic olefin (TPO) roof membranes. According to industry statistics, PVC and TPO roofing reflective membranes have become the fastest-growing segment of the commercial roofing market. It is estimated that thermoplastic membranes have increased in square footage sold by 136% from 2001 to 2012. Dark-colored membranes such as ethylene propylene diene monomer (EPDM), modified bitumen, and built-up roofing (BUR) have lost an estimated 30% in square footage sold in the same time frame. White EPDM and more-reflective modified-bitumen roofing membranes are also being promoted as energy-saving cool roofs.

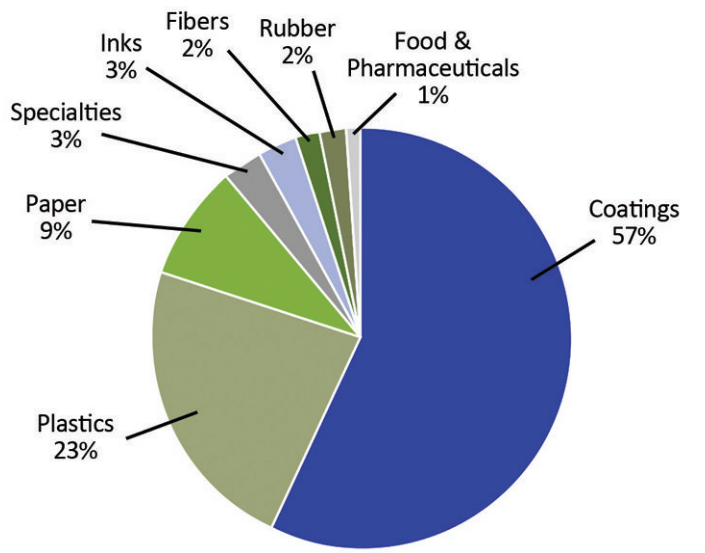

Figure 1 – 5.2 million metric tons of TiO$_2$ were consumed by diverse markets in 2013.

Another area of growth in reflective roofing is roof coatings. Although roof coatings have been around for decades, their formulations are evolving and their usage increasing. The early 1970s saw the introduction of the first acrylic-based white elastomeric roof coatings in the United Kingdom. The acrylic technology provided a durable, flexible film that typically was pigmented with titanium dioxide (TiO$_2$) to provide a reflective, "cool" surface. It is estimated that the use of reflective roof coatings that use TiO$_2$ has grown 8-10% annually in the last ten years (*Figures 1* and *2*).

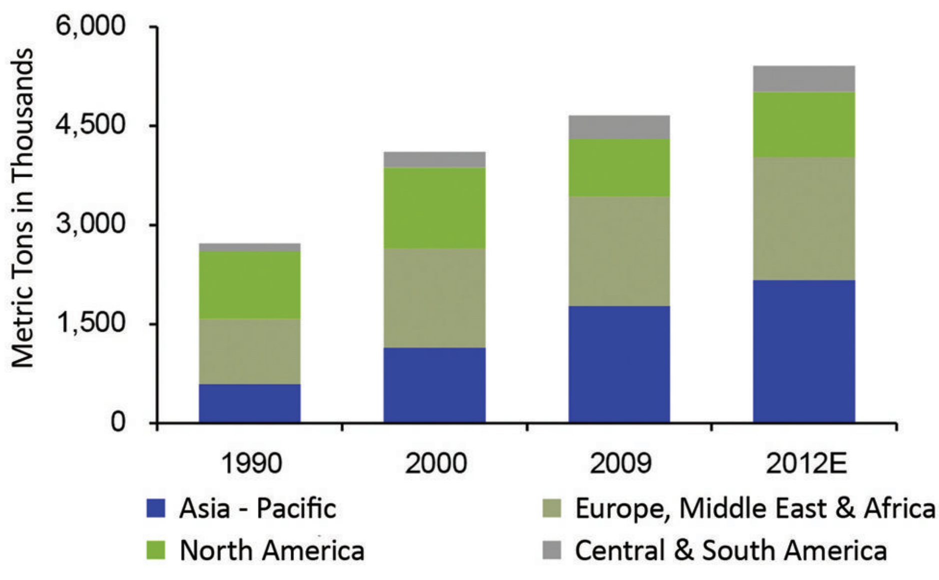

Figure 2 – Global demand for roof coatings with TiO$_2$.

TiO$_2$ is a white pigment used in a variety of applications to impart opacity, whiteness, brightness, and UV durability. TiO$_2$—its unique crystal structure, atom configuration, high refractive index, density, and very efficient scat-

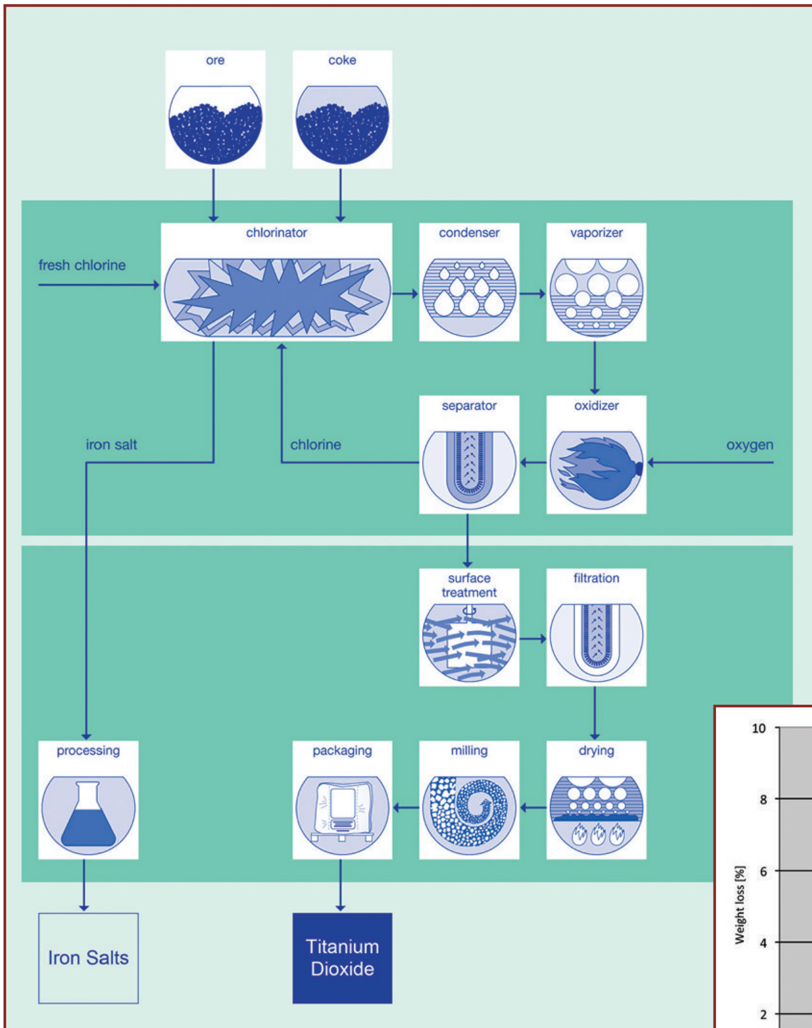

Figure 3 – Flowchart of chloride process in titanium dioxide production.

tering power—allows the material to have superior optical properties. Due to the high reflective index of TiO_2, there are few if any comparable substitutes for the majority of end-use markets. TiO_2 uniquely reflects the infrared portion of the solar spectrum, maximizing solar reflectivity.

There are two commercial processes in the manufacture of TiO_2: the sulfate process and the more modern chloride process (see *Figure 3*). In the sulfate process, extracted titanium ore or slag is fed into the feedstock digestion tank, then goes through hydrolysis, followed by calcination, along with postmanufacture treatment. In the chloride process, the slag feedstock will undergo a chlorination reaction. The raw, intermediate titanium tetrachloride ($TiCl_4$) is to be purified prior to an oxidation to the final product. The chloride process is a cleaner and environmentally preferable route, as fewer wastes are generated in the process.

Virtually all reflective (TPO and PVC) roof membranes and roof coatings made in North America use TiO_2 produced using the chloride process. TiO_2 is also used to make the top surface of EPDM white and, in many cases, to make modified bitumen more reflective.

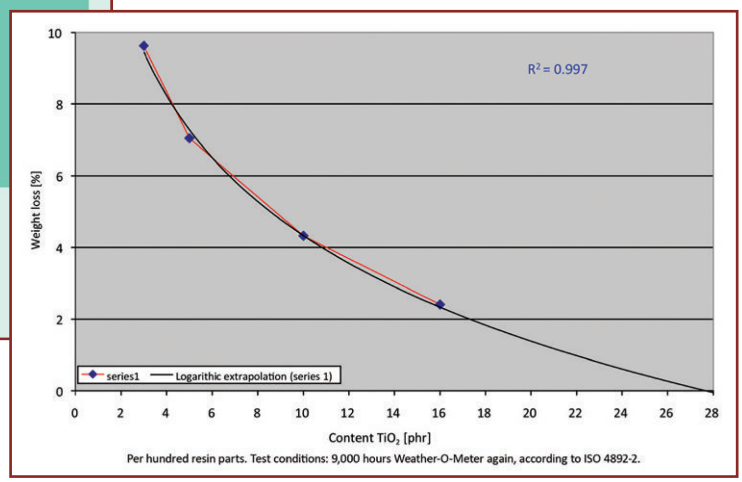

Figure 4 – Weight loss vs. TiO_2 levels.

Besides making things white, TiO_2 provides a significant weathering benefit for long-term applications such as single-ply roof membranes. In basic terms, the more TiO_2 a product has in it, the better it will weather. Laboratory testing indicates that the more TiO_2 there is in the exposed top surface of the membrane, the less weight loss occurs in the membrane (see *Figure 4*). As TiO_2 content increases, the effectiveness of protection from radiation increases, and the loss/degradation of binder/resin caused by radiation decreases.

One of the best ways to improve the weathering of a PVC or TPO membrane is to increase the loading of TiO_2 in the top surface.

TiO_2's inherent characteristics, such as high brightness, opacity, neutral and blue undertone, solar reflectivity, chalk resistance, weather durability, lightfastness, gloss, and mechanical property retentions can be built into the manufacturing process. Other surface characteristics, such as compatibility to roofing substrate, optimized dispersion, and ease of processing must be further engineered to meet the final requirements of roofing membranes.

Much has been written about the benefits of cool roofing. A study conducted by Akbari and Levinson of the Heat Island Group of Lawrence Berkeley National Laboratory (LBNL) confirmed that a cool roof lessens the flow of heat from the roof into the building, reducing electricity demand for space cooling in conditioned buildings. According to the authors of the study, substituting a weathered cool roof (solar reflectance of 0.55) for a conventional darker-colored roof (solar reflectance of 0.20) could have a far-reaching energy saving impact per square meter of roof area, annually, averaged across the U.S. (see *Table 1*).

LBNL estimated that retrofitting 80% of the 2.58 billion m^2 of conditioned commercial buildings in the U.S. would yield annual energy cost savings of $735 million. It would also offer an annual carbon dioxide (CO_2) reduction of 6.23 million tons (offsetting the annual CO_2 emissions of 1.2 million typical cars), an annual nitrogen oxides (NO_x) reduction of 9.93 kt (offsetting the annual NO_x emissions of 0.57 million cars), an annual sulphur oxides (SO_x) reduction of 25.6 kt (offsetting the annual SO_x emissions of 815 peak power plants), and an annual mercury (Hg) reduction of 126 kg.

Beyond energy savings, cool roofs contribute to the reduction of the urban heat island effect, a source of smog and other environmental burdens.

Cooling energy savings (kWh/m^2)	Heating energy penalty ($therm/m^2$)	Energy cost savings ($\$/m^2$)	CO_2 reduction (kg/m^2)	NO_x reduction (g/m^2)	So_x reduction (g/m^2)	Hg (mercury) reduction ($\mu g/m^2$)
5.02	0.065	0.356	3.02	4.81	12.4	61.2

Table 1

Despite the exceptional track record of some cool-roof technology over decades, certain individuals and some companies within the low-slope roofing industry have recently attempted to cast doubts on the fundamental science behind cool roofs and the energy impact of cool roofs in northern climates. The energy benefits of reflective roofing in southern climates have come to be broadly accepted and recognized. If one accepts that cool roofs provide energy saving benefits in cooling-dominated climates, the intuitive corollary is that reflective roof surfaces are disadvantageous in heating-dominated climates. One might assume that black, minimally reflective surfaces will absorb the sun's energy in the winter, presumably reducing heating energy loads.

The answer is not quite as simple as it might first appear. Winter days are shorter than summer days, with more overcast skies. Most importantly, the sun is much closer to the horizon in the winter and generates much less heat in the northern states. Winter solar irradiance is typically 20% to 35% of the summertime irradiance for a given location; therefore, a roof surface receives three to five times more sun in the summer than in the winter in northern states. Additionally, in many northern states, roofs will be covered by a highly reflective blanket of snow for extended periods of time, further reducing the impact of a darker-colored roof surface on heating energy.

We believe that a roof should not be selected or rejected based on color alone. The equation for a long-lasting roof = proper roof design + time-proven materials + quality installation + ongoing maintenance.

The reflective nature of TiO_2 reduces the heat load from ultraviolet sunlight, resulting in a longer-lasting roof membrane while producing cooling energy-saving benefits.

REFERENCES

Ronnen Levinson and Hashem Akbari, "Potential Benefits of Cool Roofs on Commercial Buildings – Conserving Energy, Saving Money, and Reducing Emissions of Green House Gases and Pollutants," Lawrence Berkeley Laboratory, December 2007.

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