PERFORMANCE
FLUOROPOLYMER
PARTNERSHIP

December 2023

The American Chemistry Council's (ACC) Performance Fluoropolymer Partnership (hereafter "PFP") has developed a White Paper that focuses on the Infrastructure & Construction (I&C) end-use segments noted below. The PFP's members are some of the world's leading manufacturers, processors and users of fluoropolymers, including fluoroplastics, fluoroelastomers and perfluoropolyethers polymers.

The content provided here in this White Paper was submitted to the REACH Annex XV All PFAS Restriction Proposal in 2 parts. The submittal reference numbers are as follows:

August 27, 2023: Reference number 3eb5e616-f855-4393-abbc-e1eeb7c25ff4 and

September 24, 2023: Reference number 4cc4c0df-35b8-4354-a66c-37401d364694

These comments pertain to the use of fluoropolymers (fluoroplastics) in Infrastructure and Construction (I&C) applications. This is a commercial/industrial application/use segment with little to no direct consumer use. The fluoropolymers highlighted in this submission are listed in **Table 1**.

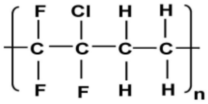
In this White Paper, we provide compelling case studies and technical data on the use of fluoropolymers in five (5) end-use applications that are often subject to continuous weather extremes based on the climate and/or their physical locations. Those uses are:

1. Building Facades and Protection - Metal Building Panels and Parts;
2. Roofing and Roofing Structures;
3. Bridge and Walkway Structures;
4. Water Towers; and
5. Solar Panels.

Please contact me if you or your colleagues have any questions.

Jay West
Executive Director
Performance Fluoropolymer Partnership

Table 1. Fluoropolymers highlighted in this White Paper

Polymer	**PVDF**	**PVDF-HFP Copolymer**	**ECTFE**	**ETFE**	**FEVE**
Name	polyvinylidene fluoride	vinylidene-fluoride, hexafluoro-propene copolymer	ethylene, chlorotrifluoro ethylene copolymer	ethylene, tetrafluoro-ethylene copolymer	fluoroethylene-vinyl ether copolymer
CAS Number	CAS 24937-79-9	CAS 9011-17-0	CAS 25101-45-5	CAS 25038-71-5	CBI
Structure	$-(CF_2-CH_2)_n-$	$-(CF_2-CH_2)_n-[CF(CF_3)-CF_2]_m-$	 $\left[-\overset{F}{\underset{F}{C}}-\overset{Cl}{\underset{F}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\right]_n$	$-(CH_2-CH_2-CF_2-CF_2)_n-$	contains fluoroethylene and vinyl ether segments

For a Glossary of Terms, see Appendix A.

For Testing and Reference Methods in the I&C End-Uses, see Appendix B. For each of the I&C end-use applications in this submission there are a set of exacting performance testing and reference methods. Appendix B contains a list of the critical test methods and what they measure. For the primary end-uses in this submission, designers, architects and builders have specific performance standards they must meet to achieve the desired long lasting coatings performance and surface protection.

Background on Fluoropolymers (Henry et al., 2018; Korzeniowski et al., 2022)

“Fluoropolymers are high molecular weight polymers with fluorine atoms directly attached to their carbon-only backbone” (Ebnesajjad 2017). The carbon-fluorine (C-F) bond is the strongest bond between carbon and another atom and imparts unique, outstanding and beneficial properties and extraordinary functional performance to fluoropolymers. (Banks et al. 1994, Scheirs 2007, Ameduri and Sawada 2017a, 2017b, Ameduri 2020, FPG 2021) These properties (fluoropolymers enable) include chemical, biological and thermal stability, heat and chemical resistance, unique dielectric properties and durability. Additional fluoropolymer properties include improved fire resistance, weather resistance, non-wetting and non-stick. Fluoropolymers are regarded as irreplaceable in many applications because their unique combination of specific properties, which are critical to help ensure optimal performance in many applications and cannot be achieved by alternative materials (FPG 2021, 2017; PFP 2020; Henry et al. 2018).

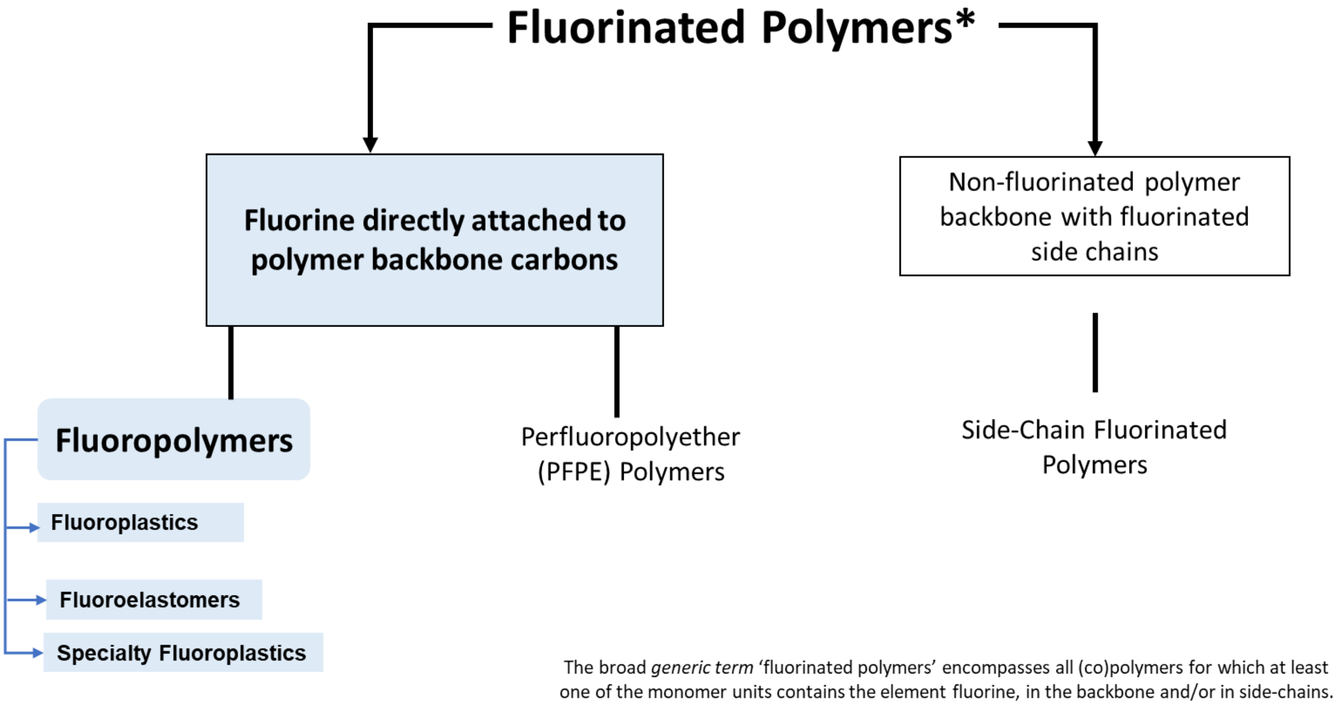
There is considerable media and public confusion and misunderstanding regarding PFAS, as the many different chemicals and groups are often not clearly differentiated under the broad term PFAS. PFAS, a large, diverse group of substances with vastly different properties, is too broad to enable effective, science-based assessment and regulation of chemical compounds as an entire group. This point has been raised in recent publications which suggest alternative approaches to effectively group PFAS for regulatory assessment (BDI 2021, Buck et al. 2021, Orgalim 2021, RSC 2021, Wallington et al. 2021, Amcham 2020a; Miller at al. 2020). PFAS must be assessed based on their chemical, physical, thermal and biological property differences and uses (Amcham 2020a, BDI 2021, Buck et al. 2021, RSC 2021, Wallington et al. 2021). As regulatory frameworks such as the subject EU REACH regulation continue to evolve, more work is needed to clearly distinguish among PFAS types, based on their properties to assure that regulations are appropriate in scope, proportional and based on science.

Fluoropolymers have material properties which help define their functionality. The unique properties of fluoropolymers include improved durability, mechanical strength, inertness, thermal stability and resistance to chemical, biological and physical degradation. Some can be classed as Polymers of Low Concern (PLC) to human health and the environment according to OECD criteria as they are chemically stable, biologically stable/inert, negligibly soluble in water, non-bioavailable, non-bioaccumulative; and non-toxic. (Henry et al. 2018, Buck et al. 2011, Korzeniowski et al 2022).

The PLC criteria were developed over time within regulatory frameworks around the world as an outcome of chemical hazard assessment processes which identified physical chemical properties of polymers that determine polymer bioavailability and thereby inform a polymer’s potential for hazard. For example, many of the physicochemical properties, such as molecular weight, limit the ability of a polymer to cross the cell membrane and therefore limit its bioavailability (Kostal 2016, USEPA 2012, Lipinski et al. 2001).

The results from the two PLC publications show that each of the 18 commercially manufactured fluoropolymers in these studies satisfy the widely accepted assessment criteria to be considered polymers of low concern and merit such designation. The study results add further evidence to show that fluoropolymers are demonstrably different and should not be grouped with other PFAS for hazard assessment or regulatory purposes.

For the purposes of this submission supporting the I&C end-use segments noted above, we will focus on uses of fluoropolymers. These are the fluorinated polymers on the left-hand side of **Figure 1** highlighted in light blue.



The broad *generic term* 'fluorinated polymers' encompasses all (co)polymers for which at least one of the monomer units contains the element fluorine, in the backbone and/or in side-chains.

Figure 1. Fluorinated Polymers: Fluoropolymers, Perfluoropolyethers and Side-chain Fluorinated Polymers (Korzeniowski et al, 2022)

Table 2 below describes some of the core properties of the fluoropolymers that are covered in this set of comments. Some of the key critical properties noted here are increased mechanical strength, significant wear resistance, low coefficient of friction, barrier properties and improved resistance to chemicals and weatherability, among others. (Korzeniowski et al, 2022)

Table 2. Fluoropolymer Properties and Functionality.

Table zzz: Fluoropolymer Properities and Functionality   Updated 19Apr

	Properties	Durable				Inert - Stable					Functional						
	Functionality	Mechanical strength	Wear resistance	Flexibility	Low coefficient of friction	Resistance to chemicals	Weatherability	Cryogenic properties (lower than -50°C)	High operating temperature range	High limiting oxygen index	Electrical insulator - high data transmission rate	Piezo-electrical properties	Barrier properties	Ultra High Purity grades for clean applications	Optical clarity	Low refractive index - used for optical effects	Polymer processing additive (PPA)*
Fluoroplastics	**PVDF Homopolymer**	●	●		●	●	●		●	●		●	●	●	●	●	●
	PVDF Co-polymer	●	●	●	●	●	●		●	●	●	●	●			●	●
	ECTFE Co-polymer	●	●		●	●	●	●	●	●	●		●				
	ECTFE Ter-polymer		●		●	●	●		●	●			●				
	ETFE	●	●		●	●	●		●	●	●		●				
	FEVE	●	●	●	●	●	●		●	●			●		●		

Polymer Processing Additives (PPA)*: also called Polymer Processing Aid, Extrusion Process Aids or Polymer Processing and Recycling Aids

Fluoropolymer Benefits, Features and Performance Properties Expected in I&C Coating End-Uses

The exceptional properties that fluoropolymers provide and/or enable in the I&C coating applications will be described more fully in the detailed end-use application descriptions that follow in this report. To help set the stage for these descriptions, we highlight below the critical parameters that determine how well a Fluoropolymer-Based Coating (FBC) and/or film functions and performs under various environmental conditions.

Flexibility is the ability of the material and its coating to bend without breaking and return to its original shape or position without damage to the exterior coating.

Wear resistance performance measures the ability of the coated surface to resist the aggressiveness of wearing medium.

Impact Resistance and Hardness is defined as the prepainted or coated metal surface’s ability to withstand various impacts under the appropriate test conditions. There are various film hardness tests including the pencil test (ASTM D3363). Relative rankings for both impact resistance and hardness are often used when comparing organic coating films.

Color Retention is the ability of the prepainted or coated metal substrate to maintain its color and appearance over extended periods of time under exterior weather conditions and/or appropriate test methods simulating outdoor exposure.

Gloss Retention is a core exterior durability property that measures the retention of film gloss under UV exposure conditions.

Film Erosion is the degree to which paint films erode under harsh and/or weathering conditions. Film erosion of exterior paints and coatings is evaluated by comparison with photographic standards or reasonable facsimile. It can also be measured as a surface loss in µm/year.

Chalking Resistance is the evaluation of the degree of chalking on white or tinted exterior paint films.

Weather Resistance – Abrasion Resistance - is the combined ability of a material or structure to withstand, resist or endure harsh atmospheric weather conditions, such as extremely hot or cold temperatures, UV light, humidity, salt air or similar corrosive conditions.

Harsh Chemical Resistance is the ability of a substance to withstand, resist, or endure a chemical challenge for a specific period of time.

Corrosion Resistance is the ability of a previously painted or coated specimen to withstand accelerated and atmospheric exposure tests and subsequent evaluation with respect to corrosion, blistering as well as loss of adhesion.

Barrier Properties refers to the property of material when a specified permeable object transmits from one side to the other (from high density side into low density side).

Fire Retardancy/Smoke Suppression refers to how the painted metal materials and/or panels are evaluated, on a relative basis, for surface flame spread and smoke density measurements with that of a select grade of red oak and fiber-cement board surfaces. The property of limiting oxygen index (LOI) is the measure of the minimum concentration of oxygen in a mixture of oxygen and nitrogen that is needed to support the flaming combustion of a material. Limiting oxygen index (LOI) is the parameter most frequently used to characterize the improvements in fire retardancy.

Low Refractive Index for Optical Effects concerns the refractive index (RI), the ratio of the speed of light in a vacuum to the speed of light through a material. The lower the refractive index, the less the material bends the light, decreasing the focusing power, the reflective effect and the light dispersion. The material of an optical lens must possess a lower value of refractive index. The clarity or transmittance of a material usually increases with decreasing crystallinity, refractive index, compressibility and intermolecular interaction. Many of the optical properties of a material are related to the refractive index.

Reduced Dirt Collection or Dirt Pick-up Resistance is the ability of a coating to resist adherence of dirt over a defined period of time and avoid film darkening and an uneven appearance.

1. Building Facades and Protection - Metal Building Panels and Parts

Relevant Fluoropolymer Products Used: PVDF and FEVE

The information below is applicable to this end use as well as the metal and cool roofing end-uses.

General Introduction

Fluoropolymer-based coatings (FBCs) offer superior performance, service life, sustainability, appearance and value for applications on a wide variety of metal substrates used in commercial and monumental building projects.

These fluoropolymer-based systems include polyvinylidene fluoride (PVDF) and fluoroethylene vinyl ether (FEVE) resin-based formulations. These two fluoropolymers are the film-forming binder resins in factory-applied industrial and construction coatings used in settings where extreme durability and lifespan of several decades or more are needed to provide substrate protection. FBCs extend the lifespan of the underlying materials and are a critical specification for certain products and end markets.

FBCs are available in both coil and extrusion applications. Each type has specific uses for metal building products.

- Coil coatings are applied to large rolls or “coils” of steel and aluminum by a continuous, automated process that can run up to 700 feet per minute. The coil is unwound, cleaned, pretreated, primed, painted and thermally cured before being recoiled for shipment. This is also known as a pre-paint process.
- Extrusion coatings are spray-applied to aluminum, preformed extruded substrates in a vertical or horizontal line. The extruded product is cleaned and pretreated, then the coating is spray applied and thermally cured to set the system. This also is known as a post-paint process.

FBCs can be applied to a variety of components used in projects ranging from pre-engineered metal buildings to municipal arenas and skyscrapers (**Table 3**).

Table 3. Fluoropolymer Application Uses and Fluoropolymer Building Project Types

Fluoropolymer Application Uses	Fluoropolymer Building Project Types
• Canopies • Column covers • Curtain wall • Decorative accents • Doors and entrances • Façade systems • Fascia • Louvers • Perimeter trim • Rain and wind screens • Roofing • Skylights • Soffits • Storefronts • Sunshades • Wall panels • Windows	• Airports • Apartments and condominiums • Auto dealerships • Banks and financial service providers • Corporate campuses and office buildings • Courthouses and government centers • Hospitals and clinics • Hotels and resorts • Libraries • Museums and galleries • Performing arts centers and theaters • Recreation and community centers • Research laboratories • Restaurants • Schools and universities • Shopping and retail centers • Stadiums and arenas • Transportation stations and transit-oriented developments • Worship and spiritual spaces

Important properties that FBCs enable for construction include, but are not limited to the following:

- Adhesion, flexibility, formability, abrasion resistance, hardness and impact resistance;
- Resistance to chemicals, flame spread/surface burning; and
- Durability as demonstrated by UV-resistance, film integrity, low film erosion rate, humidity resistance and corrosion resistance.

We are unaware of another coating technology that enables the performance parameters of durability and product longevity that are the defining characteristic of FBCs.

Outdoor exposure testing provides data showing FBCs have an erosion rate approaching 50 percent less than other coating technology options used in I&C settings. This difference explains why FBCs have a life expectancy of 50 years or more in many settings compared to 20 years or less for some alternate technologies. This reinforces why FBCs are so unique and useful in the development of durable and essential building products.

Failure of the coating system will lead to the need to recoat the metal substrate or degradation of the metal substrate can occur, which may require its eventual replacement. The difference in coating performance is profound as FBCs can retain their protective properties for more than 50 years. Given the fact that exterior surfaces on infrastructure such as skyscrapers and monumental buildings cannot be easily repainted or replaced, coating performance and its subsequent substrate protection is key to overall sustainability. Driving towards less durable technologies would result in regrettable substitutions requiring field-refinishing and building component replacement leading to increases in waste and carbon emissions.

Even for buildings where repainting or replacement of metal panels is not as difficult as for skyscrapers or other monumental structures, reduced service life can present disruptions in the use of buildings housing areas such as education, medical, government and communications. In addition, field-refinishing brings with it potential release of VOCs to the atmosphere and the possibility of chemical releases to the environment.

PVDF-based Infrastructure and Construction Coatings

Prepainted metal is a high-quality product manufactured under strict quality control in the coil coating process. **Figure 2** illustrates the typical composition of a coated metal**.**

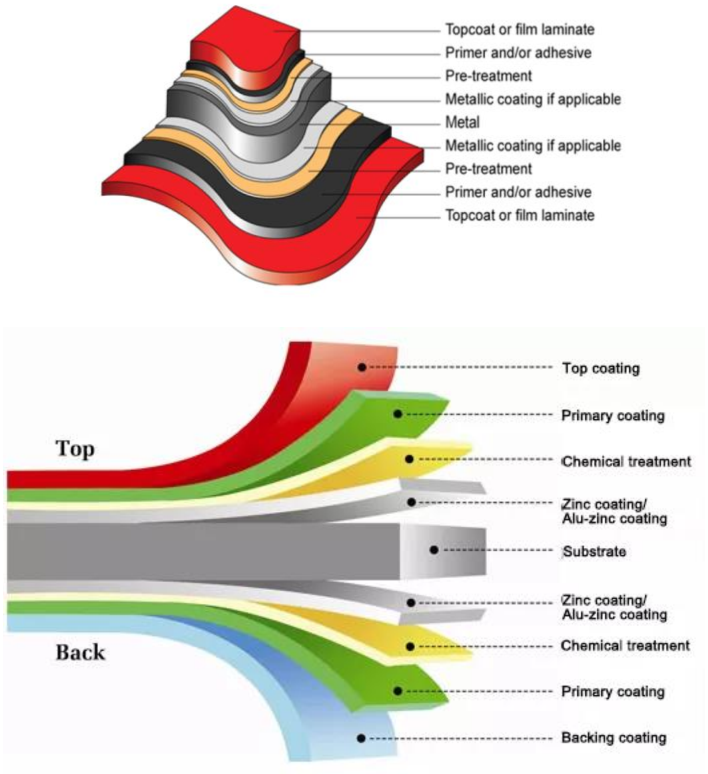
The thickness of coatings is usually quoted with a combination of top-coat and primer. In the majority of cases, the primer is a thin layer, of the order of 4 µm, the majority of the coating being the topcoat. For multi-coat systems, such as 3- or 4-coat PVDF-based coating, the total thickness including primer and 2 or 3 top-coats is usually quoted, the thickness of each layer being required for its individual function in the total system.

Liquid paints are made up of four main constituents:

- Pigments
- Binders
- Solvents
- Additives

The solvent is used as a delivery mechanism, allowing the paint to flow-out and give a smooth wet film before drying and curing. Solvents do not remain in the final, cured product. The function of the finished product is a combination of the binder, pigments and additives, but the industry standard is to refer to coatings based on the type of binder used.

Figure 2. Examples of the composition of a typical prepainted metal product.



Figures with permission from Arkema and www.yumisteel.com.

The binder is a polymeric material which gives structure to the paint. The main types of polymers used for coil coating paints are:

- Polyester
- Polyurethane
- Polyvinylidene fluoride (PVDF) and fluoroethylene vinyl ether (FEVE)
- PVC (plastisol)
- SMP (Silicone Modified Polyester)

PVDF forms a highly stable resin which is not cured in the paint in the same way as polyesters. Instead, it is fused into the paint film as a thermoplastic coating. Unlike other common coating polymers, the PVDF resins have been shown not to be susceptible to attack by UV radiation, leading to a coating that is very stable for long periods in sunlight.

FBCs tend to have coatings in the thickness range of 25 µm to 28 µm, although multi-layer systems can have higher thicknesses up to 55 µm. Unlike polyurethanes, high-build PVDF-based coatings are made up of up to 4 layers rather than the usual 2.

As mentioned above, PVDF-based film coatings have been shown not to be susceptible to attack by UV light, so the resin is highly resistant to degradation upon exposure to sunlight, unlike virtually all other polymers. This property provides a very high resistance to fading and chalking as well as very good long-term maintenance of gloss and color.

Apart from being highly resistant to UV light, the FBCs utilizing PVDF resin are also highly resistant to many chemicals and can have excellent stain resistance. Due to these superior qualities, FBCs also tend to carry a premium price compared to most other coating systems.

For this specific end-use, there has been a licensing program in place for over 50 years in order to help ensure that all specific PVDF-based coatings perform exactly at the expected level by architects and end users. All details are available online (Arkema 2022b).

Case Studies

Arkema Kynar 500® FSF® **PVDF** Building Façade Case Studies:

https://kynar500.arkema.com/en/media/case-studies/

Façade – Wall Panels Case Studies:

SEI Investments (PA, USA). Aluminum panel wall system meeting AAMA 2605 standards. PVDF Resin-based coating. 70% Kynar 500®FSF® system: https://kynar500.arkema.com/en/media/case-studies/sei-investments/

The Valley View building on SEI Investments' North Campus in Oaks, Pennsylvania, features an aluminum panel wall system finished in 70% Kynar 500® FSF® PVDF based coil coatings. Along with these architectural coatings' vivid colors, these innovative finishes are formulated with solar reflective pigments. As with other specific 70% PVDF resin-based, high-performance, architectural coating systems, this particular application meets or exceeds AAMA 2605. It has been tested to meet or exceed the equivalent of 10 years south Florida weathering exposure conditions for color retention and resistance to fading, chalking and erosion.

DeWitt Family Service Center (Northwestern College, Iowa) Wall panel system. Coil Coatings PVDF-based system: https://kynar500.arkema.com/en/media/case-studies/dewitt-family-science-center/

Completed in 2019, this eco-friendly and state-of-the-art 61,000 square-foot facility creates a grand entrance to the campus of Northwestern College. It serves health science programs including biology, chemistry and the now on-campus nursing department. The building is brought to life with flat lock panels.

Appaloosa Library (Scottsdale, AZ) Wall cladding. Duranar® VARI-cool coatings: https://kynar500.arkema.com/en/media/case-studies/appaloosa-library/

The one-story Appaloosa Branch Library in Scottsdale, AZ is a departure from libraries of the past that featured dark wood and dim lighting. As you approach the new Library, the building's metal skin-20,000 square feet (1,858 m2) of wall cladding changes colors. When applied and cured on properly prepared substrates, Duranar® VARI-Cool coatings offer brilliant color change along with exceptional color stability, chalk resistance, durability, abrasion resistance, chemical resistance and flexibility. The polychromatic coating utilized on the library is designed to help the structure remain beautiful for decades. The pearlescent pigments used in the coating reflect the sun's infrared [heat] energy, which helps the library stay cool and thereby consume less energy for air conditioning, even in the hot Arizona sun.

Stony Brook University (New York) Aluminum wall clad coil coating metal panels. Kynar 500® PVDF system: https://kynar500.arkema.com/en/media/case-studies/stony-brook-university-student-c/

An Aluminum Composite Material (ACM) was ordered in bold colors and installed as exterior cladding on an interconnected series of three buildings. The composite consists of two sheets of 0.020" aluminum thermobonded to a polyethylene core in a standard thickness in a continuous process. The composite material was pre-finished with Arkema's Kynar 500® PVDF resin-based coil coating. A wide spectrum of attractive standard and custom colors is available. Approximately 100,000 square feet of the ACM was installed on the buildings in a wide range of colors.

2. Roofing and Roofing Structures

Typical Products Used: PVDF FBCs

FBCs offer superior performance, service life, sustainability, appearance and value for applications on a wide variety of metal substrates used in commercial, monumental and other building projects. FBC systems often include polyvinylidene fluoride (PVDF) resin-based formulations. As previously discussed, PVDF is a film-forming binder resin in factory-applied industrial and construction coatings that is used in settings where extreme durability and lifespan of several decades or more are needed to provide substrate protection. FBCs extend the lifespan of the underlying end product and are a critical specification for certain end-use markets.

FBCs utilizing PVDF are typically only available in coil applications for the roofing end market. Coil-applied coatings over aluminum and steel substrates are used for metal roofing. Coil coatings are applied to large rolls or "coils" of steel and aluminum by a closed system, an automated process that runs up to 700 feet of coated material per minute.

Metal roofing can be incorporated into nearly any building type. Two typical metal roofing products are corrugated and standing seam. Additionally, metal roofing can be painted and stamped to look like other roofing substrates such as wood, shingles and slate.

Metal roofing has many inherent advantages compared to other traditional types of roofing, including:

- Better resistance to wind, hail and fire.
- Better energy efficiency, especially when incorporated with solar reflective pigment systems.
- Less weight than traditional types of roofing.
- Longer life spans (in some cases 50 years or greater) when utilizing FBCs.
- Higher circularity due to the common practices and infrastructure available for the recycling of steel and aluminum.

Important enabling properties of FBCs for metal roofing include, but are not limited to the following:

- Adhesion, flexibility, formability, abrasion resistance, hardness and impact resistance
- Resistance to chemicals, flame spread/surface burning
- Solar reflectance
- Durability as demonstrated by UV-resistance, film integrity, low film erosion rate, humidity resistance and corrosion resistance

As noted above, these fluoropolymer systems have been shown to provide numerous important benefits for both roofing and building facades. (Ref: https://kynaraquatec.arkema.com/en/products/lower-lifetime-ownership-costs/)

It is critical to understand that these many favorable attributes combine to provide a lower lifetime ownership cost:

- Lower energy usage from higher solar reflectivity and lower roof temperatures
  - lower carbon footprint
  - reduced dirt pick-up
  - significant mold and mildew resistance
- World-class UV resistance and long-life color retention
- Lower peak energy demand charge

- Longer lifespan of roof coating and longer lifespan of roof substrate
- Lower maintenance costs and less downtime
- Increased efficiency and longer lifespan of HVAC equipment
- Lower VOC emissions
- Support ability to seek tax credits, rebates and building codes
- Help enable Green Building credits applicability to buildings
- Versatile and can be applied to a wide variety of roofing types

Lower Energy Usage from Higher Solar Reflectivity and Lower Roof Temperatures

Higher Reflectivity (TSR value) throughout the roof's life results in lower cooling costs.

A properly formulated FBC can significantly reduce the surface temperature by reflecting the sun's rays. For roofs, it has been shown to reduce the roof's surface temperature by as much as 50°F (28°C) (USDOE) and interior temperatures by 6-9°F (3-5°C) (RCMA), which translates into reducing cooling costs by as much as 30% (CRRC).

Lower Carbon Footprint

Reduced air conditioning means less energy used, less carbon dioxide emitted and more comfortable building conditions. Lower energy bills mean less fossil fuels needed to generate electricity and so a lower carbon footprint. Add in less frequent roof cleanings and recoatings, and the carbon footprint of the project shrinks even further.

Furthermore, FBCs designed for roofing applications have shown the ability to maintain a 3-year Total Solar Reflectance (TSR) above 0.80 (Arkema 2022), well above industry standards for white roofs of 0.55 (as measured by the Cool Roof Rating Council, CRRC. This means a roof utilizing an FBC can reflect over 80% of the sun’s rays. By comparison, a Modified Bitumen or Asphalt Shingle has a TSR of only 0.05 - 0.25 (CMR, 2015) (**Figure 3**). FBCs can reduce the "Heat Island Effect" of cities, where the difference between outside air temperatures in a city and its surrounding rural areas can be 5 - 9°C higher (9 -16°F) (Cool Roofs).

Figure 3. Sun’s Radiation versus Solar Reflectance vs Thermal Emittance

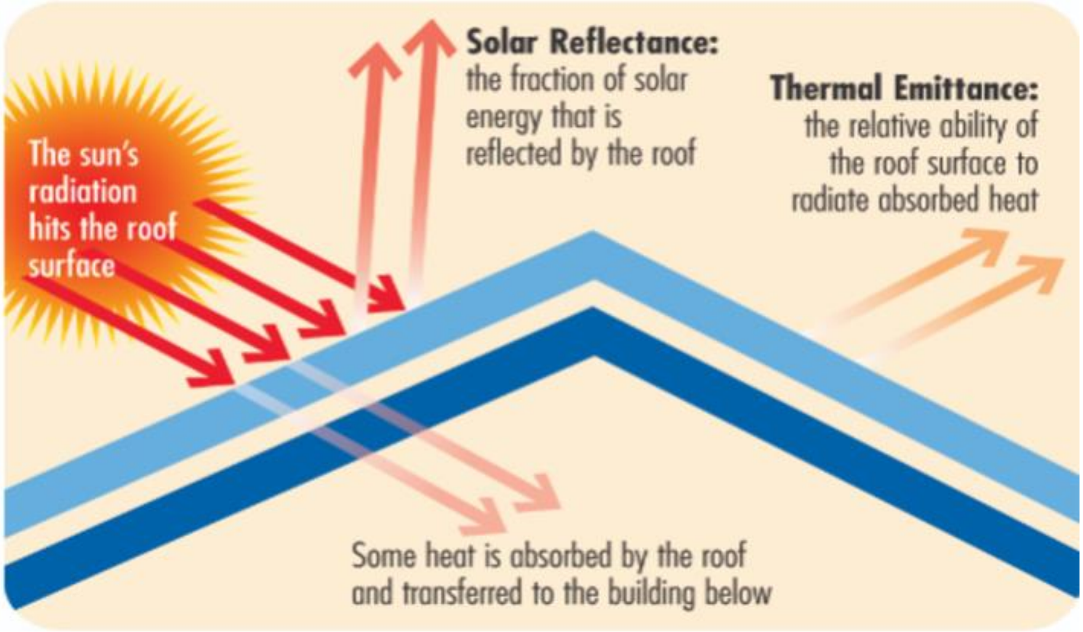


Figure with permission of Arkema.

Reduced Dirt Pick-up

An FBC topcoat's low surface energy promotes dirt shedding. The surface of a formulated FBC reduces dirt pick-up, keeping the building and other structural projects brighter and fresher looking. The pictures below show the results when a 1" square area of carbon black is applied to the paint surface and then is washed off. One can clearly see in **Figure 4** that the surface of the FBC is much easier to clean than the surface of the acrylic based coating.

Figure 4. Dirt Pick Up Study with Acrylic-Based Resin Coating vs Kynar Aquatec® Based System

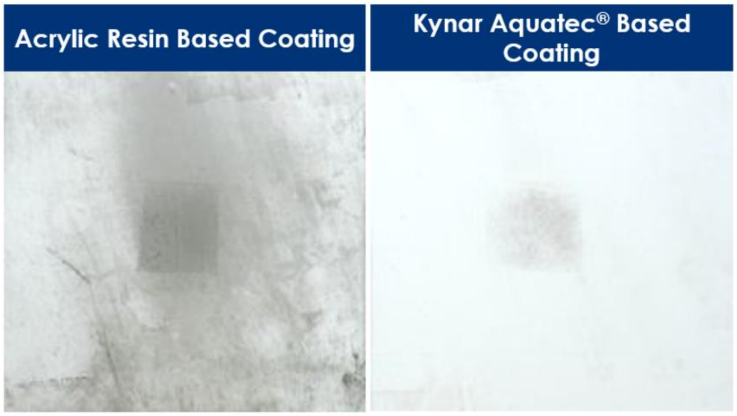


Figure with permission of Arkema

Mold and Mildew Resistance

An FBC topcoat has increased mold and mildew resistance. FBCs help to prevent mold and mildew growth. In the example below in **Figure 5**, the FBC stayed clean vs. the acrylic based coating after 19 months weathering in South Florida. No biocide was added to either coating.

Figure 5. Mold-resistance Study of Acrylic-based coating vs Kynar Aquatec® based coating

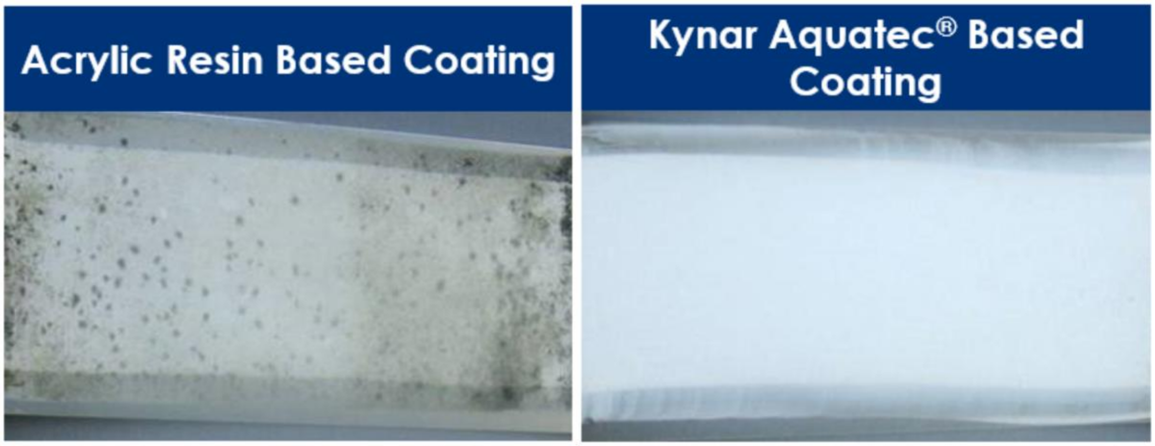


Figure With permission of Arkema.

World-class UV Resistance and Long-Life Color Retention

The FBC provides for long-lasting color retention. FBCs have been used on notable buildings since 1965. Using the same PVDF FBC technology, the FBCs have exhibited the same color fast performance. This picture (**Figure 6**) shows the color fastness after over 20 years of weathering in South Florida.

Figure 6. Twenty years of South Florida Exposure for Various Kynar Color Panels

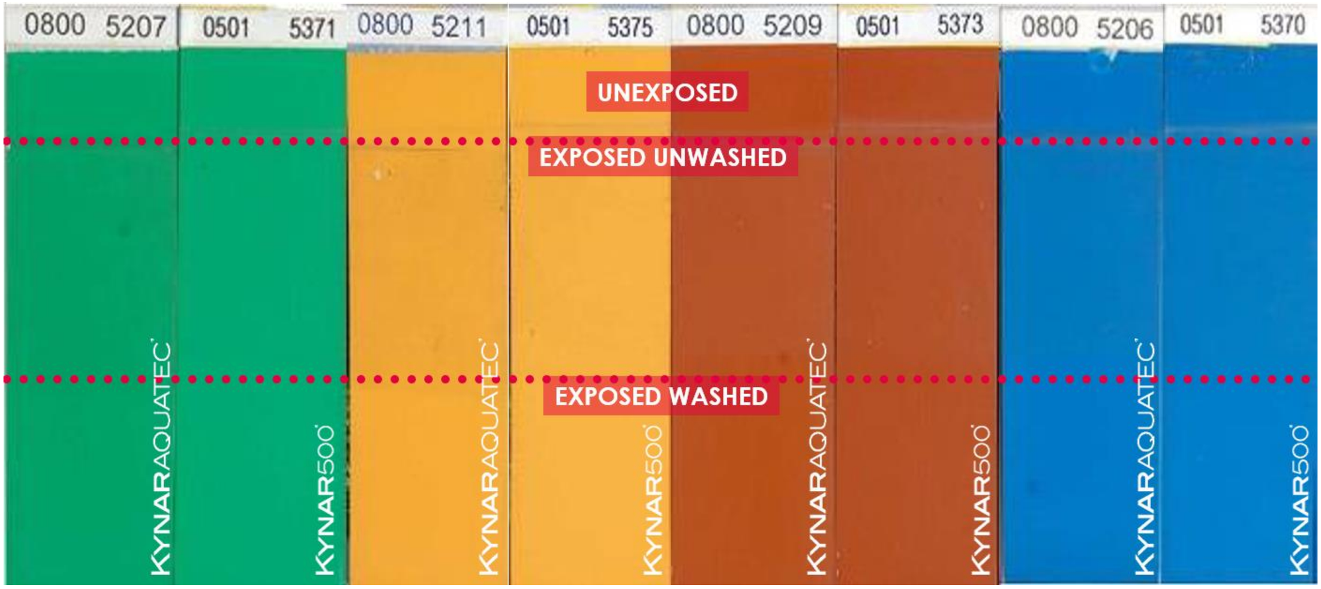


Figure with permission of Arkema.

Lower Peak Energy Demand Charges

Commercial Buildings are often charged peak demand fees by local utilities. Peak demand fees are a significant cost for commercial buildings, often greater than the electricity usage fees themselves (**Figure 7**). A 20-30% reduction in peak demand fees is common for Cool White Roofs (IRRC, 2016).

Figure 7. Kynar Aquatec® Cool Roof Energy Savings Calculator

Figure with permission of Arkema.

Longer Lifespan of Roof Coating and Longer Lifespan of Roof Substrate

Kynar Aquatec® resin-based roof coatings commonly last at least 20 years, much longer than the typical lifespan of an acrylic coating. The ability for the FBCs PVDF-based backbone to withstand the sun's UV ray is well demonstrated. This results in a longer-lasting roof coating. A lifespan of at least 20 years is expected for Kynar Aquatec®-based roof and façade coatings are quite common, well outpacing the lifespan of acrylic coatings which is low as 7 years. Additionally, the cooler surface temperature (by as much as 50°F/28°C) results in less degradation of the roofing substrate, extending the lifespan of the substrate.

Increased Efficiency and Longer Lifespan of HVAC Equipment

A cooler roof means less air conditioning (A/C) use and also means your existing equipment is more effective, extending the lifespan of your A/C unit. Alternatively, a smaller, less-expensive A/C unit could be adequate.

The cooler surface temperature (by as much as 50°F/28°C) of a Kynar Aquatec® resin-based roof coating results in several benefits: (1) less use and less wear and tear on the HVAC equipment, translating into longer service life for the equipment; (2) higher efficiency of rooftop units (due to lower inlet temperatures to rooftop air units) (Haverstic, 2016); and (3) for new construction, a small HVAC unit could be specified reducing the upfront HVAC investment.

Lower VOC Emissions

Kynar Aquatec® coatings are formulated to be low VOC. In addition, the FBCs long lifespan means less recoating (and less VOC's emitted during the recoating process) versus the other alternatives. Each time there is a recoating, volatile organic compounds (VOCs) are emitted into the atmosphere. Therefore, the less frequent coatings mean less VOCs over a defined period of time, or the lifetime of the structure. In fact, a study by Lawrence Berkeley National Laboratory showed a 30-40% reduction in VOC emissions. (CMR 2015)

No other coating technology enables the performance parameters of durability and product longevity that are the defining characteristic of FBC. Outdoor exposure testing provides data showing FBCs have an erosion rate nearly 50 percent lower than other coating technology options used in construction. This difference explains why FBCs can have a life expectancy of up to 50 years in many settings compared to less than 20 years for some alternate technologies in the same end uses. This also reinforces why FBC are critical in the development of durable and essential building products.

Failure of the coating system will likely lead to the need to repaint a metal roof or degradation of the metal substrate, which may require eventual replacement of the metal roof. The difference in coating performance is profound as FBC can last more than 50 years. Given the fact that exterior surfaces on metal roofing cannot be easily repainted or replaced, coating performance and its subsequent substrate protection is key to meeting important sustainability objectives. Driving towards less durable technologies would result in regrettable substitutions requiring field-refinishing and building component repair and replacement, which in turn will lead to increased waste and a larger carbon footprint.

Reduced service life of metal roofing can present disruptions in the use of buildings housing areas such as education, medical, government and communication. In addition, field-refinishing brings with it potential release of VOCs to the atmosphere and exposure risks to people, animal life and the environment.

Case Studies (i.e., heat reflecting and temperature reductions).

FBCs PVDF Building Case Studies: *https://kynar500.arkema.com/en/media/case-studies/*

Florida Roofing and Sheet Metal Contractors Association (FRSA; Orlando, FL): Roof and Gutters: https://kynar500.arkema.com/en/media/case-studies/frsa-case-study/

This case study employed a water-based FBC PVDF resin that does not need to be baked at temperatures over 375°F, making it ideal for air-dry, field-applied coatings. The premium, weather-resistant coating can be easily applied to a variety of substrates, including metals, plastics, concrete, fiber cement, stucco, Exterior Insulation Finishing System (EIFS) and previously painted surfaces.

The use of this PVDF FBC resin and complex inorganic pigments gives the final coating system the ability to resist film erosion, chalking and fading caused by harsh UV exposure. For more information see the case study details: https://kynar500.arkema.com/files/live/sites/hpp_kynaraquatec/files/downloads/literature-case-studies/Case-Study-FRSA-Durable-Exterior-Coating-Gets-New-HQ-Building-Ready-for-the-Long-Haul.pdf

Vinita Health Center (Tribal health center in Oklahoma): Metal Roofing. LEED Silver certified. FBC PVDF resin: https://kynar500.arkema.com/en/media/case-studies/vinita-health-center/

Cherokee Nation Health System, the largest tribally owned health care system in the United States, made plans to expand the 4,000 square-foot Vinita Health Center into a 92,000 square-foot building, making it 23 times larger than the original and the second largest center in the health system. With the overall inspiration taken from the community's past, historic materials like wood and stone were used as the primary construction materials. To help increase the durability and expand the lifespan of the center, a metal roof was installed on the structure. Furthermore, the use of a metal roof was selected to match surrounding community buildings, as standing seam roofs are commonly used on many other Cherokee Nation buildings. A standing seam roof, which required 43,500 square feet of Snap Clad panels finished in an FBC coating was installed.

Brandon Dunes Golf Resort (Brandon, Oregon): Metal Roof. Kynar 500®FSF® PVDF resin-based system: https://kynar500.arkema.com/en/media/case-studies/bandon-dunes-golf-resort/

FBCs based on PVDF resin were chosen to protect roofs of the clubhouse, snack bar and lodge against the rigors of the coastal weather.

Charles de Gaulle Airport (Paris, France). Cool Flat Roof: https://kynaraquatec.arkema.com/en/media/case-studies/charles-de-gaulle-airport/ (**Figure 8)**

The airport has taken a step forward and chose to test the concept of saving energy linked to air conditioning thanks to passive cooling via cool roofing. A white paint that reflects the sun light waves during sunny periods was applied on the West Pier of Terminal 2G. Over 1,160 square meters were covered with the Cool Roof paint from the Cool Roof France Company. The application required 10 days and two people for the preparation of the roof/ coating application. The coating system included two layers of base coat formulated with an acrylic based paint and a topcoat based on an FBC latex.

The West (with cool roof) and East Pier (without cool roof) of Roissy airport were monitored by a consultant to estimate the efficiency of the cool roof paint system in lowering the temperature at the surface of the roof. The temperature at the surface of the roof, the temperature of the ceiling above and the ambient temperature were monitored from June 1 to September 30. A weather station also measured outside temperature (°C) and solar radiation (W/m²). During this period, the two Piers were air-conditioned and used in similar conditions with regard to passengers, traffic, etc.

Figure 8. Comparison of Cool Roof Surface Treatments at CDG Airport

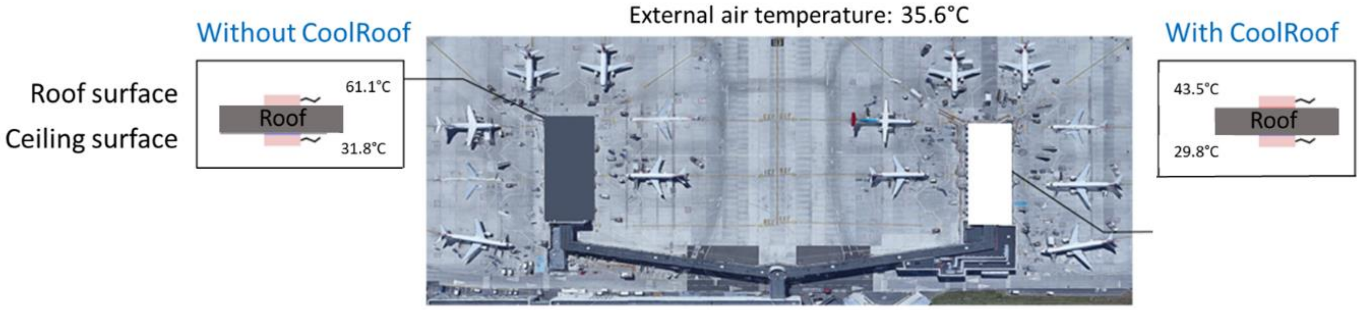


Figure with permission of Arkema.

The recorded data clearly displays the facts: the temperature of the passive cooled roof sharply lowered by 24.2°C and the energy consumption linked to air conditioning to reach desired settings inside building has seen a drop of 21% (6374 kWh, 5.5 kWh/m²). In addition, employees working all day long inside the Pier have reported a great improvement in thermal comfort during this period (as well as following years). A dark roof absorbs most of the energy received by the sun, heating the roof structure and transferring most of heat flow to the underlying building or to the surrounding air: air conditioners that suck hot air and dump it outside can further exacerbate the cooling requirement of a building. The cool roof technology not only reflects as much of the sun's energy as possible, but also affects surrounding temperatures and offset carbon emissions.

Changwon Tunnel (S. Korea). Ceiling Coating:

https://kynaraquatec.arkema.com/files/live/sites/hpp_kynaraquatec/files/downloads/literature-case-studies/changwon-tunnel-case-study-2020.pdf See **Figure 9**

The light-reflecting characteristics of a ceiling finish enhance the overall efficiency and effectiveness of tunnel interior lighting systems. The presence of moisture and engine exhaust products in the tunnel - especially emissions from diesel power trucks - creates an atmosphere that can darken unfinished surfaces, detracting from their light-reflecting qualities and the aesthetic impression it leaves upon users. The evaluation and selection process for tunnel finish materials must therefore consider reflectivity, adaptability, cleanability, durability and public safety considerations. To improve illumination, visibility, cleanliness and safety within the Changwon Tunnel, the team responsible for maintaining the structure decided to paint the unfinished ceiling, which was dulling as a result of dirt and other airborne pollutants. Because the coating was to be applied inside the tunnel, the use of a low-VOC water-based coating was a key requirement. Other important coating performance characteristics desired were long-term durability; ability to resist dirt pick-up, biological growth accumulation and other weathering factors; and retention of reflective value and color.

Figure 9. Four-lane Changwon Tunnel in South Korea

Figure with permission from Arkema.

3. Bridge Structures

Typical Products Used: FEVE

While the information in this section largely focuses on bridges, the general properties descriptions also apply to building facades and, in some cases, roofing.

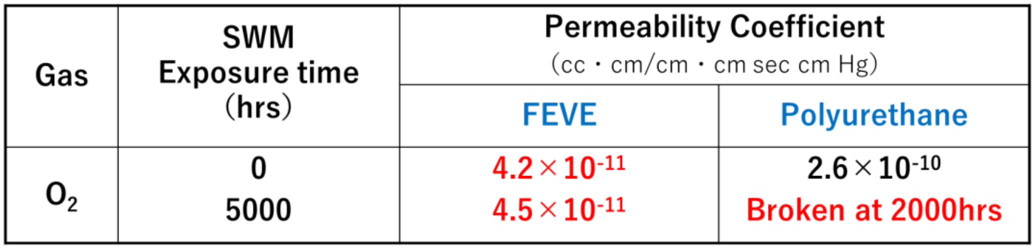
Bridge structures clearly need durable coating performance to protect the painted metal substrate below and maintain the bridge's structural integrity. Any coating system must last a long time given how difficult, disruptive and expensive the recoat process is. Bridges are subject to highly adverse environmental conditions including high intensity sunlight, fog, rain, saltwater (coastal areas) spray and constant automobile exhaust among other stressor factors. The high weathering performance of FEVE allows the paint system to prolong the bridge's service life and protecting the substrate (or coated material), which subsequently decrease the number of re-painting cycles of the bridge infrastructure or building. This eventually contributes to a better (lower) Life Cycle Cost.

With its noted performance of water resistance and low oxygen permeability, a fluoropolymer-based coating systems that typically uses an FBC utilizing FEVE as a topcoat could protect the substrate (or coated material) by increasing the anti-corrosion ability of the substrate and coated material. This has the impact of prolonging the service of the paint system. Furthermore, it contributes to the reduction of CO_2 generation by extending the life of the protected material and delaying or postponing the time between re-coating the bridge structure. Less recoating is equivalent to lowering the CO_2 generated in paint system product manufacture and installation.

Oxygen Permeability Coefficient after accelerated weathering with a Sunshine Weather Meter (or weatherometer). See **Table 4**.

Oxygen contributes significantly to the ability of a substance to corrode. FEVE has demonstrated significant shielding effect under 5000 hours accelerated weathering test. Its permeability coefficient is unchanged after the 5000 hours test while the comparative alternative polyurethane film structure was deteriorated and broken after 2000 test hours.

Table 4. Permeability Coefficient for O_2 in FEVE and Polyurethane Coatings



Gas	SWM Exposure time （hrs）	Permeability Coefficient （cc・cm/cm・cm sec cm Hg）	
		FEVE	Polyurethane
O_2	0 5000	4.2×10^{-11} 4.5×10^{-11}	2.6×10^{-10} Broken at 2000hrs

Data with permission of AGC.

Mechanical Properties

The FEVE coating film has almost the same mechanical modulus (E), complex modulus and attenuation rate even for 3,000 hours after sunshine weatherometer (SWM) irradiation. **Figure 10** shows retention of the ability to protect the underlying coating film and substrate over a long period of time. This means that the FEVE coating protects the base coating function as well as the substrate itself (i.e., bridge metal structure).

Figure 10. Mechanical Properties Graphs of FEVE Coating Film. In the legend, "SMW" stands for "sunshine weather meter."

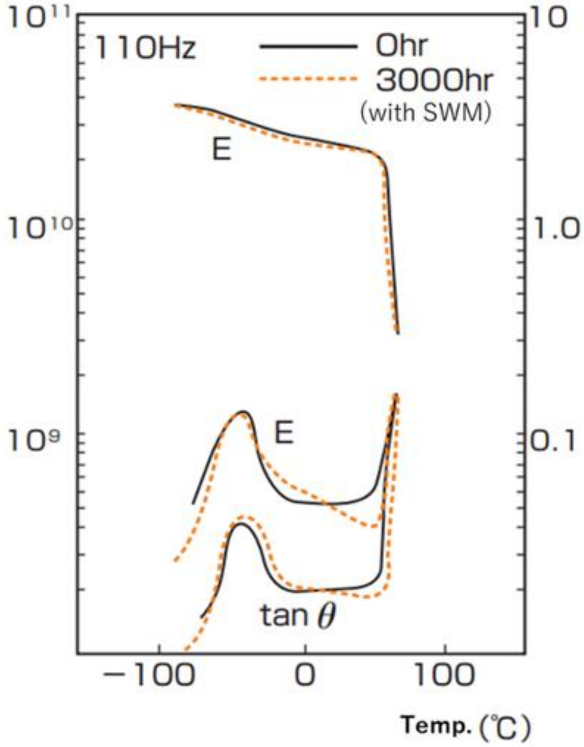
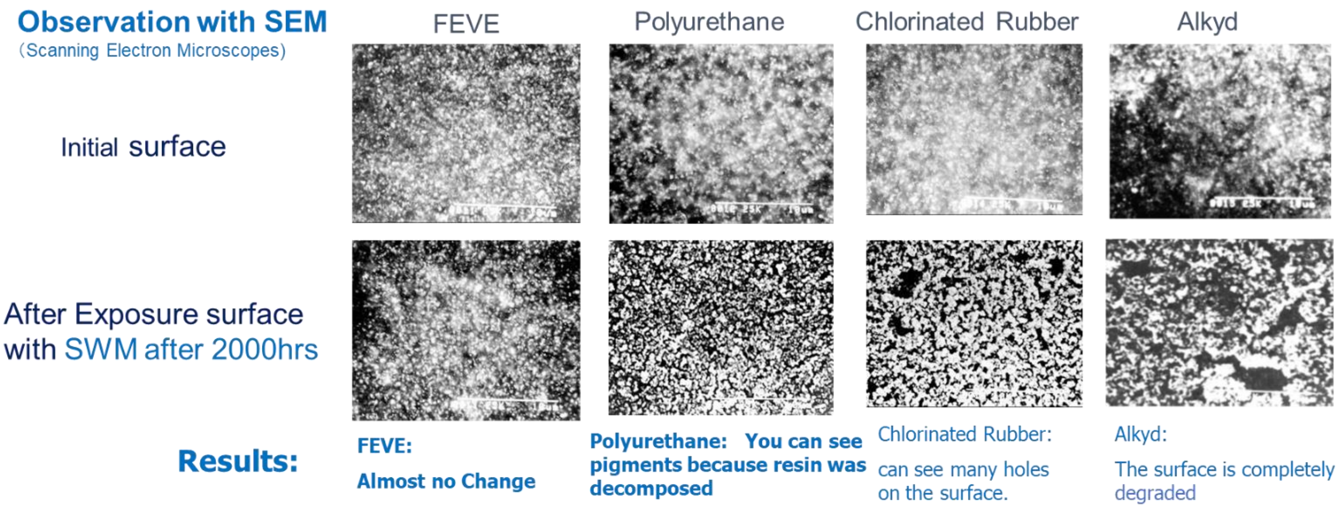


Figure with permission of AGC.

Comparison of weatherability and corrosion protection effects for four topcoat systems. FEVE was evaluated versus topcoats of polyurethane, chlorinated rubber and an alkyd system with a steel panel as the primary substrate. Each system also had a primer coating, an undercoat and an intermediate coat below the subject topcoats. These steel panels were evaluated initially by SEM (a scanning electron microscope) and then again after 2000 hours of accelerated exposure. While the alkyd surface structure was completely destroyed after the 2000 hours exposure and the polyurethane and chlorinated rubber systems also exhibited visible surface damage, the FEVE system was largely unchanged (**Figure 11**).

Figure 11. Comparison of weatherability and corrosion protection effects for topcoat systems. Picture of scanning electron micrograph for each of 4 systems along with data table for before and after exposure.

Topcoat System	**Fluoro-polymer**	**Polyurethane**	Chlorinated Rubber	Alkyd
Substrate	steel panel			
Primer	zinc-rich primer			Wash primer
Undercoat	Epoxy resin	Epoxy resin	Chlorinated rubber	Anti corrosive Undercoating
Intermediate Coat	Epoxy resin	Epoxy resin	Chlorinated rubber	Alkyd
Top coat	**Fluoro-polymer**	**Polyurethane**	Chlorinated rubber	Alkyd
Total Film thickness(μm)	255	255	245	170



FEVE: **Almost no Change**

Polyurethane: You can see pigments because resin was decomposed

Chlorinated Rubber: can see many holes on the surface.

Alkyd: The surface is completely degraded

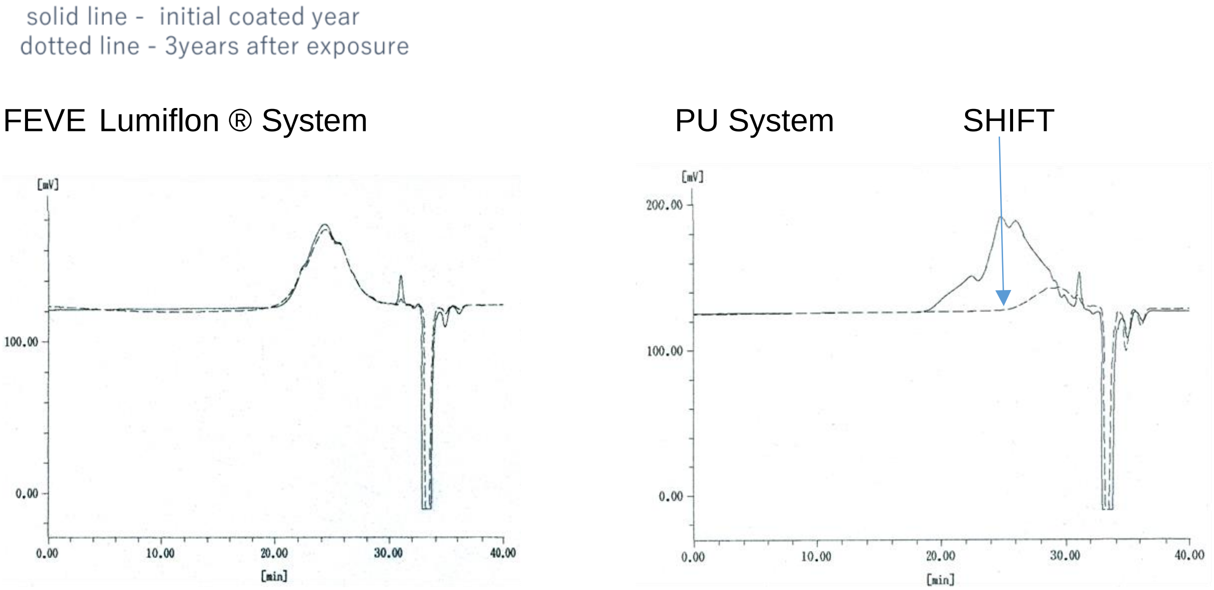
Figure with permission of AGC.

Molecular Weight Change for FEVE – Lumiflon® System vs Polyurethane. A study was conducted by the Honshu-Shikoku Bridge Authority (**Figure 12**) of the actual bridge and the test sample panel samples. **Figure 13** shows a Gel Permeation Chromatography (GPC) chart that can measure molecular weight. Molecular weight had been changed to about 1/6 for polyurethane within 3 years of offshore bridge exposure. On the other hand, FEVE has no change in the charts and little change in molecular weight. The polyurethane coating system has a broken polymer backbone. The FEVE system is intact.

Figure 12. Honshu-Shikoku Bridge Authority Coatings Study

Figure with permission of AGC.

Figure 13. Molecular Weight Change Upon 3 Years Exposure in Two Bridge Coating Systems



Resin	LUMIFLON		Polyurethane	
Period	initial	3 years	initial	3 years
Molecular Weight	9,000	8,400	3,600	600

Data and graphs with permission of AGC

Film consumptions of FEVE vs Polyurethane including 20 years of data for 4 topcoat systems: Alkyd; Chlorinated Rubber; Polyurethane; FEVE.

This test was done as a Hiroshima rooftop exposure about 1 km (0.6 miles) from the Japanese coast. All the systems except the FEVE system exhibited chalking. It was noted that the film coating for both the polyurethane and chlorinated rubber were severely eroded. The coating thickness of the FEVE and polyurethane systems were then measured to determine yearly film exposure loss after a 15-year exposure period. The evaluation showed a 2 µm loss/year for the polyurethane and a 0 – 0.1 µm loss/year for the FEVE system (**Figures 14 and 15**).

Figure 14. Film Erosion Study: 20-Year Rooftop Exposure of 4 Coating Systems. When looking at the reflection of sunlight, everything except FEVE was chalking, and the coating film of polyurethane and chlorinated rubber was severely eroded.

20 Years Exposure

A: Alkyd system
B: Chlorinated Rubber system
C: Polyurethane system
D: FEVE system

Film Consumptions by Year

Polyurethane: 2 µm /year

FEVE: 0-0.1 µm /year

Figure and data with permission of AGC.

The ability of the anticorrosion effects depends on the coating's ability to prevent the diffusion of water and oxygen moving through the coating. Maintaining film thickness is fundamental to controlling the diffusion of corrosion substances. The fact that the topcoat of FEVE maintains its thickness for a long period of time is linked to the fact that the thickness of the middle and bottom coats is maintained, and the anti-corrosion function is maintained. On the other hand, epoxy resin, which is the under layer of polyurethane resin, loses film thickness each year due to sunlight. After the topcoat of polyurethane resin wears off, the overall coating film thickness decreases rapidly, resulting in a rapid loss of anticorrosion effects.

Figure 15. Film Erosion Study FEVE vs Polyurethane: 15-Years Rooftop Exposure

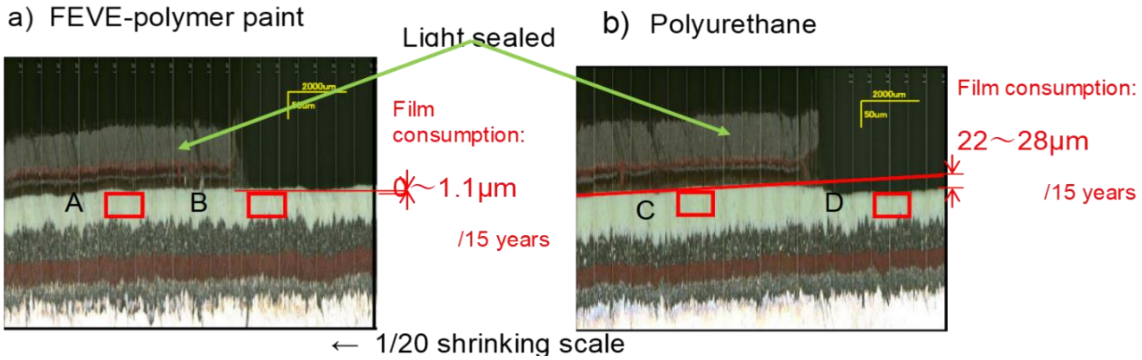


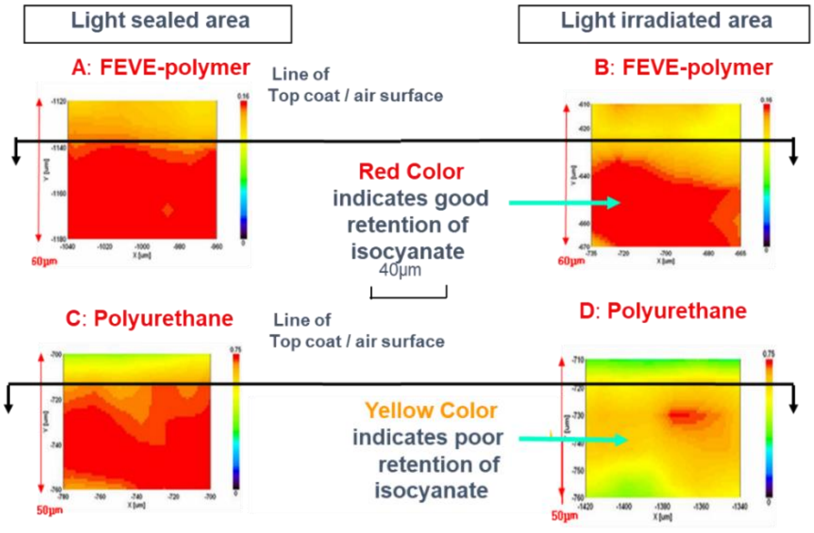
Figure and data with permission of AGC.

Polyurethane decreases by 22-28 μm in 15 years and about 1.5-1.9 μm per year. FEVE had a depletion rate of 0-1.1 μm at 15 years and less than 0.1 μm at 1 year. It can be seen that FEVE has much better weather resistance than polyurethane.

Isocyanate crosslinking retention of FEVE vs Polyurethane over a 15-year sunlight test exposure

Crosslinking in a film coating is often critical to the longevity and integrity of the film. The residual level of isocyanate cross-linking can be measured by Infrared (IR) spectroscopy. **Figure 16** shows the FEVE and polyurethane coatings in contrasting pictures, one of a light-sealed area and one in a light-irradiated area. It is quite clear that the isocyanate cross-linking in the polyurethane system was retained poorly, while the FEVE system provided good retention and will likely protect the substrate for several decades.

Figure 16. 15-Year Sunlight Exposure of FEVE polymer and polyurethane systems



The residual rate of the cross-linked portion of the coating film can be measured by IR.

The red part of the figure remains healthy.
FEVE seems to have a large amount of isocyanate cross-linked parts remaining deep in the lower section, even after 15-year sunlight exposure

The polyurethane system seems to be cut a lot, and the degree of residual isocyanate is reduced. (yellow part)

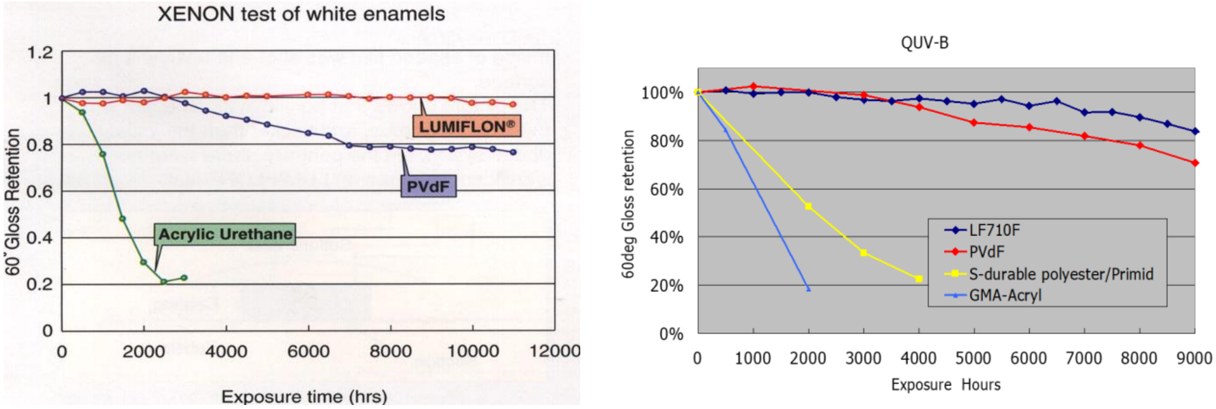
Figure with permission of AGC.

FEVE High Durability with Accelerated Weathering Tests – Gloss Retention

A standard method for evaluating exterior durability to sunlight exposure is by accelerated weathering tests. Two test types are via Xenon ARC and QUV-B. As shown in **Figure 17**, both the Lumiflon® FEVE and PVDF coatings on white enamel retained their gloss at >10,000 hours while the acrylic urethane lost about 80% of its gloss at 2,000 hours of exposure.

Similarly, both the Lumiflon® system and the PVDF coating retained their gloss even after 8,000 exposure hours in the QUV-B test. Both the Polyester and Acrylic systems suffered severe gloss retention loss at 2,000 exposure hours.

Figure 17. Fluoropolymer High Durability with Accelerated Weathering Tests



Figures with test data with permission of AGC.

FEVE low-dirt pick up systems (applicable to facades and bridges and other similar end-uses)

FEVE is compatible with many types of additives. In combination with inorganic low dirt-pick up agent such as silicate, it is possible to create hydrophilic low-staining surfaces. Façade stains are caused by dust deposited on the top, which is carried down the wall by rain and adheres to the wall. If the dirt is organic, such as black carbon, it is adsorbed by the paint film on its way down because it has a higher affinity for the same organic material than for water. Dust deposited at an angle at the top forms a strong stain on the wall with each rainfall. On the other hand, the silicate that bleeds from the silicate-added paint film onto the surface is hydrolyzed on the surface, and the silanol groups formed by hydrolysis are hydrophilic enough to adsorb water, so the surface is hydrophilic. Therefore, water forms a thin film between the paint films and dirt, and the dirt is washed away, preventing it from adhering to the paint film. Dust on the wall is washed away as water gets between the paint film. This means rain helps clean the coating system. Resin manufacturers have developed this system and shared it with paint manufacturers, making it possible to produce a much better low-dirt pick up paint film, or stain-free façade (**Figure 18).** The fact that the surface stays cleaner may well mean improved roof aesthetics, improved solar reflectivity and heat resistance as well as less need for recoating, maintenance and cleaning.

Figure 18. Dirt Pick Up and Wash Off with Fluoropolymer-based systems

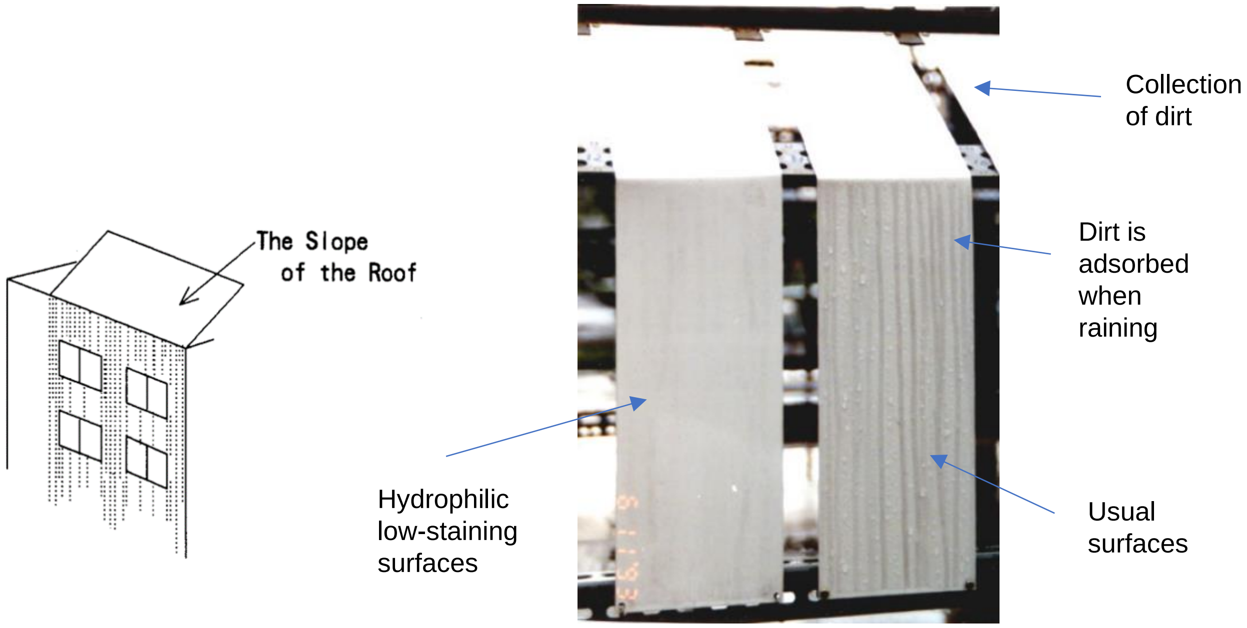


Figure with permission of AGC.

Estimation of Degradation Processes of Polyurethane System

To help visualize what occurs to a multicoat film system, a comparative FEVE versus polyurethane schematic was developed (**Figure 19**). This schematic covers a 60-year coating period for the two subject film systems. This report has provided significant information to show the longevity of the FEVE systems to indicate their useful life is in the 30–60-year range, if not longer. This schematic gives the 4-layer over substrate (steel) system – zinc rich primer, under coat, middle coat and topcoat. From the information that has been provided, it is clear that the FEVE top-coat system largely is intact throughout the study period. On the other hand, the polyurethane system exhibits marked degradation after 8-12 years and potentially catastrophic losses in the 30–60-year period of exposure.

Figure 19. Pictorial Schematic of degradation over time of FEVE vs Polyurethane

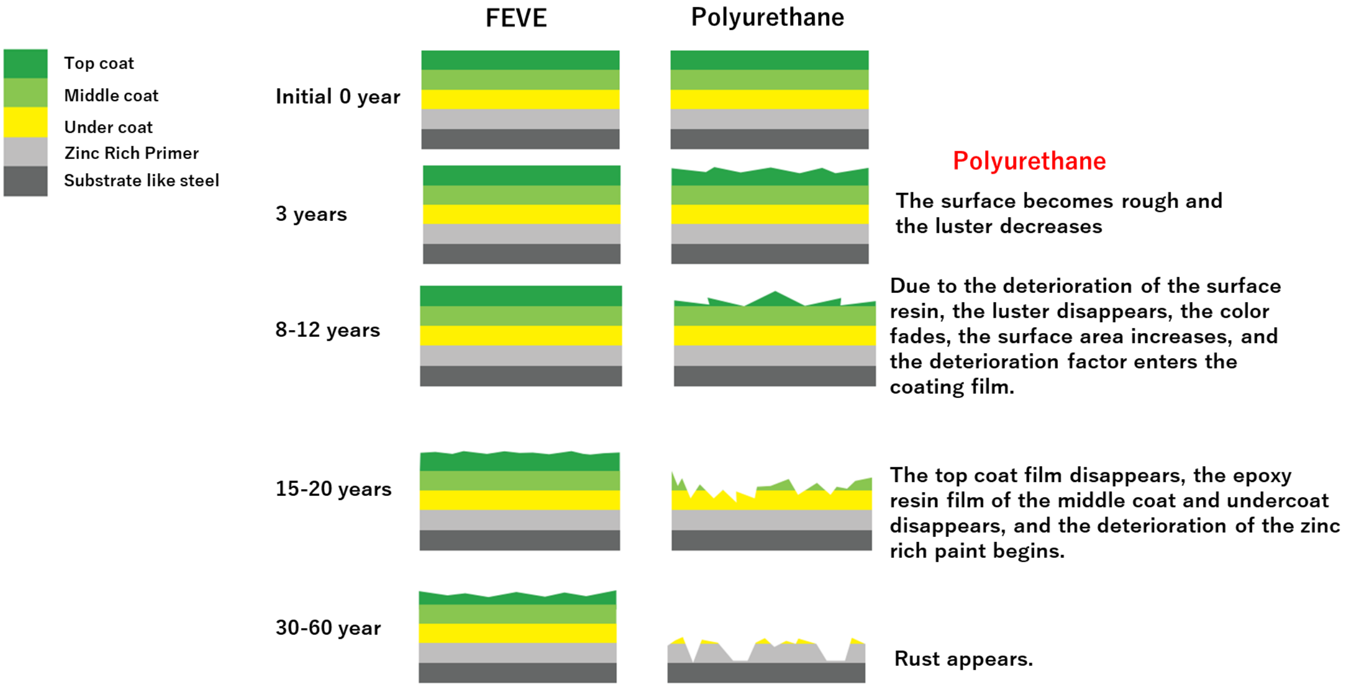


Figure with permission of AGC.

Chalking, Fading and Corrosion on Bridge Structures

Suigo Bridge Painting - 18 years of exposure for FEVE, Chlorinated Rubber and Alkyd Resin side-by-side painting comparisons.

The comparative pictures in **Figure 20** provide clear indications of the durability and long term FEVE film coating performance in terms of color fading, corrosion and chalking. A similar performance pattern can be seen when looking at the photos in **Figure 21** of the Daiichi-Mukaiyama Bridge (Mountainous area, Hiroshima). After 30 years of exposure**,** no chalking was evident. Gloss retention was excellent. The bolts, edges and abdominal plates were all in very good shape.

Figure 20. Suigo Bridge Paint Study

Figure with permission of AGC.

Figure 21. Daiichi-Mukaiyama Bridge (Mountainous area, Hiroshima): FEVE vs Alkyd Topcoats. FEVE topcoat after 30 years of exposure vs. alkyd topcoat after 16 years of exposure.

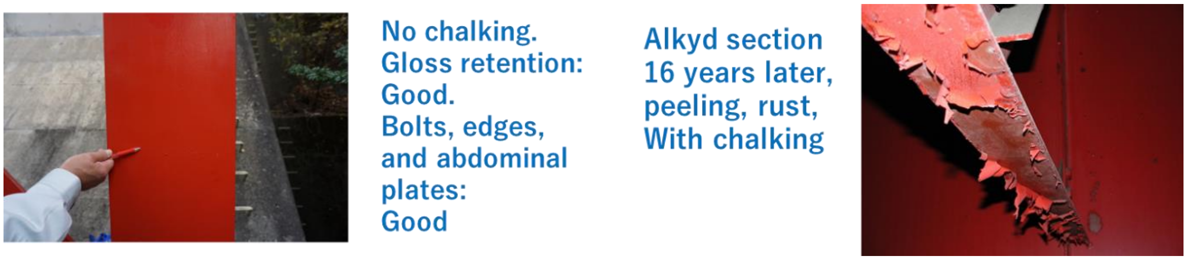
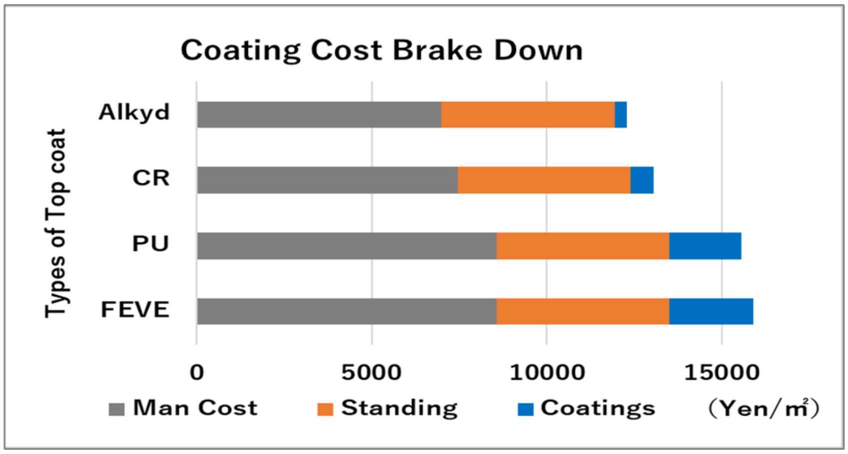


Figure with permission of AGC.

FEVE Service Life Estimated at >50 Years

Life Cycle Cost and Life Cycle Cost Reduction in Bridge Coatings using FEVE versus competitive materials such as polyurethane, chlorinated rubber and alkyd resin in **Figure 22.** It is important in creating a full picture to describe what it costs to paint a bridge structure. The estimated costs for the 4 subject topcoat systems are shown in the Cost Break Down Figure. In all 4 cases, the labor and scaffolding costs overwhelm the actual topcoat costs. The actual resin cost is only 3-15% of the total coating costs. And it is noteworthy that the FEVE system has only about a 6% price premium vs. the polyurethane system.

Figure 22. Coating Cost Breakdown for 4 Topcoat Systems. Life cycle total cost mainly consists of labor and scaffolding costs. The better the durability and the longer the repainting period interval, the lower the total cost.



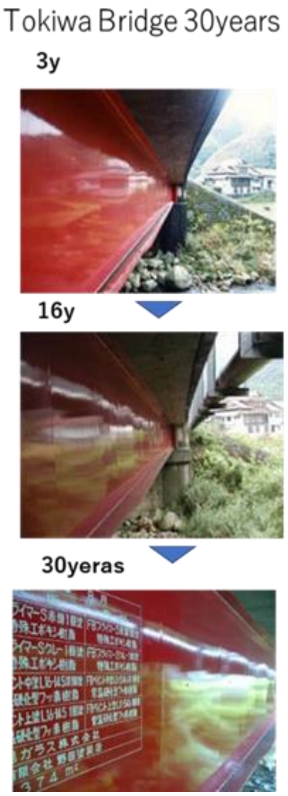
Main cost (80% up) of painting cost are mainly
Man - Labor and Standings (Scaffolders).
Resin cost is only 3-15% of total.
Only 6% difference between PU(Polyurethane) and FEVE system
of total painting initial cost including man and scaffolder.

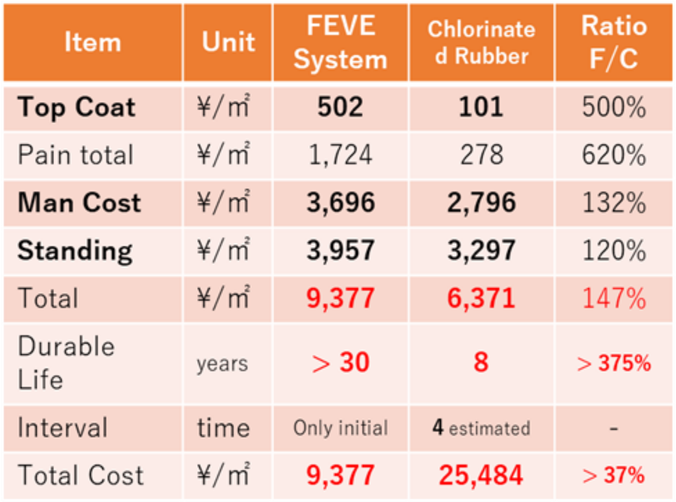
Figure and data with permission of AGC.

If a system is more durable and the recoat frequency is significantly lower (or extended), then the long-term ultimate maintenance costs can be significantly lower using the FBC system. Therefore, over time the costs can be lower, and the Life Cycle Costs (LCC) are greatly reduced with the FBCs.

In the Tokiwa bridge example shown in **Figure 23,** the study looked at an FBC FEVE-based coating system vs. a chlorinated rubber coating system over a > 30-year life span of the bridge coatings. The chlorinated rubber system needed repair every eight (8) years whereby the FBC FEVE-based system was intact even at >30 years. The pictures show the visible performance of the FEVE system even after 30 years of exposure. The overall LCC savings can be significant even though the initial total coating costs were about 47% higher. Please take note that over the >30-year exposure horizon, the FBC system costs about 37% of the alternative chlorinated rubber system.

Figure 23. Tokiwa Bridge FEVE vs Chlorinated Rubber 30-Year Exposure Test





Item	Unit	FEVE System	Chlorinated Rubber	Ratio F/C
Top Coat	¥/㎡	**502**	**101**	500%
Pain total	¥/㎡	1,724	278	620%
Man Cost	¥/㎡	**3,696**	**2,796**	132%
Standing	¥/㎡	**3,957**	**3,297**	120%
Total	¥/㎡	**9,377**	**6,371**	147%
Durable Life	years	＞ **30**	**8**	＞ **375%**
Interval	time	Only initial	**4** estimated	-
Total Cost	¥/㎡	**9,377**	**25,484**	＞ **37%**

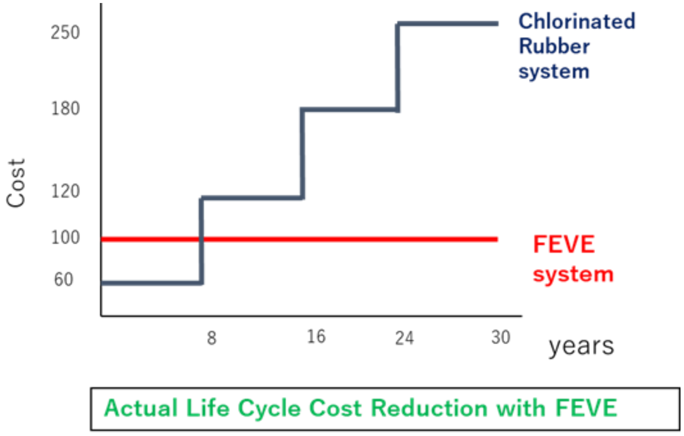


Figure with permission of AGC.

For clarity, the items in the table below include the standing cost which is the scaffolding. The Man cost is the labor. The Paint costs are the primer, under and intermediate layer costs. And the topcoat is either the FBC or the chlorinated rubber system. A relative comparison of the total cost ratio of 4 topcoat systems as well as the projected 100-year costs are shown in **Figure 24**.

Figure 24. Comparison of The Total Cost Ratio in 4 Topcoat Systems and the 100-Year Costs

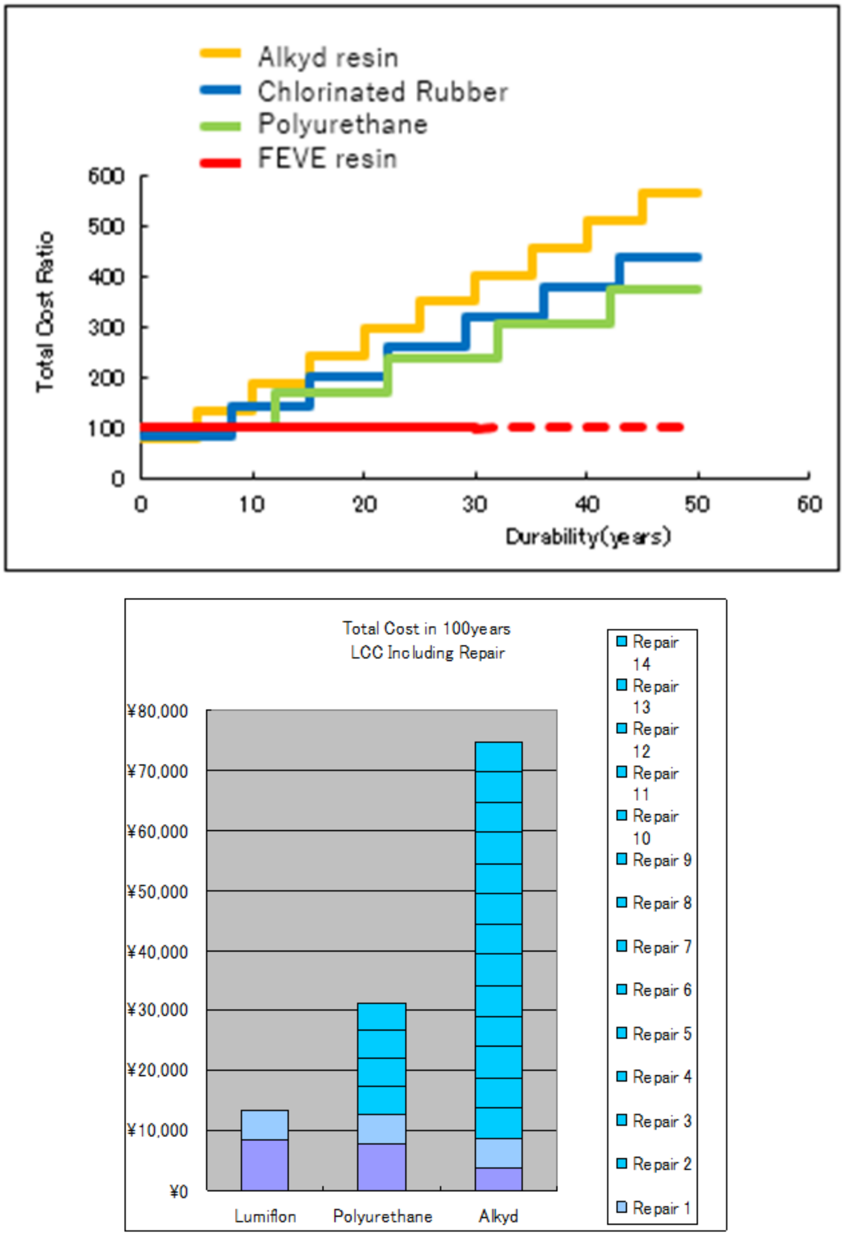


Figure with permission of AGC.

Expected Lifetime by Japan Paint Manufacturers Association (JPMA)

Table 5. Expected Topcoat Lifetime of an FEVE and a PU System

Authority	FEVE Top system	Polyurethane Top system
JPMA	60 years	18 years

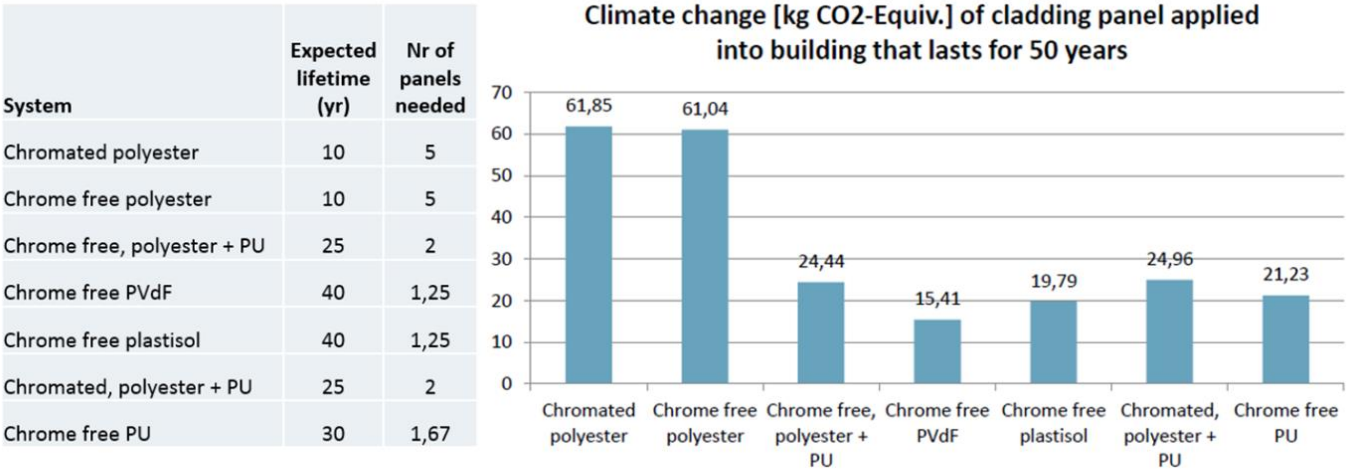
Table with permission from AGC.

JPMA calculated the lifetime as the repainting time when the film thickness of the topcoat is reduced by 80% and rust has not appeared on the coating (**Table 5**; JPMA, 2002).

FBCs have a much longer durability when compared to more standards systems/chemistries, leading to a much lower impact on the environment (in kg CO_2). The extended durability and reduced need for both recoating and repairs can lead to a much lower overall LCC. By using an FBC as a topcoat, the overall cost over the lifetime of the system can be much lower, leading to more than 50% cost decrease (ECCA, 2023).

Life cycle and global impact assessment: Independent studies have been conducted by the European Council of the Paint, Printing Ink and Artist's Colours Industry (CEPE) leading to the following conclusions in building cladding panels (**Figure 25**).

Figure 25. Comparison of kg CO_2-equivalents Emissions Estimates for Various Cladding Panels



System	Expected lifetime (yr)	Nr of panels needed
Chromated polyester	10	5
Chrome free polyester	10	5
Chrome free, polyester + PU	25	2
Chrome free PVdF	40	1,25
Chrome free plastisol	40	1,25
Chromated, polyester + PU	25	2
Chrome free PU	30	1,67

Figure with permission of CEPE.

Specification and Standards Discussions

Japan. Beginning in 2005, the only permitted topcoat system for bridges in Japan are the FBCs utilizing an FEVE-backbone. The other alternative systems, including polyurethane, chlorinated rubber and alkyd resins cannot be used as they have been withdrawn from the standards. The objective of the new regulation was life cycle cost reduction as well as sustainability. In summary:

Before 2005

For harsh environments, use a heavy corrosion protection coating system

General painting system is applied to the general environment.

⇨

New standard（2005）

Regardless of harsh or general environment
Apply the longest-lasting
anti-corrosion technology, Anywhere
< long-lasting ⇒ cheaper maintenance>

Ref: JRA 1995

Ref: JRA 2005

ISO 12944-5

This ISO standard includes binders for the coating base that contain free hydroxyl groups (e.g., polyester, acrylic, epoxy, polyether, fluororesin (FBC)) which react with suitable isocyanate curing resin. In addition, there is a description of FEVE coatings noted as a special type of polyurethane based on fluoropolymers. **Table 6** lists some of the other global standards that include fluoropolymer systems like FEVE.

Table 6. Application, Specifications and Regulation in the World

No	Nation	Name（Organization /remarks）
ISO12944-5	Global	Paint and varnish – Corrosion protection of steel structures by protective paint systems
HG-T3792-2011	China	Standard for Cross-linked Fluoropolymer Coatings (Paint Industry Association)
HG-T4104-2009		Standard for Waterborne Fluoropolymer Paint (Paint Industry Association)
TBT 1527-2011		Protection Coating Standard for Railway Steel Bridges (Ministry of Railways)
TBT 3228-2010		Protective Coating Standard for Concrete on Railroads (Ministry of Railways)
JT T722-2008		Technical Standard for Steel Corrosion Protection for Public Road Bridges (Ministry of Highway)
13201-639、99-7.7	Korea	Anti-corrosion Coating Standard for Highway Bridges, Other 2 organization
TCVN11416	Vietnam	Fluoro resin paint for steel structure
	Myanmar	QUALITY CONTROL MANUAL FOR STEEL BRIDGE
Spec2911/2PU	Aus. N.Z.	Coating Organizations (including government)
D102-06	US	Water Tank (American Water Works)
BMS10-72		Boeing Standards
Mil-L5606,L7808		U.S. Air Force Standards
AAMA2605-05		AAMA (American Aluminum Manufacturers Association)
SSPC		
Qualicoat	EU	Class 3

Table with permission of AGC.

Numerous long-span bridges were built based using these standards. The following pictures provide real-world examples (pictures with permission of AGC).

- **Akashi Strait Bridge**: At the time of construction, it was the longest suspension bridge in the world. It is now the second longest bridge in the world.
- **Tokyo Gate Bridge**: This bridge was installed at the entrance and exit of Tokyo Bay.
- **Ping Tang Bridge**: After the FBC coated bridge standard was established, this bridge was built as a combined railroad and road bridge.

Akashi Strait Bridge (1998)

Tokyo Gate Bridge (2012)

Ping Tang Bridge (China)

VOC Reduction

Figure 26 shows the VOC emissions of solvent-based resin paints over time. The calculations are for the topcoat only. The calculations were made according to the JPMA (Japan Paint Manufacturers Association) service life for Alkyd, polyurethane and FBCs utilizing FEVE, which were calculated to be 7, 18 and 60 years, respectively. The longer service life of FBCs reduces the number of re-coats and significantly reduces the amount of VOC emissions. Since the middle and bottom coats are also protected by FEVE and have a long service life and do not need to be recoated, the overall coating system, including the middle and bottom coats, can achieve even greater reductions in VOC emissions than shown in the Figure.

Figure 26. VOC Emissions Over >100 Years Service Life for 3 Topcoat Systems

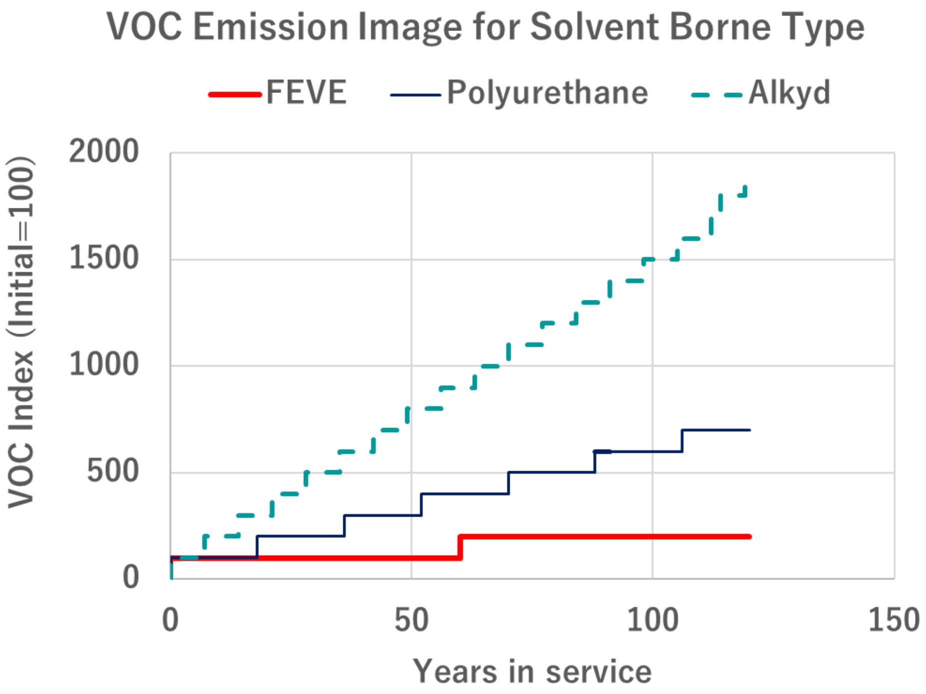


Figure with permission of AGC.

One also needs to consider the VOC reductions in powder FBCs utilizing FEVE Powder Coatings. The VOC emissions for the powder FBCs are essentially zero for the several decades of service life for the façade-wall panels or roofing panels. **Figure 27** compares the VOC index for the FEVE-Power Coating to both a polyester-water based system and a polyester-solvent based system. The VOC reduction is significant with the powder FBCs utilizing FEVE Powder Coatings.

Figure 27. VOC Emissions Index for 3 Coating Systems over 50 Years

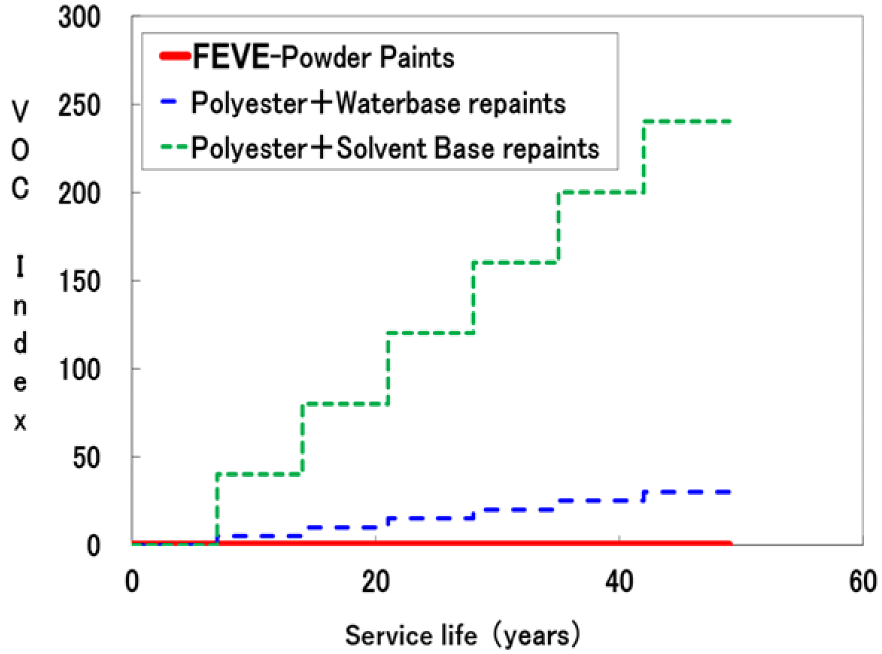


Figure with permission of AGC.

Powder FBCs utilizing FEVE ultra durability reduces VOC emissions over decades.

CO2 Reduction in the field for Façade and Building Panel Life Cycle

The CO2 emissions of paint systems using panels painted with the powder FBCs utilizing FEVE save CO2 - significantly more than polyester paint system in architectural fields over a 100-year structure evaluation.

The powder FBCs utilizing FEVE have a significantly lower life-cycle CO2 emissions than the polyester powder paint system by 47%. For emissions during the initial coating phase, the FEVE powder paint system emits more CO2 than the polyester powder paint system. However, overall emissions are lower due to its higher durability and lower number of repaints over the 100-year life of the building. Note that the repainting system is usually done twice with epoxy/polyurethane. At the time of these calculations there was no inventory of epoxy resin, so polyurethane was substituted. However, it is estimated that there is no significant difference between the two recoat systems (**Figure 28**).

Figure 28. CO2 Reduction Over 100-Year Life of Building Façade-Panel

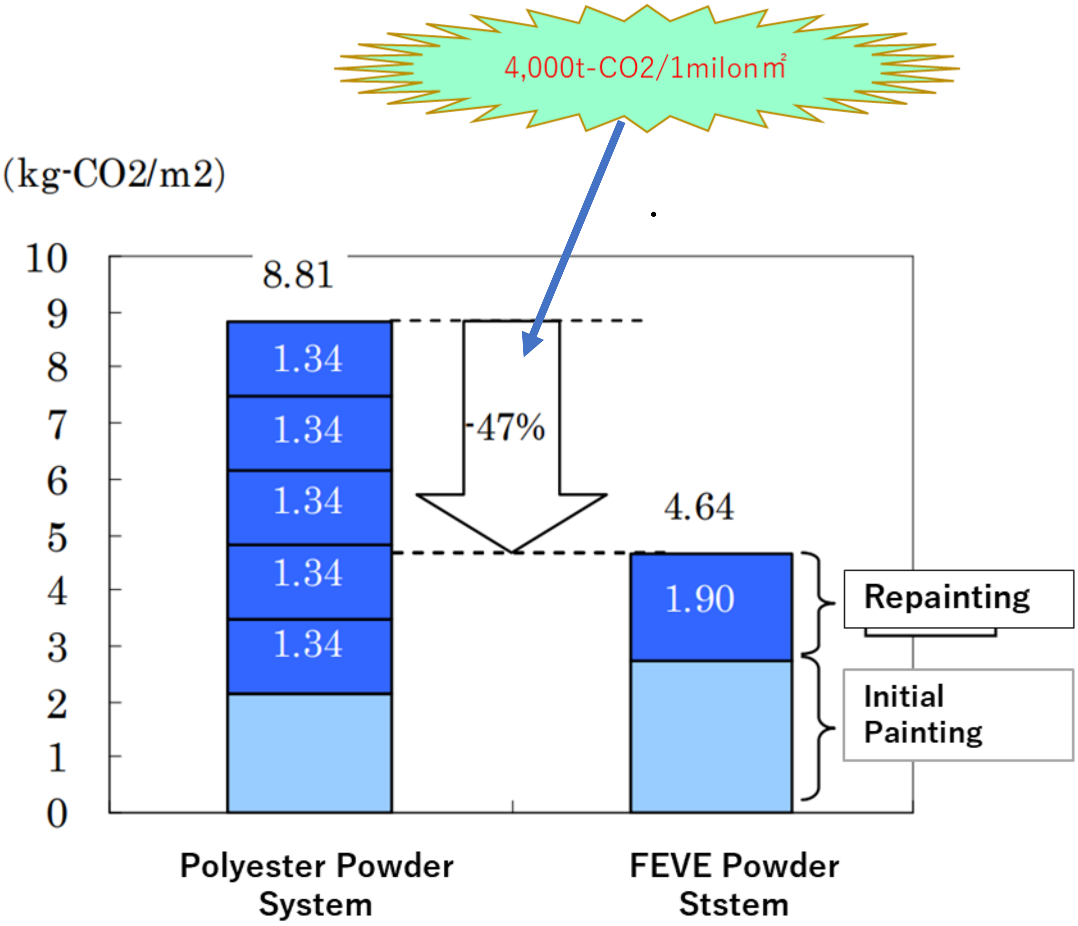


Figure with permission of AGC.

CO₂ Reduction in the field for bridges LC (Life cycle)

The FEVE protective coating system saves approximately 38% more CO_2 than a polyurethane protective system in 100-year life evaluation of bridges (**Figure 29**). As is the case above with facades and panels, the initial CO_2 emissions during the first coating were higher than the polyurethane system. Predictably, overall emissions are expected to be lower due to the FEVE system higher durability and lower number of repaints over the 100-year evaluation life of the bridge.

Figure 29. CO2 Reduction Over 100-Year Life of a Bridge

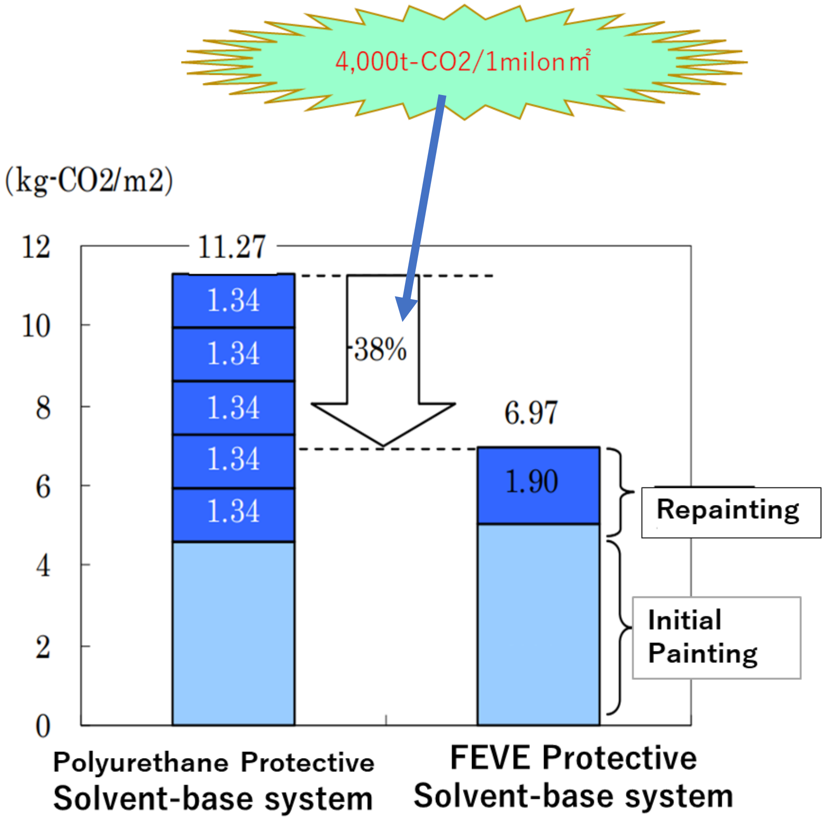


Figure with permission of AGC.

Green Building Certification

An important recent certification for CO$_2$ reduction and VOC reduction is green building certification. The certification is an important point of appeal for ESG (environmental, social, governance) investment. FEVE powder- and water-based grades earn green points with the paint maker’s declaration. In New York City, the 10 Hudson Yards building achieved LEED Platinum, while 30 Hudson Yards achieved LEED Gold.

Photo of 10 and 30 Hudson Yards, NY, NY

Permission obtained from Carlos David/Shutterstock.com.

Examples of LEED-certified buildings:

LEED Platinum Office Building Revitalized Downtown Pittsburgh with High Performance Energy Efficient Façade – Lumiflon FEVE Resins (lumiflonusa.com)

Architects Design First LEED Platinum Government Building in Maryland – Lumiflon FEVE Resins (lumiflonusa.com)

Architects Design Award Winning Multi-Family Housing Complex with Stunning Exterior Designs – Lumiflon FEVE Resins (lumiflonusa.com)

NBBJ Designs Facebook Spring District In Washington With Sustainable Design – Lumiflon FEVE Resins (lumiflonusa.com)

Architecture – Lumiflon FEVE Resins (lumiflonusa.com)

Award Winning Hudson Yards Lobby Features Mixture of Tactile Materials – Lumiflon FEVE Resins (lumiflonusa.com)

Figure 30 (photos with permission of AGC) shows three different types of low-to-no VOC concrete skyscraper coatings, including:

a. FBC utilizing FEVE which can be applied at ambient temperature and on-site solvent coating;
b. FBC utilizing FEVE which is water-based, where there is less concern about VOCs and solvent odors; and
c. Concrete panels which can be coated with FBCs utilizing FEVE in the factory at temperatures below 100°C and installed on site.

Figure 30. Three Types of Concrete Building Coating Systems Illustrated by Office Buildings in Tokyo

a. Painted on site

b. Water-based repainting on site coating

c. Low temperature coating panel in factory

Water Towers

Products Used: FEVE

FBCs utilizing FEVE have become more common for water tank coatings (in the US). These FBCs utilizing FEVE do have a price premium for the initial cost of application. As discussed below, there are considerable coating and applications cost savings over the life of the FBC utilizing FEVE-coated water tank. Therefore, coating costs are lower over the lifetime of the tank. There is also a reduced environmental burden in terms of lower solvent emissions as well as surface preparation and blast media for removing the old coating and materials disposal.

One of the most important advantages of an FBCs utilizing FEVE is that it can be cured at ambient temperature. Therefore, it is possible to apply the coating outdoors and/or on site. This would include not only newly constructed water tanks, but also existing water tanks with deteriorated coatings that can be refurbished on site and given a longer service life.

This FEVE fluoropolymer-based system can be used to coat the exterior of the water tank at the same time the tank interior is repainted with an epoxy or related system, thus reducing overall down time. The interior coatings are not subject to the exterior harsh environment of the tank itself therefore an epoxy-type system is appropriate. The interior and exterior coating life can be closely matched so they are repainted at the same time and cut down time by up to 50%. For towns and water districts with limited budgets or future budget uncertainties, lowering infrastructure costs is helpful and often necessary.

Another advantage that an FBC utilizing FEVE product has is that it can produce very beautiful and vivid colors on the exterior of the water tank. Using an FBC protects this investment. See the water tank images at https://lumiflonusa.com

These familiar designs could be used as a community amenity or landmark. It is possible for them to become one of the region's representative infrastructures. An FBC utilizing FEVE has a longer life expectancy with the expectation of not fading for decades. This has not been shown with conventional polyurethane resins that fade in a few years.

Water tanks are high above the ground and therefore have an increased safety risk to paint and repaint, and they require scaffolds for a clean finish. Painting work other than paint is usually expensive. As was noted in the bridges section, the cost of paint is less than 20% of the total coating process costs. The major costs largely consist of scaffolding and labor costs. The long-life cycle of the fluoropolymer-based paint system (extended over several decades) has not been shown with polyurethane coatings. The several decades life cycle can be realized with FEVE fluoropolymer-based resin system. The Life-Cycle Cost is reduced due to the reduction in the number of recoatings required over the life of the water tank. With fewer repainting cycles there is less tank downtime.

FEVE thus serves as a stable technology for the long-term maintenance and management of water tanks as an important infrastructure that supplies the life-giving water that is essential to human life. The FEVE Coating system has been incorporated into the water tank painting standards (AWWA, 2007).

Solar Panels

Products Used: ETFE; PVDF; Zeffle®; FEVE; PVF

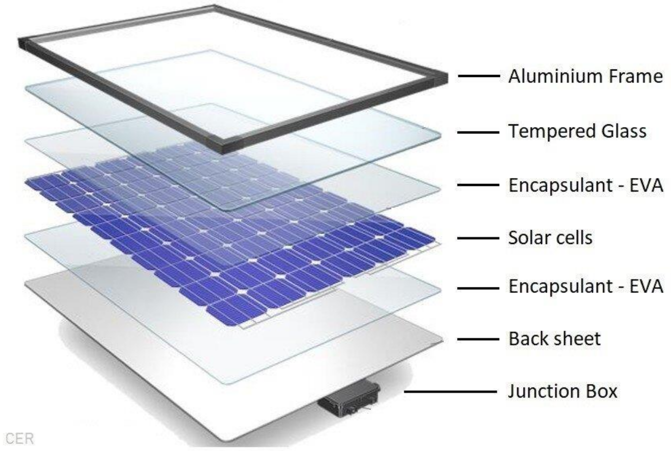
Fluoropolymers are often used as back sheets (films) in photovoltaic solar panel construction (**Figure 31**). Materials used in this end-use should have significant UV resistance and stability, corrosion resistance and flexibility. Fluoropolymers are light in weight and have extended durability in full exposure to a variety of environmental conditions, including intense sunlight and heat. Other materials used in back sheet applications are polyamides, polyethylene terephthalate (PET), glass and polyesters. A number of studies have been conducted to evaluate these materials and viable alternatives. (DuPont PV Study, 2020; OECD, 2022; GSPI, 2021)

Numerous uses of fluoropolymers are documented in solar panel manufacture and use. Fluoropolymer coatings or films may be incorporated into the glass top layer of panels, the encapsulant film that surrounds the solar cells and the back sheet. Fluoropolymers reportedly increase durability, transparency, UV-resistance, heat-resistance, mechanical strength, dirt-repellency and energy production, and they are lightweight. Halar® (ECTFE), Tefzel® (ETFE) and Lumiflon® (FEVE), as well as polyvinyl fluoride (PVF) and PVDF, are among the fluoropolymers used for solar panels. (GSPI, 2021; AGC, 2021)

Back sheets are used on solar panels to help protect the solar cell from weather, humidity, loads, and impact damage. It has also been noted that they also help provide electrical isolation for safety purposes. The proper choice of the back sheet can increase the panel life and reduce the cost of electricity generated from the panel over the solar panel cell’s life. Requirements for the back sheet include opacity and high reflectivity.

Back sheets as shown in **Figure 31** are typically laminates often consisting of PVF, PET and poly (ethyhlene-vinyl acetate) (EVA or PEVA) films. For example, PET films are used in applications where increased UV stability is desirable. These applications include back sheets on solar panels as well as architectural and automotive protective films. It should be noted that PET will degrade over time reducing its ability to protect the desired substrate. PVF and Lumiflon® FEVE have been used as a weather resistant topcoat layer that helps protects the PET and EVA from degradation, especially from UV light.

Figure 31. The 6 main components used in the construction of a solar panel



From: https://www.cleanenergyreviews.info/blog/solar-panel-components-construction

To demonstrate the benefits of the fluoropolymer coating on the non-fluorinated film layer, two examples are provided below for illustrative purposes. The first is a xenon arc accelerated weathering test. In this test, the FEVE polymer-coated PET film was subjected to 3,000 hours in a weatherometer, a device used to evaluate UV aging. The results were compared to the uncoated PET film and the Color change (ΔE) was measured. Results are shown below in **Figure 32**. After 3,000 hours, the PET film coated with the FEVE-based topcoat shows no change in color, while the uncoated film has a visible decline in appearance.

Figure 32. Xenon Arc Weatherometer Test Results of FEVE-coated and Uncoated PET Film

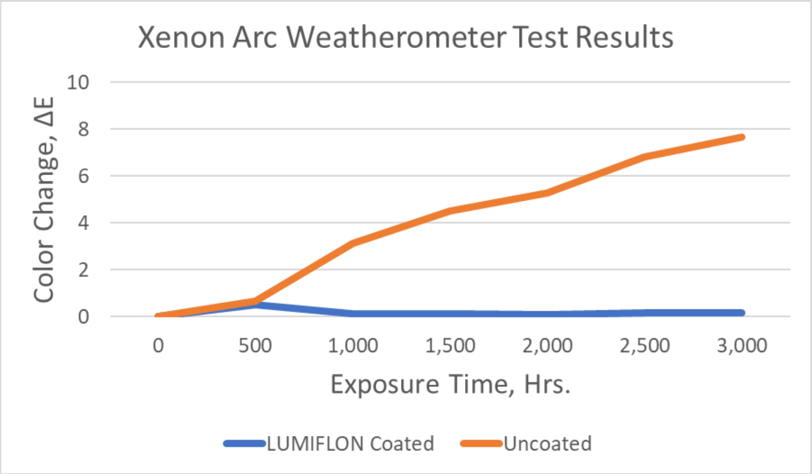


Figure with permission of AGC.

In the second test to evaluate UV stability of the Lumiflon® FEVE-based fluorourethane coating compared to that of PVF-based coating, panels were placed in the Xenon Arc Weatherometer for 5,000 hours. When color change of polymers is measured, B* is an indicator of yellowing. B* was monitored over the duration of the test; results are shown in **Figure 33** below.

Figure 33. Xenon Arc Weatherometer Test of PVF and FEVE Laminate Films

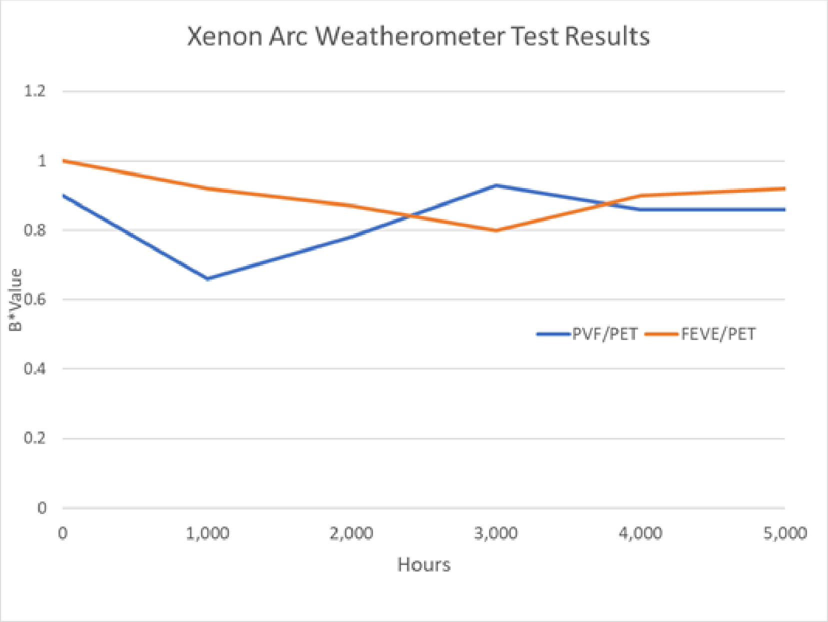


Figure with permission of AGC.

Both the FEVE-based fluorourethane coating and the PVF-based topcoat film performed extremely well in this test by preventing yellowing of the PET film over the 5,000-hour duration of the test (Madico, Inc., 2013).

Conclusions

Fluoropolymers are high molecular weight polymers with fluorine atoms directly attached to their carbon-only backbone. The carbon-fluorine (C-F) bond is the strongest bond between carbon and another atom and imparts unique, outstanding and beneficial properties along with extraordinary functional performance. These properties include chemical, biological and thermal stability, heat and chemical resistance, unique dielectric properties and durability. Additional fluoropolymer properties include increased fire resistance, weather resistance, non-wetting and adhesion resistance.

Many fluoropolymers, including the fluoropolymers used in the I&C end-uses, have been shown to meet the "polymers of low concern" (PLC) criteria, and as such, do not present a notable concern for human health or the environment (Henry et al. 2018, Korzeniowski et al. 2022). As discussed in those references, fluoropolymers are negligibly soluble in water, non-mobile, non-bioavailable, non-bioaccumulative and non-toxic.

Fluoropolymers are regarded as irreplaceable in many applications because their unique combination of specific properties, which are critical to ensure optimal performance in many applications and cannot be achieved or guaranteed by alternative materials. In the particular I&C end-uses covered in this document, there are a number of specific properties that enable the unparalleled performance fluoropolymers provide versus a number of major alternatives such as polyurethanes, chlorinated rubbers, alkyds and polyesters.

The exceptional properties that fluoropolymers provide and/or enable in the I&C coating applications are:

Flexibility;

Wear resistance;

Impact Resistance and Hardness

Color Retention

Gloss Retention

Film Erosion

Chalking Resistance

Weather Resistance

Abrasion Resistance

Harsh Chemical Resistance

Corrosion Resistance

Barrier Properties

Fire Retardancy and Smoke Suppression

Low Refractive Index for Optical Effects

Reduced Dirt Collection

The unique combination of these properties in the subject I&C end-uses provide several significant benefits that include:

- VOC reduction due to extended service life and longer (less frequent) recoat time intervals;
- CO_2 reduction due to improved functioning of building HVAC systems as a result of lower peak and regular energy demands;
- Lower energy demands lead to lower carbon footprint;
- Life Cycle Costs (LCC) that are significantly reduced due to the extended service life of the end product, requiring less recoating, better color and gloss retention as well as little to no surface chalking;
- Dirt pickup is reduced and the surface in question is easier to maintain and is less susceptible to environmental damage;

- Mold and Mildew resistance is improved with FBCs; and
- And finally, help in qualification for Green Building Certification.

We are unaware of another coating technology that meets the performance parameters of durability and product longevity that also provides the cited benefits that are the defining characteristic of FBCs.

The five (5) I&C end-use applications described in this submission are:

1. Building Facades and Protection – Metal Building Panels and Parts

Fluoropolymer-based coatings (FBCs) offer superior performance, service life, sustainability, appearance and value for various applications which are used on a wide variety of metal substrates for commercial, monumental and other building projects. These fluoropolymer-based systems include polyvinylidene fluoride (PVDF) and fluoroethylene vinyl ether (FEVE) resin-based formulations. These two fluoropolymers are the film-forming binder resins in factory-applied industrial and construction coatings used in settings where extreme durability and lifespan of several decades or more are needed to provide substrate protection. FBCs extend the lifespan of the underlying materials and are a critical specification for certain products in the building and construction markets.

FBCs are available in both coil (roll-applied) and extrusion (spray-applied) applications. Each type has specific uses for various construction and architectural metal building products. Coil coatings are applied to large rolls or “coils” of steel and aluminum by a continuous, automated process that typically occurs in a controlled factory environment. Extrusion coatings are spray-applied to aluminum preformed extruded substrates, in a vertical or horizontal line also in a highly automated factory environment. FBCs can be applied to a variety of metal components used in projects ranging from pre-engineered metal buildings to municipal arenas, skyscrapers and many others.

2. Roofing and Roofing Structures

Roofing that incorporates a fluoropolymer-based topcoat system has significant advantages versus conventional roofing. These fluoropolymer-based systems have been shown to provide numerous important benefits for both roofing and building facades. Many favorable attributes combine to provide a lower lifetime ownership cost including lower energy usage from higher solar reflectivity and lower roof temperatures. This leads to lower carbon footprint, reduced dirt pick-up and improved mold and mildew resistance. Other important benefits from using these fluoropolymer-based systems include:

- World-class UV resistance and long-life color retention;
- Lower peak energy demand charge;
- Longer lifespan of roof coating and longer lifespan of roof substrate;
- Lower maintenance costs and less downtime;
- Increased efficiency and longer lifespan of HVAC equipment; and
- Lower VOC emissions.

3. Bridge and Walkway Structures

Bridge structures need durable coating performance to protect the painted metal substrate and maintain the bridge’s structural integrity. Any coating system must demonstrate through rigorous testing to be reliable and last a long time given safety considerations and how difficult, disruptive and expensive the recoat process is. Bridges are subject to highly adverse environmental conditions including, but not limited to, high intensity sunlight, fog, rain, saltwater spray (in coastal areas) and constant automobile exhaust. The high weathering performance of the subject fluoropolymer-based resin allows the paint system to prolong the bridge's service life and protect the substrate (or coated material), which subsequently decrease the number of re-painting cycles of the bridge infrastructure or building. This eventually contributes to a better (lower) Life Cycle Cost. A fluoropolymer-based bridge coating system would typically utilize an FEVE-based resin paint as a topcoat, to protect the substrate (or coated material) by increasing the anti-corrosion ability of the substrate and coated material. This has the obvious impact of prolonging the service of the paint system. Furthermore, it contributes to the reduction of CO_2 generation by extending the life of the protected material and delaying or postponing the time between re-coating the bridge structure. Less recoating is equivalent to lowering the CO_2 generated in paint system product manufacture and application.

4. Water Towers

Water towers are high above the ground and therefore have an increased safety risk to coat and recoat. They require scaffolds to obtain a clean finish. In addition to the cost of the coatings package, application costs are significant as well. In fact, the cost of paint is typically less than 20% of the total coating process costs. The major costs of application largely consist of scaffolding and labor costs. The long-life cycle of the FBCs (extended over several decades) has not been shown with polyurethane and other coatings. This decades long life cycle can be realized with an FBCs system due to the durability provided by the fluoropolymer-based resin. Here again, the life-cycle cost is reduced due to the reduction in the number of recoatings required over the life of the water tower.

5. Solar Panels

Fluoropolymers are often used as back sheets (films) in photovoltaic solar panel construction. Materials used in this end-use need UV resistance and stability, corrosion resistance, flexibility, light in weight and have extended durability in full exposure to a variety of environmental conditions and intense sunlight and heat. Other materials used in back sheet applications are polyamides, polyethylene terephthalate, glass and polyesters.

Supplementary description of FEVE and PVDF Fluoropolymer Properties and Applications (Korzeniowski et al., 2022 and noted links)

FEVE

(Main references: see primarily https://www.agcchem.com and https://www.lumiflonusa.com)

FEVE fluoropolymer resins are polymers consisting of alternating **f**luoro**e**thylene and alkyl **v**inyl **e**ther segments. They were developed in 1982 as the first solvent-soluble fluoropolymers in the world. The fluoroethylene segment is largely responsible for the coatings' improved weatherability, durability and chemical resistance. Similarly, the vinyl ether segments provide for clarity, gloss, hardness, flexibility as well as a cross linking site for solubility if needed. The general features of the FEVE fluoropolymer include solubility in general organic solvents as well as being a non-crystalline resin with high transparency. The structure provides for the ability to introduce amorphous functional groups into the vinyl ether segments and as noted the alternating copolymerization structure gives high weather and chemical resistance. FEVE resins are used to make ultra-weatherable coatings for architectural, aerospace, automotive, bridge and industrial maintenance markets. These resins can be used to make both clear and pigmented coatings. They can be formulated with a wide range of gloss (from high gloss to flat finishes) and colors. The FEVE polymer is a platform chemistry that is supplied in various forms, including solvent-based liquid for easy application, water-based resins for low VOC (Volatile Organic Compound) and low odor coatings and a flake for sustainable powder coatings. FEVE powder coating materials provide essentially zero VOC and HAPS (Hazardous Air Pollutants) free coatings.

FEVE coatings protect steel, aluminum and other metals as well as concrete from degradation by UV light, wind and rain and corrosion. Because of their ultra-weatherability, FEVE based coatings offer substantial life cycle cost savings over conventional coatings. They can be used in the field for re-coating of structures or in the shop to manufacture pre-coated panels. FEVE resin chemistry allows for use in coatings that cure at ambient or low temperatures. This is important for use with heat-sensitive substrates like vinyl and fiberglass. Solvent- and water-based FEVE resins may be used to create highly weatherable coatings for vinyl and fiberglass building materials that allow for a cure process that meets the specific needs of these sensitive substrates.

High performance FEVE coatings can extend the lifetime of bridges and water tanks and reduce the frequency of maintenance, by helping to prevent coating degradation at the hands of UV radiation, salt and water. These coatings contain anti-corrosive properties that help maintain the coating's structural integrity for decades. Costs associated with bridge downtime, including increased traffic congestion, are significantly reduced over the life of the coating.

FEVE resins have outperformed even the best acrylic urethane coatings on steel, aluminum, magnesium and plastics like ABS, polyurethane, FRP, PVC, polyethylene, polypropylene and polycarbonate enabling transportation manufacturers to create and maintain the appearance for years. FEVE-based topcoats have been shown to yield over five times the lifespan of acrylic urethane coatings typically used in the transportation industry. FEVE resins can also be blended with traditional resins like acrylics to significantly increase their performance. For example, FEVE-based coatings can reduce maintenance costs in the aerospace market by as much as 50 % over the life of the plane, in addition to substantially reducing the loss of revenue during scheduled repainting. Aircraft coated with FEVE resin typically require no repainting for at least eight years, maintaining outstanding appearance and a durable surface that allows for easy cleaning. In contrast, acrylic urethanes typically begin to fade and chalk after only three years and require repainting after five.

FEVE Alternatives Assessment

The two main alternatives for an FEVE-based coating are polyurethanes and polysiloxanes. Urethanes have a long performance history and are still widely used as durable coatings. In general, polyurethanes will usually start to chalk and change color within 5-10 years. Due to degradation, the coating thickness of urethanes starts to decrease and after 15-25 years will no longer function as a barrier against corrosion. Polysiloxanes come in two types, epoxy and acrylic.

Siloxanes have a couple of advantages. First, they do not require an isocyanate crosslinker; they crosslink via a moisture cure mechanism. Second, they can be used as a two-coat system consisting of a zinc rich primer and a higher film build of siloxane (usually around 6-8 mils). This saves time especially in fabrication shops.

Neither coating system discussed above has been shown to weather as well as FEVE. A typical FEVE coat system will retain color and gloss for 25+ years and can prevent corrosion for up to 60 years, depending on the environment. Outdoor testing done in Japan over a 16-year period showed that a 25 µm FEVE-based coating retained 21 µm of thickness after 16 years. A 75 µm (3 mil) topcoat, typical thickness in a coating project, has a theoretical life of >100 years. In that same test, a 25 µm polyurethane coating was gone after 12 years. There are 30-year test results from bridges in Japan where gloss retention of the FEVE-based coating was 97% with a very small color change. There are test results that show that FEVE-based coatings retain their protective properties for a longer period than either of the other coatings. This makes sense in that the main purposes of the topcoat are to preserve its initial appearance for as long as possible and to act as a barrier film to corrosion initiators like chloride, water and oxygen.

The characteristics and advantages of various FEVE resin forms are summarized in Table 7.

Table 7. The Resin Form of FEVE and Features and Applications

Type of FEVE Resin	Features and Applications
Solvent Base	Use of general organic solvents. Used for general construction. Suitable for new installations
High Build	Can be painted thicker. Low VOC content
Exempt Solvent	Use volatile organic compound (VOC) exempt solvents as determined by EPA. Used for repainting airplanes
Mild Solvents	Mild solvent has smaller number of MIR VOC, (MIR VOC: maximum incremental reactivity VOC. They are classified by their ozone generation ability). With a mild odor, this system can be used for repainting in the city and repainting bridges
Water Base	Emulsions and Dispersions; The amount of VOCs is not more than 5%. Frequently used for repainting on-site coating. Reduced VOCs even in factory coatings
Powder	Essentially zero VOCs. Frequently used for Aluminum panels and building components. Factory painting only. Cannot be painted on site. Grade with the lowest environmental impact.

The benefits of utilizing a FEVE resin in a FBC are:

1. The excellent durability of FEVE lasts for several decades and protects the underlying paint film and substrate, thus reducing the number of surface re-coatings and protection of the underlying paint film and substrate over a long period of time.
2. High affinity for various solvents, hardener, paint additives and antifouling agents allows users to apply the product to a wide range of coating equipment and to achieve a wide variety in coating performance.
3. The high affinity for a wide range of pigments and the ability to select very vivid colors make it possible to achieve a high level of color design including clear metallic color and natural stone.
4. The ability to have colorful designs makes these systems also suitable for stone-like walls, higher design wall, amenities, landmarks and even vehicles.
5. FEVE is amorphous, which makes the coating film very smooth and provides a high gloss and mirror-like surface for itself. On the other hand, its high pigment affinity allows the gloss to be freely adjusted from 0-80 gloss units by using matting agents.

6. An isocyanate curing agent and resulting cross-linking can function at ambient to medium temperature. A block isocyanate curing agent will dry at higher temperatures in a short period of time. After drying, the product has not been shown to dissolve in solvents and exhibits excellent solvent resistance.
7. Long span bridges and large buildings that can only be air dried with crosslinking can be coated outdoors at ambient temperature.
8. FEVE coating reduces the difficult repainting for large, massive structures including existing buildings and structures with deteriorated coatings which can be repainted onsite. The old coating can be given a new life and be given decades of longevity.
9. Using an essentially zero VOC content coating does make a rapid contribution to VOC reduction versus competitive materials. Powder grades which do require baking are factory applied.
10. FEVE requires relatively low temperatures even when curing.

In addition to the increased oxygen permeability, improved weatherability, CO_2 generation reduction and lower overall Life Cycle Costs benefits that were previously noted, there are a number of other advantages and benefits fluoropolymers provide. These additional important benefits and features are as follows:

- Improved mechanical properties, lower corrosion rates, little to no molecular weight changes on exterior use,
- Lower top film consumption, isocyanate crosslinking retention, significantly improved durability,
- Significantly improved chalking performance as well as less fading, much better gloss and color retention
- Improved VOC reduction over the life of the structure

From the available technical data, FBC systems significantly outperform the competitive alternative systems such as polyurethanes, alkyds and chlorinated rubber coatings

PVDF and PVDF Copolymer

(Main reference : https://www.extremematerials-arkema.com/en/product-families/kynar-pvdf-family/download-performance-characteristics-data-brochure/

Polyvinylidene fluoride (PVDF) is a tough engineering thermoplastic that offers a balance of performance properties. It has the characteristic stability of fluoropolymers that help to resist harsh thermal, chemical and ultraviolet environments. PVDF, in addition to being readily melt-processed by standard methods, can be dissolved in polar solvents, such as organic esters and ketones, for coating applications. PVDF can be produced by homopolymerization or copolymerization, providing a full range of products with different molecular architecture along with different ranges of properties. Some of the important properties of PVDF homopolymers and copolymers are a function of the crystalline content and type of crystalline structure, both of which are affected by the processing methods and conditions.

Features

- Outstanding resistance to sunlight/UV exposure
- Tremendous chemical resistance to a wide range of aggressive chemicals
- Radiation resistance
- Excellent burn characteristics / flame and smoke properties (low flame spread and low quantity of smoke generated)
- Easy processing on industry-standard equipment and easy post-processing, such as fabrication
- Extremely high purity for the most demanding applications
- Extremely high electrochemical stability
- Excellent abrasion resistance
- High temperature rating: RTI 150 °C

Applications

- **Chemical Processing**: Due to its high temperature resistance, low permeability and high mechanical strength, PVDF is used as a contact surface for the production, storage and transfer of corrosive fluids (chemically resistant to halogens and acids). PVDF resin is used in mechanical components, fabricated vessels, tanks, pumps, valves, filters, heat exchangers, tower packing, piping systems and many other applications.
- **Wire and Cable**: PVDF has excellent fire, abrasion, chemical and impact resistance. Depending on the test method, it can have up to a 150°C rating and can be irradiated for even higher ratings.
- **Electricity and Electronics**: Its fire resistance, abrasion resistance, low-smoke emission, chemical and mechanical properties make PVDF resin suitable for protective sheathing, plenum and communications wiring insulation and binder resin for battery manufacture.
- **High Purity**: As semi-conductor and pharmaceutical production require increasingly pure materials, high purity PVDF resin grades meet industry needs (low extractables values). PVDF resin regulatory compliances include food and water use certifications (in FDA 177.2510 and/or 177.2600 compliance, NSF Standard 51 – Food Equipment Materials, NSF Standard 61 – Drinking Water System Components) as well as compliance for use in industries such as healthcare (USP Class VI approval).
- **Transportation**: PVDF resin is used in both public and private transport vehicles as a barrier liner for automotive fuel line and gas station fuel pipes, in decorative films, as a binder in HEV/EV batteries, as molded and thermoformed body components (weathering, anti-grime/graffiti) and as tank trailer linings for corrosion protection. PVDF resin has strength, flame resistance, durability and versatility that make it a preferred material in automotive wiring harnesses, general coatings and plastic optical fibers.

  - Focus on Battery: PVDF polymers are used in the battery industry as binders for cathodes and anodes in lithium-ion batteries and as battery separators in lithium-ion polymer batteries. PVDF is helping to design thinner and smaller lithium-ion batteries.
- **Architecture**: The excellent outdoor aging and weathering properties of PVDF resin led to its use in long-lasting paints for coating metal sheet for the past 50 years. PVDF resins can also be used to protect thermoplastics through coextrusion or film lamination techniques to obtain anti-grime and anti-graffiti surfaces with excellent weathering properties.
- **Photovoltaic**: PVDF Film is used in the protection of back sheet and for front sheet glazing. Those films provide exceptional solar transmittance and also have excellent dirt shedding and fire resistance properties.
- **Membrane**: PVDF resin is a respected membrane material for applications ranging from bioprocess separations to water purification because it is extremely chemically resistant and well suited to aggressive chemical environments. PVDF tolerates ozone and chlorine (an oxidant increasingly used for water purification) very well. Grades with United States Food and Drug Administration and/or NSF International compliance are compatible with food and/or beverage contact applications. It is used to manufacture flat sheet, hollow fiber and TIPS (thermally induced phase separation) process membranes and/or enclosed shapes that cannot be lined or coated in a conventional manner.
- **Fabrics**: Woven and non-woven fabrics can be produced using specific PVDF grades. These fabrics offer excellent chemical resistance, stability to sunlight and flame retardant properties.

General physical and mechanical properties

PVDF homopolymers and copolymer resin grades give the option to combine rigid and flexible materials when processing. As a material of construction for pumps and pipe, PVDF exhibits excellent resistance to abrasion. PVDF can also be manufactured in thin, flexible and transparent films, filament and tubing. Sunlight has little to no effect on PVDF resins.

- **Strength and toughness**: PVDF fluoropolymers are inherently strong and tough as reflected by their tensile properties and impact strength. An ambient temperature tensile strength at yield of 35-55 MPa (5,000-8,000 psi) and an unnotched impact strength of no break offered by select resins emphasize this. These characteristics are retained over a wide range of temperatures
- **Flexural creep**: Compared to many thermoplastics and fluoropolymers tensile yield of 15-55 MPa (2,200-8,000 psi), PVDF polymers have excellent resistance to tensile creep and fatigue also at elevated temperatures. Likewise, the short-term flexural creep resistance of PVDF homopolymer resins reflects superior load bearing performance.
- **Tensile creep**: Compared to many thermoplastics and fluoropolymers tensile yield of 15-55 MPa (2,200-8,000 psi), PVDF polymers have excellent resistance to tensile creep and fatigue also at elevated temperatures. PVDF resins are able to

maintain a low tensile creep when subjected to constant stress even at high temperatures.

- **Flexural creep**: PVDF is highly rigid and resistant to creep under mechanical stress and load. Likewise, the short-term flexural creep resistance of PVDF homopolymer resins reflects superior load bearing performance.
- **Thermal properties**: PVDF resins exhibit high thermal stability. Prolonged exposure of some PVDF grades at 250 °C (482 °F) in air does not lead to weight loss. No oxidative or thermal degradation has been detected during continuous exposure at 150 °C (302 °F) for a period of ten years. In testing, select resins have been given an RTI of 150 °C. PVDF resins thermally decompose at temperatures greater than 375 °C (707 °F). However, the melt processing range of unfilled PVDF homopolymer resins is very broad – from slightly above the melting point of 155 - 170 °C (311-338 °F) up to 300 °C (572 °F).
- **Electrical properties**: PVDF combines high dielectric strength and excellent mechanical properties over a broad temperature range. This has led PVDF resin to be used for thin-wall primary insulation and as a jacket for industrial control wiring. With proper shielding, PVDF resin can be used as jacketing for high frequency plenum-rated data cables because of its excellent flame and smoke performance.
- **Stability to weather and UV effects**: Many years of outdoor exposure in direct sunlight have little effect on the physical properties of PVDF. Some increases in tensile strength and reduction in elongation do occur over time.
- **Ozone resistance**: Ozone is a powerful oxidizing agent characterized by a high degree of chemical instability. PVDF offers excellent chemical resistance to ozone exposure.

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Appendix A. Glossary

AAMA	American Architectural Manufacturers Association; http://www.aamanet.org
ACC	American Chemistry Council
A/C	Air Conditioning
ACM	Aluminum Composite Material
ARC	Xenon ARC testing uses a highly specialized type of gas discharge lamp, an electric light that produces light by passing electricity through ionized xenon gas at high pressure. It produces a bright white light to simulate sunlight.
ASTM	ASTM International; https://www.astm.org/
AWWA	American Water Works Association; https://www.awwa.org/
CAS Number	Chemical Abstracts Service Number
CEPE	European Council of the Paint, Printing Ink and Artists' Colors Industry; https://www.cepe.org/
CR	Chlorinated Rubber
ECHA	European Chemicals Agency; https://echa.europa.eu/
ECTFE	Ethylene-chlorotrifluoroethylene copolymer
EIF	Entry into Force
EIFS	Exterior Insulation Finishing System
EOL	End of Life
ETFE	Ethylene-tetrafluoroethylene copolymer
EVA	Ethylene vinyl acetate or PEVE: poly (ethylene-vinyl acetate)
FBC	Fluoropolymer Based Coating
FEVE	Fluoroethylene-vinyl ether copolymer
Fluorinated Polymer	The broad generic term to encompass all polymers for which one or more of the monomer units contains the element fluorine, in the backbone and/or in side chains.
Fluorochemical	General, nonspecific name that describes a universe of organic and inorganic substances that contain at least 1 fluorine atom, with vastly different physical, chemical and biological properties. Synonyms include “fluorinated substance” and “fluorinated chemicals.”
Fluoroelastomer	An elastic rubber-like polymer to which fluorine is bound. Fluoroelastomers are highly durable and resistant to heat, oils, solvents, fuels and ozone.
Fluoroplastic	A distinct subset of polymers and plastics where some or all of the hydrogen atoms of the hydrocarbon backbone have been replaced with fluorine atoms.
Fluoropolymer	Distinct subset of polymers, namely, those made by (co)polymerization of olefinic monomers, at least one of which contains fluorine bound to one or both of the olefinic carbon atoms, to form a carbon-only polymer

	backbone with fluorine atoms directly attached to it, e.g., polytetrafluoroethylene.
Fluorosurfactant	A substance used to lower aqueous surface tension in which the hydrophobic portion contains F bound to C, often as a perfluoroalkyl moiety, often referred to as ‘‘fluorinated surfactants’’, ‘‘fluorosurfactants,’’ ‘‘fluorinated tensides,’’ or ‘‘fluorotensides’’
FPG	Fluoropolymers Product Group, a group within Plastics Europe, the association of Plastics manufacturers; https://fluoropolymers.plasticseurope.org/index.php/about-us
GPC	Gel Permeation Chromatography
Homopolymer	A polymer made with only one monomer
HVAC	Heating Ventilation Air Conditioning
IR	Infrared
I&C	Infrastructure & Construction
ISO	International Organisation for Standardization; https://www.iso.org/about-us.html
JPMA	Japan Paint Manufacturers Association; https://www.toryo.or.jp/eng/
LC	Life Cycle
LCC	Life Cycle Cost
LEED	Leadership in Energy and Environmental Design; https://www.usgbc.org/leed
LOI	Limiting oxygen index
MIR	Maximum Incremental Reactivity
OECD	Organisation for Economic Co-operation and Development; https://www.oecd.org/
PET	Polyethylene terephthalate
PFAS	A very diverse group, per- and poly-fluoroalkyl substances (PFAS), including polymers (fluoropolymers, perfluoropolyethers, side chain fluorinated polymers) and non-polymers. Perfluoroalkyl substances are those for which all hydrogens on all carbon atoms not associated with functional groups have been replaced by fluorine, and polyfluoroalkyl substances are those for which all hydrogens on at least one, but not all, carbon atoms have been replaced by fluorine.
PFP	U.S.-based Performance Fluoropolymer Partnership; https://www.americanchemistry.com/industry-groups/performance-fluoropolymer-partnership-pfp/
PFPE	A perfluoropolyether is a polymer in whose backbone $-CF_2-$, $-CF_2CF_2-$ and possibly -CF(CF3)CF2- units are separated by oxygen atoms.
Polymer of Low Concern (PLC)	A polymer that does not present a notable concern for human health or the environment.
PU	Polyurethane
PVC	Polyvinyl Chloride
PVDF	Polyvinylidene fluoride

REACH	Chemical Control regulation in the European Union (Registration, Evaluation, Authorisation and Restriction of Chemicals); https://environment.ec.europa.eu/topics/chemicals/reach-regulation_en
RI	Refractive Index
SCFP	Side-chain Fluorinated Polymer
SEM	Scanning Electron Microscope, or Micrograph
SMP	Silicone Modified Polyester
SWM	Sunshine Weatherometer, or Weatherometer
TSR	Total Solar Reflectance
USEPA	US Environmental Protection Agency
UV	Ultra Violet Light
VOC	Volatile Organic Compounds

Appendix B. Infrastructure & Coatings Testing and Reference Methods

For each of the I&C end-use applications in this submission there are a set of exacting performance testing and reference methods. This appendix contains a list of some of the critical test methods and what they measure. For the primary end-uses in this submission, designers, architects and builders have specific performance standards they must meet to achieve the desired long lasting coatings performance and surface protection.

Test Method	**Test Method Title**	**Test Method Description**
AAMA 621	Voluntary specifications for high performance organic coatings on coil coated architectural hot dipped galvanized (HDG) and zinc-aluminum coated steel substrates	AAMA 621 provides specifications and methods for evaluating coil coatings on hot dipped galvanized and zinc-aluminum coated steel substances for adhesion, impact resistance, chemical resistance and weatherability.
AAMA 2604	Voluntary Specification, Performance Requirements and Test Procedures for Superior Performing Organic Coatings on Aluminum Extrusions and Panels	AAMA 2604 measures film integrity, exterior weatherability and general appearance over years of exposure. It includes humidity resistance (300 hours), salt spray resistance, Florida exposure (5 years), color retention, chalk resistance and gloss retention.
AAMA 2605	Voluntary Specification, Performance Requirements and Test Procedures for Superior Performing Organic Coatings on Aluminum Extrusions and Panels	AAMA 2605 measures film integrity, exterior weatherability and general appearance over years of exposure. It includes humidity resistance (4,000 hours), salt spray resistance, Florida exposure (10 years), color retention, chalk resistance and gloss retention.
ANSI/CRRC S100	Standard Test Methods for Determining Radiative Properties of Materials	From the publicly available online standard:[1] "This standard provides a practice and method for testing and reporting the *radiative properties* of roofing products before and after a specified test exposure. Roofing specimens are exposed to specific tests and to the exterior environment throughout a specified time period. The tests provide a relative measure of the roofing product response to the test conditions. The standard does not purport to be representative of all conditions that roofing products experience in the

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[1] https://coolroofs.org/documents/ANSI-CRRC-S100-2021_Final.pdf

		field. Variations of the test conditions or specimen construction also affect the specimen response.”
ASTM B117	Standard Practice for Operating Salt Spray (Fog) Apparatus	From the public ASTM B117 website:[2] “This practice provides a controlled corrosive environment which has been utilized to produce relative corrosion resistance information for specimens of metals and coated metals exposed in a given test chamber.” “This practice covers the apparatus, procedure, and conditions required to create and maintain the salt spray (fog) test environment.”
ASTM B244	Standard Test Method for Measurement of Thickness of Anodic Coatings on Aluminum and of Other Nonconductive Coatings on Nonmagnetic Basis Metals with Eddy-Current Instruments	From the public ASTM B244 website:[3] “This test method covers the use of eddy-current instruments for the nondestructive measurement of the thickness of a nonconductive coating on a nonmagnetic basis metal. It is intended to supplement manufacturers’ instructions for the operation of the instruments and is not intended to replace them.” “This test method is particularly useful for measuring the thickness of an anodic coating on aluminum alloys. Chemical conversion coatings are too thin to be measured by this test method.”
ASTM D522	Standard Test Methods for Mandrel Bend Test of Attached Organic Coatings	From the public ASTM D522/D552M website:[4] “Coatings attached to substrates are elongated when the substrates are dimensionally unstable, or are bent during the manufacture of articles or when the articles are abused in service. These test methods have been useful in rating attached coatings for their ability to resist cracking when elongated. They have been useful in evaluating the flexibility of coatings on flexible substrates.”

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[2] https://www.astm.org/standards/b117
[3] https://www.astm.org/b0244-09r21.html
[4] https://www.astm.org/d0522_d0522m-17r21.html

ASTM D523	Standard Test Method for Specular Gloss	From the public ASTM D523 website:[5] “Measured gloss ratings by this test method are obtained by comparing the specular reflectance from the specimen to that from a black glass standard. Since specular reflectance depends also on the surface refractive index of the specimen, the measured gloss ratings change as the surface refractive index changes. In obtaining the visual gloss ratings, however, it is customary to compare the specular reflectances of two specimens having similar surface refractive indices.”
ASTM D662	Standard Test Method for Evaluating Degree of Erosion of Exterior Paints	From the public ASTM D662 website:[6] “Erosion failure of paint films can occur in use. This test method provides a means of evaluating the degree of failure by comparing to pictorial standards.”
ASTM D968	Standard Test Method for Abrasion Resistance of Organic Coatings by Falling Abrasive	From the public ASTM D968 website:[7] “These test methods cover the determination of the resistance of organic coatings to abrasion produced by abrasive falling onto coatings applied to a plane rigid surface, such as a metal or glass panel.”
ASTM D1308	Standard Test Method for Effect of Household Chemicals on Clear and Pigmented Coating Systems	From the public ASTM D1308 website:[8] “Resistance to various liquids used in the home is an important characteristic of organic finishes. These test methods provide the means by which the relative performance of coating systems may be evaluated. It should be recognized that continuous films are necessary for reliable results.” “This test method covers determination of the effect of household chemicals on clear and pigmented organic finishes, resulting in any objectionable alteration in the surface, such as discoloration, change in gloss, blistering, softening, swelling, loss of adhesion, or special phenomena.”

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[5] https://www.astm.org/standards/d523
[6] https://www.astm.org/d0662-93r19.html
[7] https://www.astm.org/d0968-22.html
[8] https://www.astm.org/d1308-20.html

ASTM D1400	Standard Test Method for Nondestructive Measurement of Dry Film Thickness of Nonconductive Coatings Applied to a Nonferrous Metal Base	From the public ASTM D1400 website:[9] "This test method covers the nondestructive measurement of the dry film thickness of electrically nonconductive coatings applied over a nonferrous metal base using commercially available eddy current instruments. This test method is intended to supplement manufacturers' instructions for the manual operation of the gages and is not intended to replace them."
ASTM D1654	Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments	From the public ASTM D1654 website:[10] "This method provides a means of evaluating and comparing basic corrosion performance of the substrate, pretreatment, or coating system, or combination thereof, after exposure to corrosive environments." "This test method covers the treatment of previously painted or coated specimens for accelerated and atmospheric exposure tests and their subsequent evaluation in respect to corrosion, blistering associated with corrosion, loss of adhesion at a scribe mark, or other film failure."
ASTM D2244	Standard Practice for Calculation of Color Tolerances and Color Differences from Instrumentally Measured Color Coordinates	From the public ASTM D2244 website:[11] "This practice covers the calculation, from instrumentally measured color coordinates based on daylight illumination, of color tolerances and small color differences between opaque specimens such as painted panels, plastic plaques, or textile swatches."

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[9] https://www.astm.org/d1400-94.html

[10] https://www.astm.org/d1654-08r16e01.html

[11] https://www.astm.org/d2244-23.html

ASTM D2247	Standard Practice for Testing Water Resistance of Coatings in 100% Relative Humidity	From the public ASTM D2247 website:[12] "Water can cause the degradation of coatings, so knowledge of how a coating resists water is helpful for assessing how it will perform in actual service. Failure in tests at 100 % relative humidity may be caused by a number of factors including a deficiency in the coating itself, contamination of the substrate, or inadequate surface preparation. This practice is therefore useful for evaluating coatings alone or complete coating systems." "This practice covers the basic principles and operating procedures for testing water resistance of coatings by exposing coated specimens in an atmosphere maintained at 100 % relative humidity so that condensation forms on all surfaces of test specimens."
ASTM D2248	Standard Practice for Detergent Resistance of Organic Finishes	From the public ASTM D2248 website:[13] "This practice covers the determination of the resistance to failure, in an accelerated manner, of organic finishes when immersed in a detergent solution."
ASTM D2794	Standard Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact)	From the public ASTM D2794 website:[14] "Coatings attached to substrates are subjected to damaging impacts during the manufacture of articles and their use in service. In its use over many years, this test method for impact resistance has been found to be useful in predicting the performance of organic coatings for their ability to resist cracking caused by impacts." "This test method covers a procedure for rapidly deforming by impact a coating film and its substrate and for evaluating the effect of such deformation."

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[12] https://www.astm.org/d2247-15r20.html
[13] https://www.astm.org/d2248-01ar18.html
[14] https://www.astm.org/d2794-93r19.html

ASTM D3359	Standard Test Methods for Rating Adhesion by Tape Test	From the public ASTM D3359 website:[15] “This test method is limited to evaluating lower levels of adhesion (see 1.3). The intra- and inter-laboratory precision of this test method is similar to other test methods for coated substrates (for example, Test Method D2370 and Test Method D4060), and is insensitive to all but large differences in adhesion.”
ASTM D3363	Standard Test Method for Film Hardness by Pencil Test	From the public ASTM 3363 website:[16] “Pencil hardness measurements have been used by the coatings industry for many years to determine the hardness of clear and pigmented organic coating films. This test method has also been used to determine the cure of these coatings, especially when using forced dried heat.”
ASTM D4145	Standard Test Method for Coating Flexibility of Prepainted Steel	From the public ASTM D4145 website:[17] “This test method describes a procedure for determining the flexibility and adhesion of organic coatings (paints) on metallic substrates that are deformed by bending when the sheet is fabricated into building panels or other products. The metal substrate must be capable of passing this test without fracturing and with no excessive grain development.”
ASTM D4214	Standard Test Methods for Evaluating the Degree of Chalking of Exterior Paint Films	From the public ASTM 4214 website:[18] “The procedures provide a broad range of techniques and photographic references to evaluate chalking of exterior paints.” “These test methods cover the evaluation of the degree of chalking on white or tinted exterior paint films. These test methods describe the procedures recommended for transferring the chalk to a fabric or fingertip, which is then compared to photographic reference standards, or in the case of adhesive tapes, compared to a reflectance table or photographic reference standards, to determine the degree of chalking.”

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[15] https://www.astm.org/standards/d3359

[16] https://www.astm.org/d3363-22.html

[17] https://www.astm.org/d4145-10r22.html

[18] https://www.astm.org/d4214-07r15.html

ASTM D4585	Standard Practice for Testing Water Resistance of Coatings Using Controlled Condensation	From the public ASTM D4585 website:[19] “Water can cause degradation of coatings, so knowledge of how a coating resists water is helpful in predicting its service life. Failure in a condensation test may be caused by a number of factors including a deficiency in the coating itself, contamination of the substrate, or inadequate surface preparation. The test is therefore useful for evaluating coatings alone or complete coating systems.” “This practice covers basic principles and operating procedures for testing water resistance of coatings using controlled condensation. Condensation is produced by exposing one surface of a coated specimen to a heated, saturated mixture of air and water vapor, while the reverse side of the specimen is exposed to the cooling effect of room temperature air.”
ASTM D7897	Standard Practice for Laboratory Soiling and Weathering of Roofing Materials to Simulate Effects of Natural Exposure on Solar Reflectance and Thermal Emittance	From the public ASTM D7897 website:[20] “The solar reflectance of a building envelope surface affects surface temperature and near-surface ambient air temperature. Surfaces with low solar reflectance absorb a high fraction of the incoming solar energy. Sunlight absorbed by a roof or by other building envelope surfaces can be conducted into the building, increasing cooling load and decreasing heating load in a conditioned building, or raising indoor temperature in an unconditioned building. It can also warm the outside air by convection. Determination of solar reflectance can help designers and consumers choose appropriate materials for their buildings and communities.” “Practice D7897 applies to simulation of the effects of field exposure on the solar reflectance and thermal emittance of roof surface materials including but not limited to field-applied coatings, factory-applied coatings, single-ply membranes, modified bitumen products, shingles, tiles, and metal products.”

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[19] https://www.astm.org/d4585_d4585m-18.html

[20] https://www.astm.org/d7897-18.html

ASTM E84	Standard Test Method for Surface Burning Characteristics of Building Materials	From the public ASTM E84 website:[21] "This test method is intended to provide only comparative measurements of surface flame spread and smoke density measurements with that of select grade red oak and fiber-cement board surfaces under the specific fire exposure conditions described herein." "This fire-test-response standard for the comparative surface burning behavior of building materials is applicable to exposed surfaces such as walls and ceilings. The test is conducted with the specimen in the ceiling position with the surface to be evaluated exposed face down to the ignition source."
ASTM E1918	Standard Test Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field	From the public ASTM E1918 website:[22] "Solar reflectance is an important factor affecting the temperature of a sunlit surface and that of the near-surface ambient air temperature. The test method described herein measures the solar reflectance of surfaces in natural sunlight." "This test method covers the measurement of solar reflectance of various horizontal and low-sloped surfaces and materials in the field, using an albedometer or pyranometer. The test method is intended for use when the sun angle to the normal from a surface is less than 45°."

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[21] https://www.astm.org/standards/e84
[22] https://www.astm.org/e1918-21.html

ASTM E1980	Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low-Sloped Opaque Surfaces	From the public ASTM E1980 website:[23] “Solar reflectance and thermal emittance are important factors affecting surface and near-surface ambient air temperature. Surfaces with low solar reflectance, absorb a high fraction of the incoming solar energy. A fraction of this absorbed energy is conducted into ground and buildings, a fraction is convected to air (leading to higher air temperatures), and a fraction is radiated to the sky. For equivalent conditions, the lower the emissivity of a surface the higher its steady-state temperature. Surfaces with low emissivity cannot effectively radiate to the sky and, therefore, get hot. Determination of solar reflectance and thermal emittance, and subsequent calculation of the relative temperature of the surfaces with respect to black and white reference temperature (defined as Solar Reflectance Index, SRI), may help designers and consumers to choose the proper materials to make their buildings and communities energy efficient. The method described here gives the SRI of surfaces based on measured solar reflectances and thermal emissivities of the surfaces.”
ASTM G7	Standard Practice for Natural Weathering of Materials	From the public ASTM G7 website:[24] The relative durability of materials in natural exposures can be very different depending on the location of the exposure because of differences in ultraviolet (UV) radiation, relative humidity, time of wetness, temperature, wet-dry cycling, freeze-thaw cycling, pollutants, and other factors. Therefore, it cannot be assumed that results from one exposure in a single location will be useful for determining relative durability in a different location. Exposures in several locations with different climates which represent a broad range of anticipated service conditions are recommended.
AWWA D102-6	AWWA Standard for Coating Steel Water-Storage Tanks	From the public AWWA D102-6 website:[25] This standard describes coating systems for coating and recoating the inside and outside surfaces of steel tanks used for potable water storage in water supply service.

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[23] https://www.astm.org/standards/e1980
[24] https://www.astm.org/g0007_g0007m-21.html
[25] https://engage.awwa.org/PersonifyEbusiness/Bookstore/Product-Details/productId/27171

VDA 233-102	Cyclic Corrosion Testing of Materials and Components in Automotive Construction	From the public VDA 233-102 website:[26] “The purpose of this specification is to provide an accelerated test procedure for the assessment of the corrosion behaviour of components and of the corrosion protection provided by coating systems. The accelerated test covers in particular the delamination/corrosion creep around a defined artificial defect in a coating as well as surface and edge corrosion on special test plates, bonding specimens or components. Compared to tests with a higher humidity availability a decreased ageing rate of adhesive is to be expected. This laboratory-scale cyclic corrosion test is also suitable for assessing perforation corrosion in flanged areas or gaps and of unpainted surfaces.” “This method induces corrosion processes and generates reproducible corrosion patterns which correlate well with the results obtained in natural weathering tests (DIN 55665) and driving operation. In particular, the corrosion patterns for the substrates steel, galvanised steel and aluminium closely reflect real-life phenomena.” “The test method is based on real corrosive climate conditions and delivers differentiated results for a large number of uses in automotive applications.”

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[26] https://webshop.vda.de/VDA/en/vda-233-102-06-2013