Report on technical advancements for photocatalytic coatings

D3.7

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Partner in charge	PURETI	
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NO2	Nitrogen dioxide
NO	Nitrogen oxide
CO2	Carbon dioxide
CO	Carbon oxide
TiO2	Titanium dioxide
UV	Ultraviolet
O2	Oxygen
H2O	Water
NOx	Nitrogen oxides
SOx	Sulfur oxides
VCOs	Volatile organic compounds
PCO	Photocatalytic Oxidation
OH^-	Hydroxide
PC	Photocatalysis
TPC	Peroxid Complex Amorphous Solution
PING	PURETi Inorganic Nano Glue
ABS	Type of Plastic
NASA	National Aeronautics and Space Administration
PT	Platinium
AU	Gold
AG	Silver

Abstract

Nanometer-sized titanium dioxide (TiO2) is an environmentally friendly optical semiconductor material. The photocatalytic process of nano-TiO2 converts light energy into electrical or chemical energy under mild conditions. This review describes the state of the Technical Advancements for Photocatalytic Coatings with a focus on PURETi TiO2 used on the testing site of the University of Bologna.

Keywords: Nano-TiO2, Photo semiconductors, Air Quality, Self-Cleaning, Decontaminating products

1. Executive Summary

The photocatalytic process converts light energy into electrical or chemical energy under mild conditions and through this process converts gaseous pollutants from the atmosphere into inert solids. Nanometer-sized titanium dioxide (TiO2) is an environmentally friendly optical semiconductor material that has been known to drive this process. PCO or photocatalytic oxidation (the light activated reversal of photosynthesis) is a 50-year-old technology that has been the subject of 9,000+ patents and 40,000+ scientific manuscripts. It has a wide application value in many fields due to its excellent structural, optical, and chemical properties.

This report describes the technical advancements for photocatalytic coatings that could be utilized in areas amply exposed to natural light. The key for this advancement was PURETi's state-of-the-art technology for transparent films, suitable for application in all types of build-up areas including facades or road tarmac.

The innovations carried out through this project are the improvements of the underlying principles of nanoparticles, the description of the features of the coatings and the comprehensive listing of new industrial applications based on functional modifications, of PURETi TiO2.

This report also describes the details of how this product was applied on the testing site in Bologna and is complementary to the information provided in the D3.6 and D3.8 reports that demonstrate the expected efficiencies at the same deployment site.

2. Introduction

In this report we are analyzing the technical advances for photocatalytic coatings, based on the technological development of PURETi as photocatalytic solutions. The PURETi Group LLC is an American manufacturer of aqueous photocatalytic solutions currently utilizing 3rd generation, advanced form of PCO. These products can be sprayed onto building materials and surfaces and highway/transportation infrastructure as a watery mist that dries clear to form, after several hours, an invisible nano-film, tightly bonded with the surface that was sprayed, with long lasting polymeric characteristics such as those of ceramic films.

PURETi, in the presence of light, also acts as a self-cleaning, bio-static and air purifying film. This product, based on laboratory tests over the past 30 years, is one of the safer, stronger, easier to apply, and more versatile and cost-effective coatings manufactured today.

PURETi is expected to work for more than 10 years and in its various forms, been successfully applied to 500,000 square meters of buildings and building materials.

These coatings have been utilized by NASA as a dual-purpose Technology Partner, have received 8 environmental awards and have been approved after extensive testing from the US National Institute of Occupational Safety and Health.

The key to the efficiency of a photocatalytic product is the strength of the catalyst and the amount of exposed surface of the active ingredient - nanoparticles of anatase TiO_2. The greater the exposed surface area, the greater the interaction between the catalyst and light, air, humidity, and the contaminants. Stronger catalysts with greater exposed surface area yield better results. These properties have been described at the deliverable D1.2 "Guidelines to Promote Passive Methods for Improving Urban Air Quality in Climate Change Scenarios", on catalytic coatings, where it was also explained how these allow the covered areas to self-clean, cause the painted surfaces to reflect sunlight, improve cooling considerably during the summer months (therefore saving energy), protect and repel dispersed air particles and make the exterior surfaces more resistant to extreme weather conditions.

Within this project the coatings were applied in two specific sites and monitoring of their effectiveness examined during three time periods representing a winter period, a summer period and a transitional period in spring/autumn. The coatings as such are not influenced by the annual season, their functionality depends on the activation by light and by the existence of sufficient gaseous pollutants that could be suitably converted into inert salts (more detail available in D1.2 and section 4 of D3.3). The annual seasons of course influence the intensity and the duration of time for which the PCO process will occur on the area spayed with the PURETi products. On the other hand, due to the regenerating characteristics of these products, rain periods help in demonstrating their regenerating characteristics. For the reasons above it was decided to deploy these coatings on building facades for testing their performance as pollution absorbers under realistic meteorological conditions.

For indoor uses such products are equally important because in addition to PCO they can also demonstrate antibacterial and anti-mold actions. Several deployments of these type of products have been carried out in Japan, Italy, France, the United Kingdom and the USA. This indoor application of PURETi was not however part of iSCAPE Project.

In the following section, we describe the evolution of the photocatalytic technology since its discovery, and the potential of this technology as a source of passive measures that could be used to improve air quality and to estimate the potential in the domains that are part of the iSCAPE project.

3. The Evolution of Technological Advances

The development of photocatalysis began with the discovery of the dissociation of the water molecule by Fujishima and Honda in 1968, published in Nature in 1972. Since then the photocatalytic properties of certain materials have been used to convert solar energy into electrons and vacancies after absorption of ultraviolet (UV) light. This reaction also produces chemical energy to oxidize or reduce materials to obtain other useful materials such as hydrogen, hydrocarbons and to destroy or remove contaminants and bacteria on wall surfaces and in air and water.

Although the Nanotechnological PCO was discovered in 1968, it took 30 years for the first products to appear in the real world. The first generation PCO technology, based on the use of TiO2 powder soil (applied through melting, mixing and gluing) emerged in 1998 in Japan and has been replicated to create hygienic tiles, self-cleaning glass, cement, smog reducers and air purifying light bulbs and self-cleaning coatings in construction. Due to manufacturing limitations, the performance of the first two generations of photocatalytic products was limited because many TiO2 particles were left without receiving enough sunlight. Hence, its performance was weak and expensive.

The PURETi team began its work in the field of PCO more than 10 years ago when the market saw the development of 2nd generation or aqueous TiO2 photocatalytic products. Titanium dioxide, TiO2, was considered a widely available mineral, (Ninth most abundantly on planet earth) and used in the additives industry as a pigment to provide whiteness and opacity of products like paints, coatings, plastics, papers, inks, food, medicines, and most toothpastes. The high catalytic photo property of TiO2 in its crystalline form was discovered in Japan in 1968. Since then, there have been more than 15 international conferences on the use of TiO2 for the treatment of air and water pollution.

The PURETi team spent three years perfecting the photo-catalytic chemistry of TiO2 - eliminating discoloration, smoothing the final result and expanding production in a highly profitable way. The production of the 3rd generation TiO2 by PURETI began with TiCl4 in water and the incorporation of nano-crystals that then growed in situ to culminate in a clear, transparent film of great adherence.

The main advancements in the evolution of these products following the commercial launch of photocatalytic TiO2 about twenty year ago can be summarized as follows:

1. Generation 1 - Embedded Powders - ex. Toto tiles, Pilkington Glass, Italcementi Cement, Alcoa Cladding - these products are made by embedding, sintering, mixing or coating powders or nano particles of anatase TiO2 into the body of a building product or material. Photocatalytic efficacy is constrained by particle agglomeration and the reduction of exposed surface area. Cost effectiveness in hardscape applications is constrained by a requirement to re-pave or re-surface with a skim coat.

2. Generation 2 - Coatings or Sols - ex. Airlite, Cristal, Gens Nano, Global Engineering, KNOxOut, Sto - these relatively thick paints or coatings are applied at the rate of approximately 15 sm per liter to road surfaces. While the photocatalytic efficacy of these coatings or sols is greater than the products from the previous generation, it is still sub-optimal and the cost effectiveness is constrained by low coverage rates and varying durability.

3. Generation 3 - Aqueous Surface Treatments - ex. - eg. PURETi - this unique and versatile suspension of amorphous and crystalline Titania bonds durably to roads, barriers and facades with the least agglomeration index. PURETi is the only photocatalytic product in the market that once applied creates a nano structured mesh with the greatest spread rate. The existence of another third-generation product is not known. What PURETi adds to products already known from other generations is: Adhesion on any substrate (steel, ceramic, textile), efficiency between 10 and 25 times better and is totally invisible. One liter of PURETi will treat 75 sm of road or barrier or facade surface.

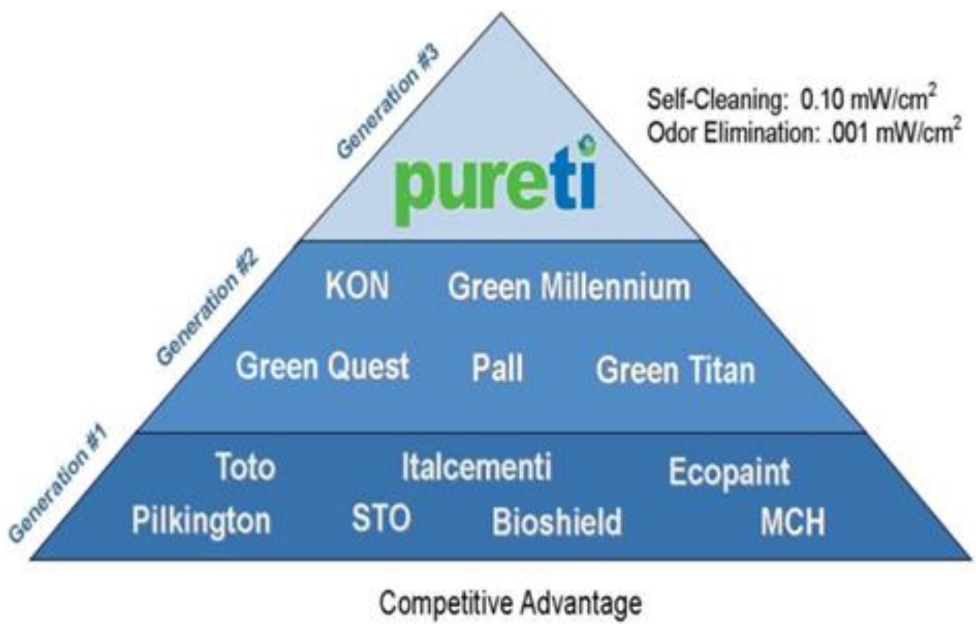

Figure 1: Evolution of Technology

PURETI is a PCO (Photo Oxidative Catalysis); This is a non-toxic solution, based on titanium dioxide that is applied by spraying and dries in seconds to form a high photoactive, mineral film. These durable, ultra-hidden and invisible films adhere to virtually any surface. PCO is produced when UV-A light (sunlight, fluorescent light or UV-A LED) reaches the TiO2, this leads to the almost instantaneous formation of the hydroxyl radical and superoxide anions. These highly reactive chemical agents, now almost instantaneously interact on the treated surface to accelerate the decomposition in the environment of organic pollutants (molds, oil, rubber, bio-film, methane and volatile organic compounds), through oxidation and the reduction / neutralization of inorganic contaminants (such as NOx and SOx).

The hydroxyl radicals (OH^-), the non-poisonous agent, the strongest oxidant of nature, are part of the light energy that acts on the TiO2, extracting a hydrogen atom out of the water vapor (H2O) of the air (humidity). The hydroxyl radicals formed on the treated surface aggressively attack the carbon hydrogen bonds that are present in all organic sources and once again, it is not an oxidation process, just water and a small amount of CO2. In PCO's "Life Cycle Analysis" we have found / discovered the technology to be of great environmental benefit. The small amount of CO2 produced is more than offset by the benefits of reducing methane, NOx and VOC (all major pollutants and toxics), in the atmosphere and the benefits of reducing chemicals, water and the use of energy through reduced maintenance by more than 50%.

Superoxide anions (O2-), are one of the strongest reducing agents in nature, and are formed when the energy in the air (O2) interacts with light and the already energized TiO2 by receiving an extra form and create O2-. PCO technology is documented in the scientific literature and key publications are included at the end of this report.

4. The Current State of Technology

The pre-requisites for photocatalysis are for there to be enough light for several hours during the day and high pollutant concentration that could be absorbed for PCO. For the coatings, many factors influence the performance of these materials. These include the particle size, surface area, pore volume, pore structure, crystalline phase, and facets of exposed surfaces.

The material used for this project has been developed and optimized to maximize the specific surface area, the pore volume, the pore size and the dispersion level when applied. Overall, the size of the accessible surface area is increased and consequently the rate of mass transfer for absorption and decomposition of organic pollutants is increased accordingly. Additionally, these structural factors increase the light collecting capacity by allowing the maximum light to interact with the maximum surface.

Because photocatalytic reactions are based on chemical reactions on the surface of the material. only very thin layers are necessary to obtain optimum results. In a very thick layer UV light would neither activate the molecules that are more than a certain depth nor the organic compounds to be decomposed would be in contact with the surfaces where the chemical reactions occur.

Technology evolution led to PURETi using Cristal Active sol technology that allows efficiency.

In the following figure, you can see examples of different photocatalytic coatings in the market:

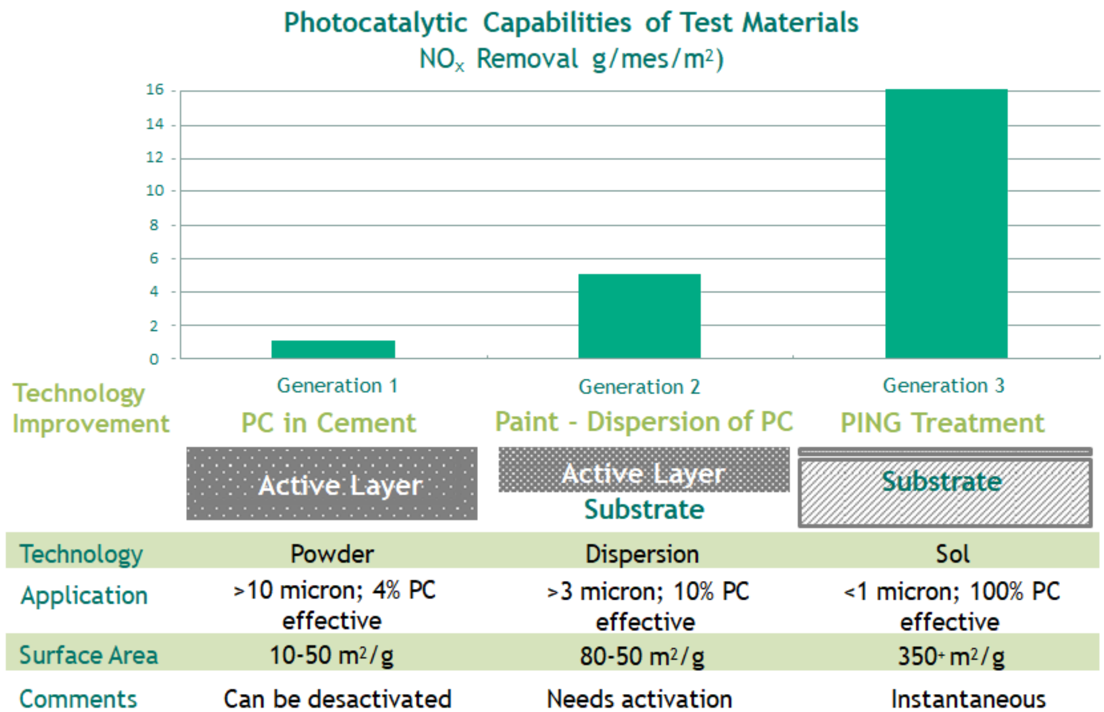

Figure 2: Technology evolution

The main difference between these technologies are the way the coating is applied on the surface to be used, and the function of the PCO process with the spectrum of light close to the naturally visible range. The application process is driven by the use of ultra-fine spray; one gallon covers ˜ 4,000 square feet (˜ 100 m2 / liter) under normal conditions. For the purposes of the light activation, it is expected that the site in Bologna during the summer month to be adequate for demonstrating both these advancements with the measurements described in D3.8.

4.1. PURETi Commercially Available Products

All PURETi products combine patented binding technology with nano-sized particles of titanium dioxide encapsulated in water to deliver a wide range of economic and health benefits. The oxides of titania in all PURETi products comes from two sources: PURETi's proprietary formulation and sols that we purchase from Cristal, Inc. The sols are added to our binder during the manufacturing process, but we inquired as to whether the sols on a stand-alone basis would require a Prop 65 warning. Their response reads:

"… based on our understanding of Proposition 65, Cristal's sols would not be classified as 'Titanium Dioxide (Airborne, Unbound Particles of irrespirable size" given that they are delivered dispersed in a dispersant/water matrix."

In the image below, are shown the different PURETi products, with their uses and forms of application. It's a unique and cost-effective spray application is guaranteed for 5 years outdoors and 3 years indoors, keeping surfaces cleaner for longer, reducing the consumption of water, energy and chemicals.

-PURETi Base: It's a primer. Protects adjacent surface and increases adhesion and photocatalytic activity.

-PURETi Clean: Top layer photocatalytic. Applicable to any opaque surface including cement, stone, ceramic tile, painted walls, plastic and metal. Applies only on the top of "PURETi Base". Our most used photocatalytic product.

-PURETi Coat: One-steps and multipurpose product to almost any surfaces. Specially for cement, stuccoes and asphalts.

-PURETi Clear: One-steps product for applications of glass surfaces and deep and dark colored surfaces. It can also be applied on the top of "PURETi BASE".

-PURETi Clean & Fresh is a ready-to-use cleaner and surface treatment for glass, mirrors, and stainless steel.

PURETi Clear, PURETi Coat, PURETi Base, and PURETi Clean are our "certified product line" and are spray applied by trained applicators on a variety of surfaces.

5. Process Innovation in the Site Application

In addition to the advancements of the manufacturing of the coatings used in this projected described in the previous chapter we have also introduced several innovations at the site application processes. These are described at the sections together with the precise actions carried out at the site of Bologna.

According to PURETi specifications, the application process requires a good pre-cleaning, to ensure the correct adhesion of the product on the original surface and not on the dirt that may be on the surface. Once the photocatalytic product is applied, a completely transparent structured net is created that is highly effective and durable thanks to the PING.

The conditions and forms of application were guided by the establishment of a protocol. Because of the need to create an application tunnel that would generates an air flow to allow a better measurement of the decontaminating effect of the product, different tests of application procedures were carried out to guarantee the correct function of the TiO_2 nanoparticle mesh.

The main innovation is linked to the pre-treatment of exterior soiling, the improvements in the application process and the innovation in the tools used for the application.

5.1. The Bologna Testing Site

The application tests of the PCO coating were carried out at the University of Bologna with the support and collaboration of UNIBO. The site was selected by UNIBO.

5.1.1. The Site Overviews

The application of PURETi in Bologna, Italy was carried out during the month of August, in line with the provisions highlighted and described by the UNIBO in report published in february 2019. The products used were PURETi Coat. PURETi Coat was selected because it is a cost-effective solution to reduce many maintenance problems of the facilities. A unique spray application on a cement surface uses the energy of natural sunlight to break down organic dirt. High-pressure washing is needed because organic particles similar to glue decompose before they can adhere. The total area treated was limited to 1250 m2 as requested by the UNIBO and described in the following Table. The figures below identify the areas painted with PURETi product as well the area situated two blocks away from the area selected for the background measurements, these are described in D3.6 and D3.8.

TREATED AREAS	
Street	250 square meters
Facade 1	450 square meters
Facade 2	550 square meters
Total Area:	1250 square meters

Table 1: Treated areas att both facades of the alley

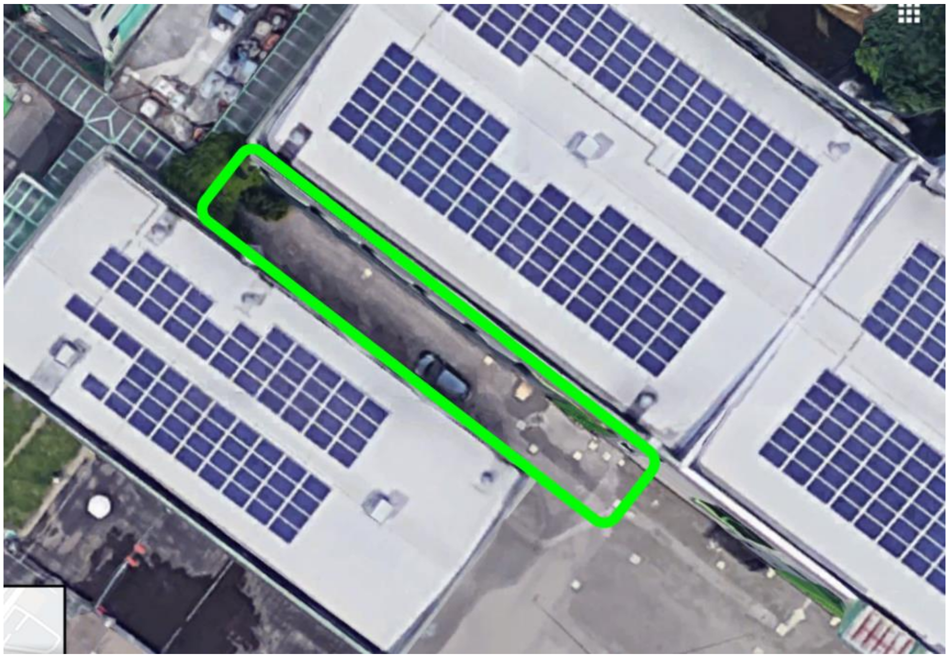

Figure 3: Street Area: 250 square meters

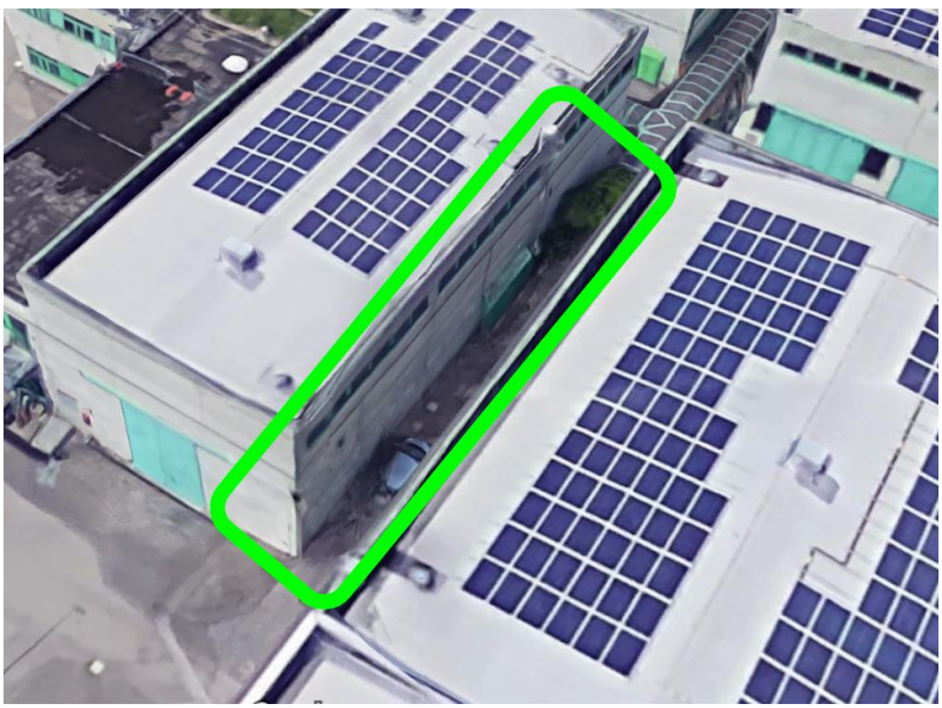

Figure 4: Area Facade 1: 450 square meters

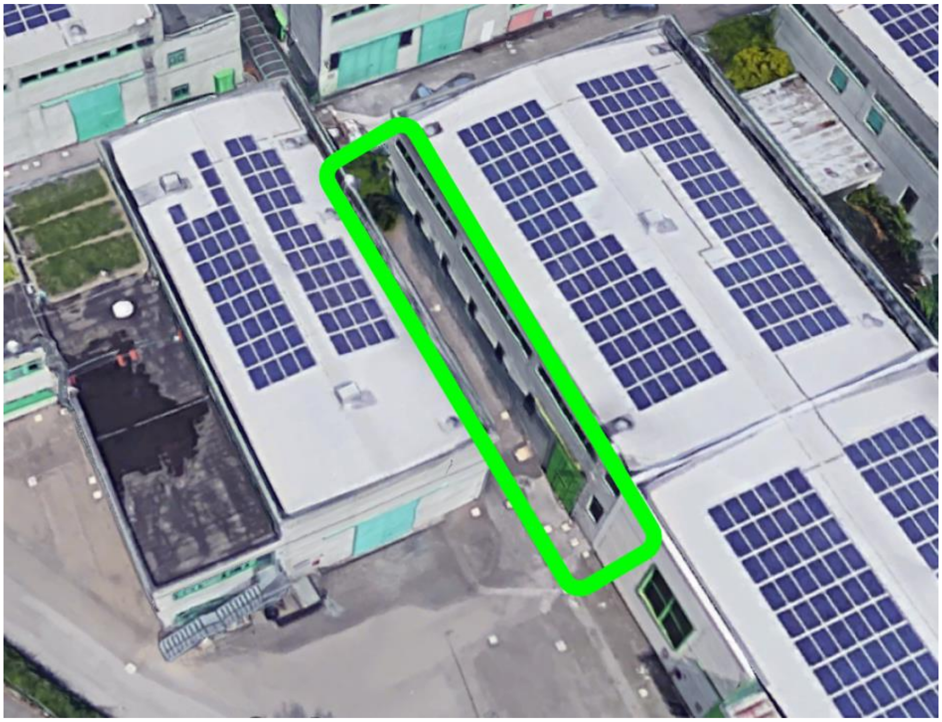

Figure 5: Area Facade 2: 550 square meters

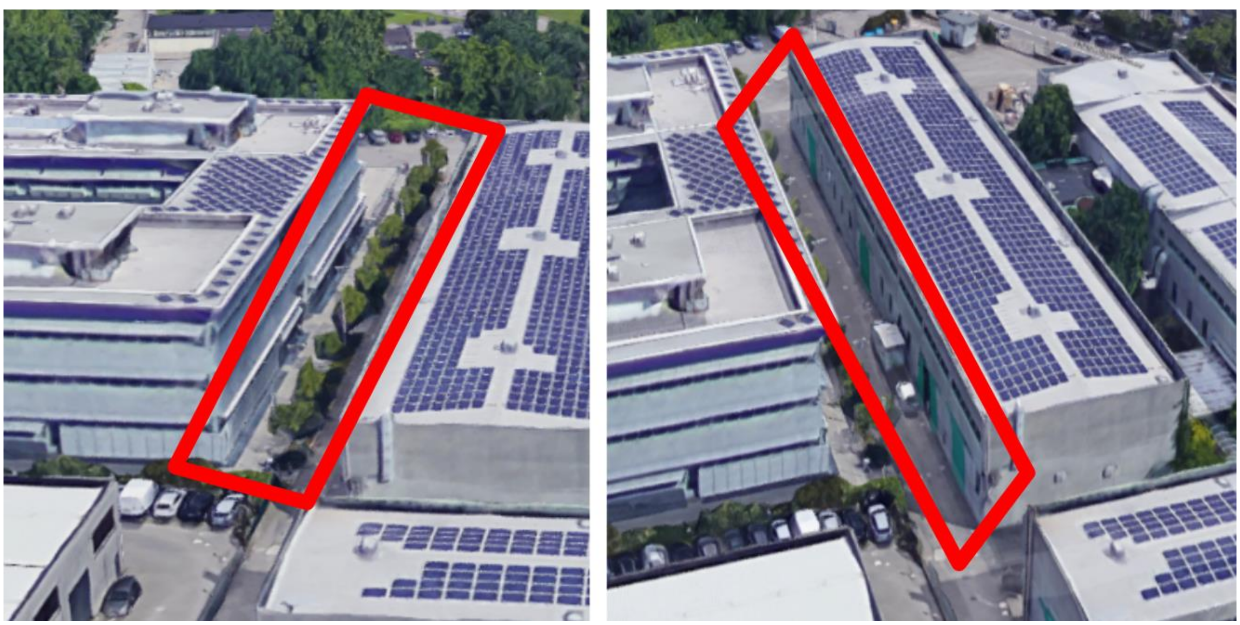

Figure 6: Control area

Figure 7: Map of the surrounding areas

5.1.2. Process Improvements

The application involved the following improvements that are presented in the three sections that follow on the treatment of exterior soiling, the improvements in the application process and the innovation in the tools used for the application. The fourth section presents the final outcomes of the application at the test site.

5.1.2.1. Exterior Surface Soiling Pre-Treatment

We have discovered that the adhesion of PURETi Coat to exterior surfaces increases significantly if the surfaces are first cleaned with high pressure water. PURETi Coat modifies the way in which dirt can adhere to the surface, significantly reducing the ability to adhere to it.
The leading ingredients in grime are, micro-particles of tire rubber (organic), soot from the exhaust of cars and factories (organic), silicates (inorganic sand and soil) and, in some climates, black mold (organic)

High pressure water or chemicals are required to clean most outside surfaces because the organic contaminants form glue-like bonds that are very hard to break.

Figure 8: Cleaning with water under high pressure

In this context:

- PURETi oxidizes (breaks down) the organic particles at the molecular level before they can stick to the surface.
- PURETi does not break down sand, but the sand rinses easily because there is no "glue" to hold it in place.
- PURETi changes the way that surfaces get dirty, so it makes them easier to clean.

5.1.2.2. Description of the Application Process

The application protocol is easy, but it must be followed in a disciplined manner to ensure the correct adhesion, durability and performance of PURETi. We have developed a system of application easy to teach and replicate.

The Professional Application Process is made up of the following steps after a deep cleaning or pressure wash to best-possible condition:

- Step 1: Spray apply PURETi product
- Step 2: Allow product to dry (10 seconds) and fully cure (48 hours) without disruption
- Step 3: Modify cleaning protocol after application to use less water pressure and no chemicals. (They should not be needed).

Other important matters:

- Professional Spray Application.
- Water based solution dries in seconds, cures in 24-48 hours.
- Dries invisibly. It will not change the appearance of the surface.
- Ideal application conditions are right after a pressure washing or other cleaning.
- Environmental conditions must be similar to painting (no high wind or rain)

Application of PURETi – "Cross Hatch" Pattern

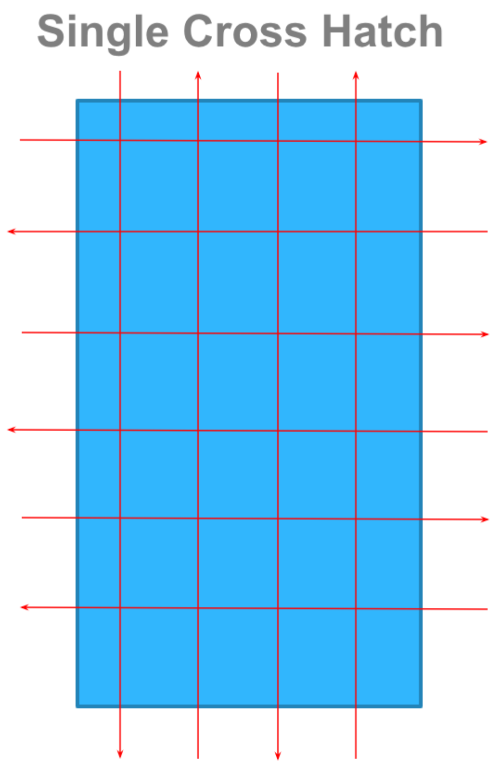

Figure 9: Single Cross Hatch

- PURETi is applied at a rate of ~ 10 ml/m^2
- On porous surfaces (concrete, asphalt, etc), coverage rate will decrease to 13-15 ml/m^2
- We use Cross Hatch Pattern to apply PURETi
- 1 Vertical + 1 Horizontal pass= 1 CrossHatch
- Only 1 cm overlap to ensure even coverage
- Always wait for the 1st pass to dry before applying the 2nd pass.
- Go past your 'target area' on both sides

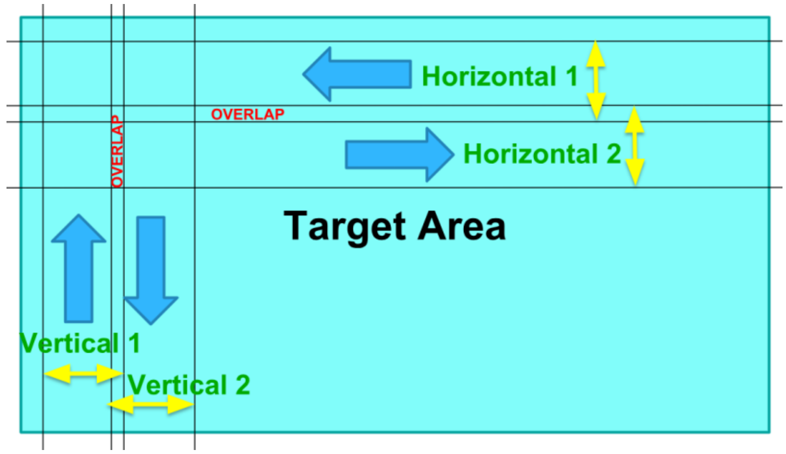

Figure 10: Target area

- PURETi is extremely durable once cured, but is vulnerable immediately after applied
- PURETi is rain/water-safe after 24-48 hours, but surfaces should not be actively cleaned (physical abrasion and/or chemicals) for at least 2 weeks after application.
- Curing is accelerated in presence of heat/UV

5.1.2.3. Innovation in Tools

The equipment used for the test in Bologna was modified and tested ad-hoc for the test and included:

- Electrostatic Gun

The aim of the electrostatic process is to get as much coating material on the part as possible and eliminate wasteful overspray. This is achieved by negatively charging atomized material particles so that they are attracted to the grounded workpiece...opposites attract.

A charging electrode is located at the tip of the electrostatic spray gun. The material is atomized as it moves past the electrode and its particles become ionized - negatively charged. An electrostatic field is created between the charging electrode and the grounded workpiece, and the spray is concentrated within.

Further atomization is achieved as charged particles repel each other to form a fine cloud. As a result of electrostatic attraction, spray that would normally be lost, attracts to the back and sides of the workpiece to produce "wrap-around".

- Benefits

Increased transfer efficiency, a significantly increases quality and production, positive environmental impact and reduces overspray.

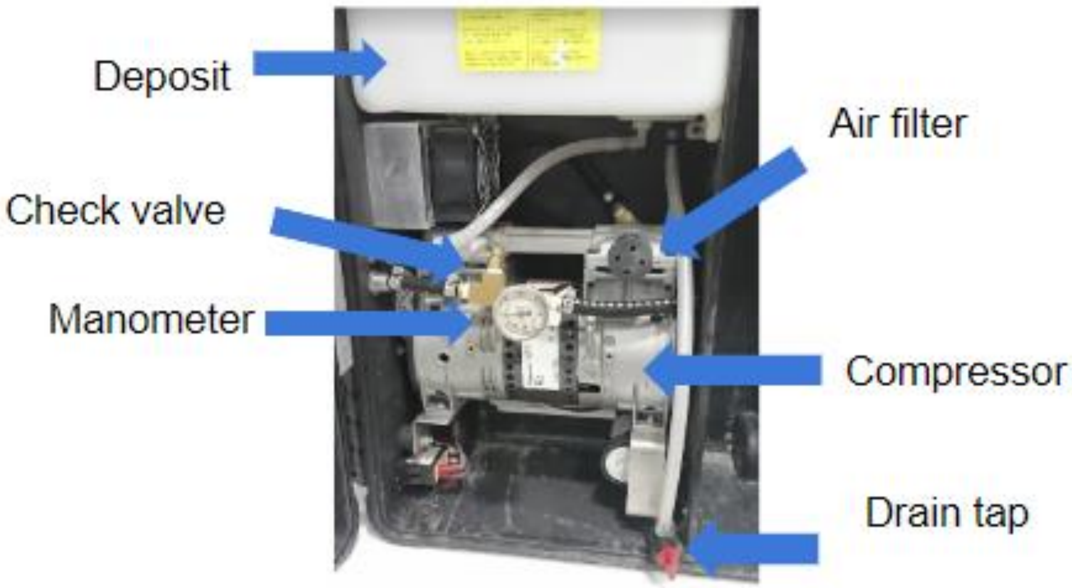

Figure 11: Parts of the Suitcase

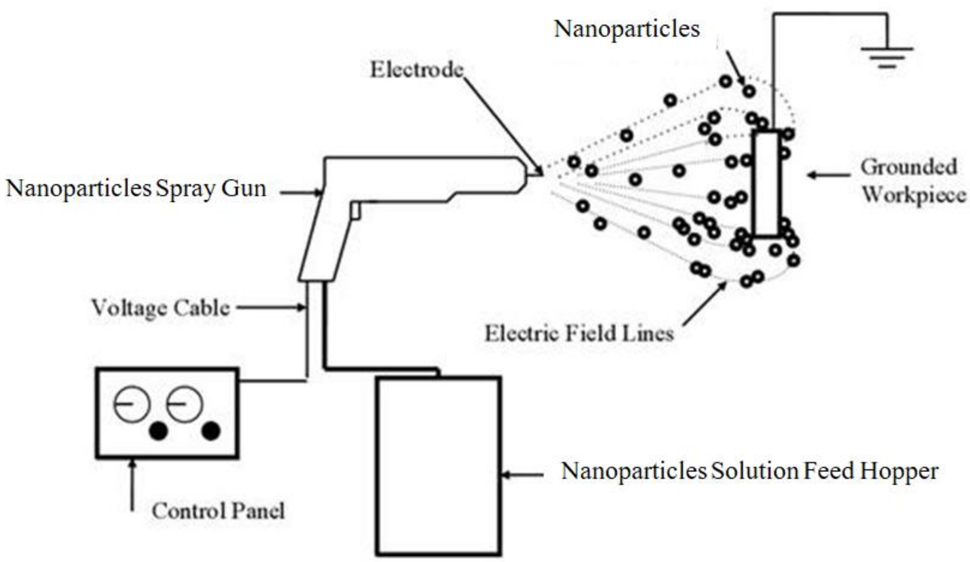

Figure 12: Electrostatic Gun Function

5.1.2.4. The Cleaning and the Painting Processes of the Application in Bologna, Italy

Below we will see several pictures of cleaning with water pressure. A retractable crane very common in the market has been used for all the cleaning and application tasks. Any means of elevation can be used to perform these tasks.

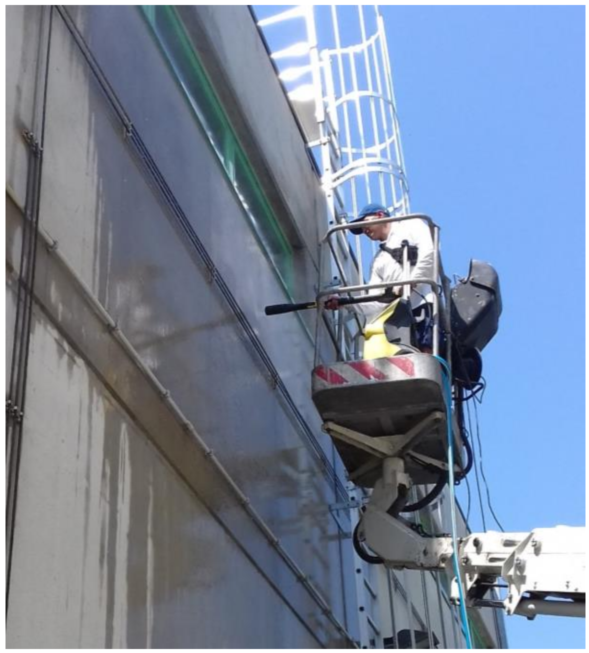

Figure 13: Cleaning the area with high pressure of water

Figure 14: Cleaning the area with high pressure of water

Figure 15: Cleaning the floor with high pressure of water

In the following photo we see how Pureti is applied on the already clean and completely dry surface.

Figure 16: Application of the product

5.2. Implications of the Process Improvements

The incorporation of titanium dioxide in building materials or surface coatings imparts to them self-cleaning and de-polluting properties. A consistent reduction in levels of NOx by approximately 80% was observed for paints and cements containing titanium dioxide nanoparticles tested in large indoor facilities. Such facilities will allows online monitoring of ozone, NOx, CO, and VOCs inside an environmental chamber with controlled temperature, relative humidity, air quality, air exchange rate.

In canyon street tests, NOx concentrations were reduced from 40 up to 80% depending on differences in emission sources, wind direction and orientation of the walls. The photocatalytic conversion of NO and toluene increases with decreasing relative humidity and toluene degradation is enhanced by the presence of NO.

The next steps will be to investigate, in dynamic mode, the efficiency of pollutant conversion and release of by-products, the influence of light intensity, and the effect of multicomponent mixtures (benzene, acetaldehyde, formaldehyde, CO and NO2, xylenes, naphtalene, styrene, toluene, a-pinene, d-limonene).

In air purification typically only 0.01 % of the incident photons are actually used for photocatalysis (e.g. by self-cleaning glass) but 10% might ultimately be achievable. Photocatalytic activity can be enhanced by using noble metal (Pt, Au, Ag) nano-contacts, Sn0i/TiO2 composite materials, or by doping with Fe(III). Nanoparticles of TiO2 in colloidal suspensions form chain-like structures, which can act as antennae to enable transport of electron-hole pairs. This mechanism explains the high quantum yields of formaldehyde formation during the CH30H- Oxidation at TiOi/Fe(III) colloids.

The following are additional topics with realistic PCO advancements in the coming years:

- Gas phase remediation of sulphur dioxide and nitrogen dioxide is the area with the most potential applications. Now, nanotechnology offers the possibility for development of new materials for process intensification.
- There is a need to develop monitoring devices that can determine whether a remediation process has worked correctly or not.
- It is necessary to find more effective methods to deal with the problem of transport of pollutants - molecules could be immobilized in situ by chemical binding.
- Additional research is needed on methods to demonstrate the effectiveness of products.
- Life cycle analysis is an essential tool for assessing the environmental consequences of implementing new technological approaches.
- Support for research networks in environmental (nano) technologies and field sites to establish proof of concept is needed.
- The most effective new methods for environmental remediation are likely to consist of a combination of more than one technology in hybrid systems. Some technologies, such as nano-

filtration, are already quite close to market but additional research and development are needed to improve their efficiency.

Worth also mentioning for the proliferation of PCO advancements is the European-Japanese Initiative on Photocatalytic Applications and Commercialization (EJIPAC]) that establishes collaboration between Japanese and European companies and institutions in the field of self-cleaning surface coatings and air and water purification methods. Following the successful completion of the use of the PURETi coating in real-scale it might be useful to communicate our results in this and similar fora.

6. Conclusions

This report describes the technical advancements for the manufacturing and application of photocatalytic coatings. That could harness the oxidation process over areas amply exposed to natural light. The heart of the advancement was realized with the manufacturing technology and in the application process over all types of build-up areas including facades or road tarmac.

The finals results will be provided by UNIBO (University of Bologna – Beatrice Pulvirenti | Dr. and Silvana Di Sabatino | PhD, MPhil, MSc) expected September 2019.

7. Annex

7.1. Testimonials of the Key Industry Partners

The following are the key industry partners of PURETi in the market today together, with a brief description of their current role in the market:

- AUNDE GROUP, GERMANY World leader in smart fabrics for public transportation applies PURETi to their fabrics and existing buses and trains adding new environmental and sustainable solutions.

Figure 17: Application in public transportation seats (buses, railways)

- NEOLITH, SPAIN. One of the largest international ceramics manufacturers is applying PURETi to their tiles in factory creating self-cleaning and decontaminating façades. Neolith has received various awards up to date, one of which is the Gold Medal of the prestigious Edison Award ™ 2018 in recognition of its Neolith + Pureti treatment. The outstanding awards, inspired by the persistence and inventiveness of Thomas Edison, recognize innovation and creativity in new products and services that meet the strict quality criteria of the awards as judged by more than 3,000 academic experts.

Figure 18: Edinson Gold Awards NEOLITH + PURETi

- EZPELETA, SPAIN. Ezpeleta produces advertising umbrellas for leading brands of the alimentation industry. Mahou-San Miguel, in Spain has launched the production for 2019 of 250.000 sun umbrellas for bar terraces in Spain and Portugal with fabric treated with PCO materials. Other important drink brands are supposed to do the same in other countries in UE.

Figure 19: Parasols for Mahou San Miguel By Ezpeleta

- EIFFAGE, FRANCE. Eiffage is the 5th largest public construction multinational in EU. They apply PURETi on top of their asphalts specially of treating the parking spaces of IKEA malls.

Figure 20: Application on asphalt (Streets, parking)

- TELSTAR , JAPAN (AZBIL GROUP). Telstar is applying PURETi to their biological cabinets to enforce the sterilization of all surfaces of their hospital equipment.

Figure 21: Telstar's biological cabinets

7.2. PING: PURETi NANO GLUE Technology

PING is the primary ingredient in PURETi Base and is also used to help formulate PURETi Clear, Clean, Coat and Fresh. The product we applied in the iSCAPE Project pilot test was Pureti Coat.

At the core of advancing of current PCO technology is an inorganic mineral film former we call PING (for PURETi Inorganic Nano Glue). PING is a unique inorganic solution and is not a sol gel. This is a highly adhesive solution that is 99.5% water and 0.5% amorphous Titania. PING currently functions as an adhesion promoting, surface protecting, base coat for our photocatalytic topcoats (the self-cleaning, air purifying architectural finishes that are the main commercial focus of our firm).

The general chemical description of PING is Ti(O)(OOH)2.nH2O, with a variable range for n. upon evaporation of the hydrated water molecules, the peroxide groups in PING will condense to form an inorganic amorphous titanium oxide film. This form of the titanium oxide is a polymeric like ceramic similar to the naturally occurring form of Titania known as Brookite. PING is unique in that it is inorganic and not subject to any further attack by oxygen, oxidation, or water, hydrolysis, and thus is environmentally stable. It is an ideal carrier for the anatase form of titanium dioxide, which is photocatalytic in nature. PING is a semiconductor in nature and enhances the photo-catalytic reaction when used as a carrier for the anatase TiO2. PING is the backbone of our range of photocatalytic products.

PING has also been found to function as an inorganic adhesive to immobilize a variety of nanoparticles onto a variety of micro particles and substrates - with great adhesion and minimal agglomeration. PING was found to add value as the foundation carrier for an ink that is being developed for the printing of thin solar films. In a related application, PING was also found to add value in preventing the delamination of flexible, multi-layer solar films. We believe these initial projects represent the “tip of an iceberg” and that PING will eventually be deployed in a broad range of beneficial nanomaterial applications.

The manufacturing process of PING are:

1. The Immobilization of nanoparticles - In a variety of laboratory experiments, the PURETi R&D team has, solely or in collaboration with others, successfully used PING to:

- Immobilize sub-micronic iron oxide pigments on 40 micron diameter glass microspheres and have them survive plastics extrusion processing intact.
- Coat Kevlar and Xylon fibers and improve their abrasion resistance 300% - Professor German Mills, Auburn U.
- Bond 40 nm particles of TiO2 onto various substrates with great adhesion.

● Immobilize single wall carbon nanotubes on a variety of substrates – Professor Menachim Elimelech, Yale University

The potential of this "water based inorganic nano-glue" as a carrier to fix or immobilize a broad range of nanoparticles – without agglomeration - in a variety of real world applications deserves full exploration.

2. Metal Oxide Film Formation - PURETi's lab (using our patented method of creating, in-situ, nanoparticles of metal oxide in aqueous film formers) has also produced a number of non- titania mineral film formers. Our lab has used this same, robust, patented method to produce lithium oxide film formers, platinum oxide film formers and zinc oxide mineral films – and believes it can produce others.

These mineral films need to be characterized and work needs to be done to understand if this novel method of film formation offers any additional value above and beyond other methods of creating such nano thin mineral films. We have received indication from other interested parties that there is significant merit to this approach.

For Non-Photocatalytic Applications of PING as a film it can act as a carrier for other metal oxides as well as certain polymers. The other oxides that it can carry (and the ones that we have worked with) are zinc oxide and cerium oxide. These oxides are nano-dispersions in water. Colloidal silver in PING has and is still being looked at for its antimicrobial activity. The polymers that have been added are polyurethane as well as polyacrylics and polyethylene. These polymers have been formulated for use on concrete, textiles, asphalt, and certain glass products. They also can provide adhesion to other types of substrates such as acrylic, ABS plastic and vinyl.

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