1. PVC Roof Membranes: A Resilient, Sustainable Solution

Overview.

PVC roof membranes are a resilient, high-performance plastic composite that stands out as a sustainable roofing solution due to its exceptional durability, versatility, and low environmental impact. With a proven track record in North America for over 40 years, PVC roof membranes have provided long-lasting protection against the elements, including ultraviolet exposure (UV), extreme weather conditions, and chemical exposure. Because of these attributes, PVC roof membranes are a reliable option for various roofing needs. PVC roof membranes align with modern environmental standards and recycling initiatives and provide long-term use, creating a win-win scenario for performance and eco-consciousness.

This white paper discusses the benefits, chemistry, criticisms, and regulations regarding PVC roof membranes. Based on this discussion, this paper concludes that PVC roof membranes meet applicable standards, exceeding the threshold definition for durable plastics. PVC roofing membranes should remain an option for long-term weatherproofing roofing applications. Durable applications such as PVC roofing membranes differ from single-use or short-term-use plastics and should be considered separately in legislation, regulation, and customer perception. In addition, this white paper will discuss the large-scale use of PVC roof membranes and industry efforts to recycle, upcycle, and repurpose PVC roof membranes, further decreasing their environmental impact. Thus, this discussion will inform the conversation by suggesting that PVC roof membranes belong to a separate plastic

category: resilient, high-performance plastic composites, which remain an option for waterproofing applications.

2. PVC Roofing should be categorized as a *Resilient, High-performance Plastic Composite*

All plastics are not the same. It is essential to understand that all plastics are intentionally designed and engineered for specific purposes. Various plastics have empowered significant technological advances and improved the quality of life, from transportation to lifesaving devices. All plastics differ based on design, life, intended use, and end-of-life capabilities.

Focusing on the advancements of PVC roof membranes amplifies this need to look at plastics based on their differences in intended use, anticipated use life, and sustainable and environmental properties.

The Environmental Protection Agency (EPA) currently categorizes plastics into two categories;

Single-Use Plastics: Single-use plastics are defined as plastics that are typically used once or briefly before disposal. Typical uses include packaging and wrapping. Plastics within this category carry a recycled resin I.D. number (1-7). This code identifies the type of plastic and does not indicate its ability to be recycled. Certain recyclable plastics within this category can be mechanically recycled or chemically broken down into feedstocks for regenerating monomers when collected and properly sorted.

Durable plastics: Durable plastics are a long-lasting category of plastic designed to have a service life of 3 years or more. As with single-use plastics, at the beginning of their initial life, durable plastics can be mechanically or chemically recycled as feedstock for downstream reprocessing into new plastic products.

This white paper advocates for a third classification for *Resilient, High-performance Plastic Composites* that vastly exceed the minimal service life of 'durable plastics' and are

known for their exceptional resistance to wear, impact, and degradation over time. These resilient, high-performance plastic composites can withstand harsh environmental conditions, mechanical stress, and chemical exposure, making them highly durable and long-lasting. The polymers used in this type of plastic have superior durability (often with decades of design life). They are frequently achieved through advanced engineering and manufacturing processes that enhance their molecular structure and physical properties. Applications for the resilient, high-performance plastics category can be found in various industries, including automotive, aerospace, construction, medical field, and consumer goods, where longevity and resilience are paramount.

Developing and using resilient, high-performance plastic composites contributes to products with extended lifespans of 10 years or longer and a reduced need for frequent replacement, promoting sustainable goals and resource efficiency.

PVC roof membranes best fit this new category. And are frequently used in building installations. These membranes have effectively served the vital purpose of preserving dry, conditioned spaces for decades. Certain configurations have been engineered to endure for 30 years or beyond.

3. Historical Environmental Impact Concerns for PVC Roofing Membranes.

The chemistry of PVC roofing membranes will help frame our premise that these materials should be considered *Resilient, High-performance Plastic Composites*. The properties of plastics are created through the interactions of long chains of repeating units called monomers, the fundamental building blocks of plastics. These monomers link together end to end through a process called polymerization, forming a polymer.

The interactions between and dynamics of these polymers create a vast array of observed properties. In addition to the interactions of these chains, this unique adaptability allows plastic to serve many purposes, from lightweight packaging materials to robust structural components, making them indispensable in our modern world.

Furthermore, polymerization transforms the material. For example, as a monomer, vinyl chloride is a short carbon chain highly volatile material, [1] yet when it is polymerized into long carbon chains in polyvinyl chloride (PVC), it is inert and certified as safe for drinking water and is the material of choice for many applications.[2]

Additives add a vast range of specific properties to the final PVC mixture. Examples of these properties can include flexibility, UV and thermal stabilization, fire resistance, and pigments. Combined, these enable PVC roof membrane performance as an admirable roofing material.

[1] Vinyl Chloride Toxicity - StatPearls - NCBI Bookshelf (nih.gov)
[2] PVC Remains Material of Choice for Life-Saving Medical Devices (plasticstoday.com)

PVC is the third most produced plastic globally, boasting an annual volume of 45 million metric tons[3]. PVC is valued for its low cost of production, versatility, strength, toughness, natural fire resistance, and durability. PVC is remarkable for its adaptability, as it is used in two distinct forms: rigid and flexible. In its rigid form, PVC exhibits impressive strength, making it an ideal choice for applications such as piping, conduit, siding, window, and door profiles. However, when a plasticizer is added to PVC, it transforms into a remarkably flexible material. This dual nature, encompassing the gamut from robust rigidity to supple flexibility, empowers PVC with a versatility that underpins its widespread usage across an extensive array of industries and applications. For example, PVC is critical to medical applications, accounting for 25% of all medical plastics.[4] PVC is also called infrastructure plastic, as 70% of the production volume is used in long-duration building and construction applications such as single-ply roofing, pipes, cables, siding, flooring, fencing, and decking.[5]

Their alternatives would not be as sustainable or environmentally friendly as PVC. PVC has been selected in the marketplace as the adaptable choice of materials for many applications based on the versatility of combining the base polymer's properties with functional additives. One of the most successful applications of flexible PVC is single-ply roofing. Single-ply PVC roofing is often selected from the marketplace of material choices due to the combination of properties, including cost, durability, and low carbon footprint. The native durability of PVC roofing allows it to be printed or even colored white, creating a "cool roof" reflecting solar energy, thereby decreasing the energy required to maintain condition spaces. PVC roofing membranes' innate durability and toughness also enable various modern roofing applications. These include solar

[3] https://www.chemanalyst.com/industry-report/polyvinyl-chloride-pvc-market-60
[4] PVC Remains Material of Choice for Life-Saving Medical Devices (plasticstoday.com)
[5] https://www.plasticsnews.com/news/vinyl-institute-recycled-pvc-has-role-infrastructure-projects?

installations, green roofs, or even entertaining rooftop spaces. Looking for alternatives for other low-sloped roofing products finds that most are made from 100% fossil fuels and may contribute to increased GHG emissions.

4. Current Environmental Guidance and Concerns About the Formulation of PVC Materials

Throughout its century-long existence, few polymers have faced the level of scrutiny PVC has endured. The bulk of this scrutiny has revolved around the various individual components and additives historically used in PVC production rather than the material's overall performance or current production practices. Some of the most significant concerns have centered on the historical use of lead and cadmium as stabilizers, chlorine in PVC, the incorporation of phthalate additives, and the potential generation of dioxins during its production processes. Each of these concerns is addressed below.

Lead and Cadmium

PVC, while widely used in various applications, is vulnerable to thermal degradation. Fortunately, for many applications, this is not a significant concern. For instance, PVC piping plays a vital role, dominating 66% of the water distribution market and 75% of sanitary sewer pipe applications. [6]. However, in certain applications like cables or roofing membranes, PVC necessitates the incorporation of additives that can ensure thermal stability and prevent the release of harmful HCl (hydrochloric acid). Thankfully, the utilization of lead and cadmium as PVC stabilizers has become obsolete, with cadmium being phased out in the U.S. and Canada since 2000,[7] followed by

[6] De Martins J.N., Freire E., Hemadipour H., Applications and market of PVC for piping industry, Polimeros (2009) https://doi.org/10.1590/s0104-1428200900010001

[7] A Turner, M Filella, Polyvinyl chloride in consumer and environmental plastics, with a particular focus on metal-based additives, Environ. Sci.: Processes Impacts, 2021, 23, 1376-1384, DOI: 10.1039/D1EM00213A

Europe in 2001.[8] Likewise, lead was phased out in the U.S. in 2006[9] and Europe in 2007,[10] marking significant steps toward safer and more sustainable PVC production.

Modern PVC materials, including roofing membranes, are widely considered safe, evidenced by the USEPA, ASTM/ANSI certification for use in drinking water systems, determination safe issuance letter by the California Office of Environmental Health Hazard Assessment,[11]

Due to their proven durability, PVC roofing membranes are a great foundation for solar arrays and vegetative roofs. The life span, along with highly reflective colors, PVC roofing membranes aid in preventing the urban heat island effect, saving energy, especially in hot summer months where peak demand is a problem, as shown by the Cool Roof Rating Council (CRRC). It can also assist HVAC equipment located on rooftops in providing a lower-temperature operating environment, thus enhancing the durability of the HVAC equipment.

Chlorine

PVC roofing membranes owe much of their unique properties to the presence of chlorine in their molecular structure. This chlorine content alters the polymer's density and imparts several valuable characteristics, including enhanced chemical resistance, flame retardancy, durability, and dimensional stability across various temperatures.[12]

[8] VinylPlus_Contribution-Cefic_Eu-Industry.pdf (stabilisers.eu)
[9] A Turner, M Filella, Polyvinyl chloride in consumer and environmental plastics, with a particular focus on metal-based additives, Environ. Sci.: Processes Impacts, 2021, 23, 1376-1384, DOI: 10.1039/D1EM00213A
[10] VinylPlus_Contribution-Cefic_Eu-Industry.pdf (stabilisers.eu)
[11] Issuance of a Safe Use Determination for Diisononyl Phthalate in Certain Single-Ply Polyvinyl Chloride Roofing Membrane Products - OEHHA (ca.gov)
[12] Ayodeji Emmanuel Amobonye, Prashant Bhagwat, Suren Singh, Santhosh Pillai, Chapter 10 - Biodegradability of Polyvinyl chloride, Pages 201-220, Editor(s): Anjana Sarkar, Bhasha Sharma, Shashank Shekhar, in Biodegradability of Conventional Plastics, Elsevier, 2023, , ISBN 9780323898584, https://doi.org/10.1016/B978-0-323-89858-4.00017-8.

It is important to distinguish between elemental chlorine gas, which can indeed be hazardous, and the elemental chlorine chemically bound within PVC itself. Even though the PVC molecule comprises 57% by weight of chlorine, PVC is essentially inert. It is also noteworthy that chlorine is a naturally occurring element ubiquitously found in seawater, urban soil, and the earth's continental crust. Chlorine is essential to sanitize drinking water, public swimming pools, etc. According to medicine.net, 85% of pharmaceuticals are chlorine-based. Moreover, chlorine serves as one of the six essential macronutrients vital for providing ions required for various cellular functions[13] and is primarily found in common table salt,[14] highlighting its ubiquity and significance in the natural world.

Because chlorine is a natural fire inhibitor, it lends this property to PVC roof membranes, which self-extinguish as demonstrated by a zero rating for PVC in the Underwriters Laboratory UL94 flammability test.[15]. The Southwest Research Institute conducted a fire resistance study comparing three single-ply roofing membranes. And demonstrated that only PVC was self extinguishing where the other petroleum based membernes were completely consumed by fire. [16]

Vinyl Chloride exposure to manufacturing employees

[13]https://chem.libretexts.org/Bookshelves/General_Chemistry/Book%3A_General_Chemistry%3A_Principles_Patterns_and_Applications_(Averill)/01%3A_Introduction_to_Chemistry/1.09%3A_Essential_Elements_for_Life
[14] https://chemistry-guide.com/10-reasons-why-chlorine-is-important/
[15] Zhang, L., Chen, T., Su, K. *et al.* Fire behavior and transparent properties of polyvinyl chloride film with different plasticized systems. *J Polym Res* **30**, 17 (2023). https://doi.org/10.1007/s10965-022-03371-1
[16] SWRI project #01.11810.01.241 available at: https://vinylroofs.org/wp-content/uploads/2019/10/swroject.pdf

Vinyl Chloride, the monomer from which PVC is made, is highly regulated and has strict guidelines on exposure to employees and surrounding areas from OSHA[17] and the EPA[18]. As reported by the CDC, [19]

> "Over the past several decades, significant reductions in vinyl choloride emisions have been achieved from improved engineering control in PVC manufacturing facilities. Moreover, optimization of the PVC production process has lowered residual levels of vinyl chloride in finished products such as PVC pipe and food and nonfood packaging material. Current PVC roof membrane manufacturing processes."

A European Chemical Agency report states that: "This information (in the report) seems then to indicate that the operational conditions and risk management measures implemented in the VCM/PVC industry are adequate and effective to control the risk for workers from VCM."[20] A report on the vinyl chloride – PVC industry's occupational hazards that appeared in the National Library of Medicine, [Prog Clin Biol Res. 1984:141:155-75.] data was presented and stated the exposure reductions in 1974 may have "virtually eliminated the VC-associated risk of liver cancer if the current U.S. standard is met. To the extent that V.C. exposure is associated with other cancers, a similar risk reduction would be expected."

Dioxins

In the 1980's there was concern over dioxin emissions from PVC production. It's important to note that when most plastics, wood or other materials are burned or improperly incinerated, dioxins are produced.[1] Dioxin emissions have been reduced by 90% for PVC production since the 1980's through a combination of laws and

[17] 1910.1017 - Vinyl chloride. | Occupational Safety and Health Administration (osha.gov)
[18] Polyvinyl Chloride and Copolymers Production: National Emission Standards for Hazardous Air Pollutants (NESHAP) - 40 CFR 63 Subparts J & HHHHHHH | US EPA
[19] https://www.atsdr.cdc.gov/toxprofiles/tp20-c5.pdf
[20] European Chemical Agency Report, Investigation Report on PVC and PVC additives, 22/11/2023.

regulations on dioxin production during PVC manufacturing.[21] To bring this into perspective, the regulations governing the production of PVC resin (PVC MACT)[22], include required reporting to the EPA National Emission Standards for Hazardous Air Pollutants (NESHAP) for all industrial and utility processes that yield hazardous air pollutants (e.g., steel manufacturing, petroleum refining, electrical generation, waste incinerators, etc). This has played a crucial role in mitigating the release of dioxins into the environment. The production of PVC resin and its monomers contributes less than 5% of the total dioxin emissions to air and water, as reported by USEPA in its annual Toxic Release Inventory. [reference RK SPE Vinyltec presentations]

Phthalates

PVC stands out for its inherent strength and natural rigidity, surpassing many other polymers in these aspects. This rigidity proves to be advantageous in various applications, particularly in products like pipes and conduits. What makes PVC truly unique is its adaptability – the addition of plasticizer additives allows PVC to become flexible. Flexible PVC finds application in a wide range of products, including roofing membranes, [1] plastisol fishing worms, [1], blood bags, [1] and surgical gloves. [1] PVC's exceptional versatility allows it to be both rigid and flexible within the same application, enabling a diverse array of uses, such as oxygen masks, blister packaging, and complete assemblies for the delivery of IV and dialysis fluids.

Traditionally, phthalates, being lower molecular weight compounds, raised concerns about their potential to diffuse out of PVC over time. This potential diffusion is a greater potential concern in applications where PVC encounters food or the skin. However, it's less of a concern in applications like roofing membranes, where the

[21] PVC Production and Waste Incineration dioxins eliminated PVC Production and Waste Incineration dioxins eliminated - VinylPlus
[22] CFR40, Part 63, Subpart HHHHHHH.

environmental degradation of any free plasticizer mitigates the potential for exposure. Recognizing other issues, the PVC industry has made strides in developing new types of plasticizers that offer comparable performance while minimizing the risk of diffusion from the PVC matrix.[1] This innovation addresses environmental and regulatory concerns and enhances the overall durability and performance of PVC-based products, making them safer and more reliable for a wide range of applications. For example, the (heavy-weighted) flexible agent or phthalate used in the majority of PVC roof membranes (DINP)[23] has received a Safe Use Determination (SUD) from California.[24] The 2013 study by the State of Washington studied the leaching of chemicals or other additives into water run-off collected from various roofing materials. The PVC roofing membrane showed zero plasticizers or phthalates leaching into the runoff in all rain events.[1]

Today' 's PVC roof membranes are manufactured to internationally recognized environmental standards and have undergone extensive testing. These have been certified as meeting the performance requirements for the intended use by many international codifying bodies. Such as:

- ASTM International D4434, E108 fire performance.
- European Committee for Standardization (CEN)
- ANSI/NSF Facility manufacturing production. NSF 347 certification.
- Listed in 3rd party audited for UL, FM,
- OSHA ,

[23] Jayflex™ plasticizers for advantaged performance (exxonmobilchemical.com) available at: https://www.exxonmobilchemical.com/en/resources/library/library-detail/2930/jayflex_didp_dinp_ap_en
[24] https://oehha.ca.gov/proposition-65/crnr/issuance-safe-use-determination-diisononyl-phthalate-certain-single-ply and https://oehha.ca.gov/proposition-65/crnr/correction-analysis-supporting-safe-use-determination-diisononyl-phthalate.

These organizations follow consensus standard development procedures with industry experts, manufacturers, regulatory agencies, and stakeholders to develop and update standards that ensure building materials like PVC roof membranes' safety, quality, and performance.

5. The Economic and Environmental Impact of Replacing PVC Roof Membranes

In response to improperly managed post-use plastic waste, three approaches have historically been promoted to address this issue, including reducing, reusing, and recycling plastics at the end of their useful life.

To reduce plastic use altogether, strategies for imposing taxes, implementing production quotas, and banning certain single-use plastic items have been proposed. However, federal lawmakers in the U.S. have given these actions limited consideration.[25] Contrary to these approaches, manufacturers and retail goods industries have taken voluntary steps to reduce the footprint of plastic packaging and to design plastic products for recycling, thus making it difficult to quantify their aggregate benefit. As a result, the benefits of these efforts should be noticed. Local and regional bans on single-use plastic cutlery, straws, and food containers have been implemented, but with mixed results.[26]

These approaches to reduce overall plastic consumption using taxes, quotas, or bans impact construction-grade PVC products and may adversely affect the production and use of PVC roof membranes, which could limit highly sustainable choices in environmental construction projects.

These actions would have unintended consequences as some alternatives to PVC roof membranes have higher GHG emissions. In July of 2022, McKinney & Company published an extensive study on the climate impact of plastics. The report showed that

[25] The US falls behind most of the world in plastic pollution legislation - EHN accessed 2/04/2024 available at: https://www.ehn.org/plastic-pollution-2655191194.html
[26] The Case against paper straws, Annie Lawrey, The Atlantic

the move toward decarbonization in 2050 would be "hard to achieve" without PVC and other plastics. It examined the total GHG contribution of plastics versus its alternatives, including product life cycle (cradle to grave) and impact of use. [27]Its findings were that in 13 out of 14 cases, products made from PVC and other plastics had lower total greenhouse gas contribution than their likely alternatives. Their alternatives would not be as sustainable or environmentally friendly as PVC. PVC has been selected in the marketplace as the adaptable choice of materials for many applications based on the versatility of combining the base polymer's properties with functional additives.

According to the Single Ply Roofing Industry (SPRI), PVC roof membrane accounted for 17% of the low-slope market in 2023 and is the second largest single-ply membrane by category tracked by SPRI. Regarding the benefits of PVC roof membranes mentioned earlier in this paper, heavier petroleum-based, low-sloped roofing alternatives could have higher environmental impacts than PVC roof membranes.

[27] https://www.mckinsey.com/industries/chemicals/our-insights/climate-impact-of-plastics

6. Longevity and Embodied carbon of PVC roof membranes

The decades-long design life and low embodied energy of PVC roof membranes suggest that it is a sustainable roofing solution with exceptional versatility and environmental benefits. The proven track record of providing long-lasting protection against the elements, including ultraviolet radiation, extreme weather conditions, and chemical exposure, makes them a reliable option for various roofing needs. Given the significant difference in the required minimal lifespan of durable plastics, a resilient, high-performance plastic composites category would better help individuals understand the critical contribution of products with extended lifespans of 10 years or longer.

A 2005 study analyzed 44 PVC roofs throughout Europe and North America, testing their performance after long-term field exposure. The table below shows the study's results.

The study considered the age and the condition of the roofs analyzed, the data indicated that a properly formulated, properly maintained, reinforced PVC roof membrane system could perform in excess of 20-30 years in various climates throughout Europe and North America.

Table 1: Summary of all projects. Samples 1-26: North America, samples 101-137: Europe

ID	Project Location	Type*	Instal-led	Age years	ID	Project Location	Type*	Instal-led	Age years
1A	Canton MA	G – 12	1979	22	21A	Haileybury ON	G - 12	1981	20
1D	Canton MA	S – 12	1979	22	21C	Haileybury ON	S - 12	1981	20
2A	Wenham MA	G - 12	1984	17	22A	Hamilton ON	S - 12	1984	17
2D	Wenham MA	S - 12	1984	17	23A	Alouette QC	G - 12	1983	18
3A	Woburn MA	G - 12	1983	18	25A	Sarnia ON	G - 12	1984	17
4B	Dickson TX	G - 12	1984	17	26	Calgary AB	G - 12	1982	19
5B	Tyler TX	G - 12	1981	20	101	Bregenz, A	S - 12	1978	24
5C	Tyler TX	S - 12	1981	20	102	Villach, A	S - 12	1981	21
6A	Euless TX	S - 12	1984	17	103	Hausmannstätten, A	S - 18	1984	18
7A	City of Industry CA	G - 12	1979	22	104	Vlotho, D	S - 12	1975	27
8A	El Segundo CA	G - 12	1982	19	105	Freiburg, D	S - 12	1977	25
9B	Mountainview CA	S - 12	1983	18	106	Memmingen, D	S - 12	1978	24
10B	Lacey WA	G - 12	1982	19	107	Niedergösgen, CH	S - 12	1978	24
11B	Ft. Steilacoom WA	G - 12	1983	18	108	Schwyz, CH	S - 12	1978	24
12A	Atlanta GA	S - 12	1986	15	109	Geneva, CH	S - 12	1978	24
13A	Jacksonville FL	S - 12	1982	19	110	Bursins, CH	S - 18	1993	9
14A	Appleton WI	S - 12	1985	16	111	Spreitenbach, CH	S - 18	1985	17
15B	Mt. Prospect IL	G - 12	1981	20	112	Canobbio, CH	S - 18	1985	17
15D	Mt. Prospect IL	S - 12	1981	20	131	Arnoldstein, A	G - 14	1986	16
16A	Park Ridge IL	S - 12	1984	17	132	Dortmund, D	G - 14	1979	23
17B	Hackensack NJ	S - 12	1986	15	133	Kempten, D	G - 12	1976	26
18A	Englewood NJ	G - 12	1985	16	134	Camorino, CH	G - 27	1976	26
18C	Englewood NJ	S - 12	1985	16	135	Personico, CH	G - 12	1968	34
19A	Iowa City IA	S - 12	1982	19	136	Lugano, CH	G - 12	1970	32
20B	Davis CA	G - 12	1981	20	137	Reading, UK	G - 12	1987	15

Note: *: Type of membrane, G: glass reinforced, S: polyester reinforced, "- xy": thickness in mm

The embodied carbon emissions of PVC roof membranes are calculated using the life cycle inventory using the industry-wide EPD conducted by the Chemical Films and Fabric Association (CFFA). (The 60-mill thickness is the most popular thickness, but this information is also available for other thicknesses in the full EPD.)

Measured in Table 11 is the global warmth potential (GWP) of 1 sq meter of 60 mil PVC roof membrane in various phases of its life cycle. The production phase is A1-A3, the construction phase is A4-A5, and C1-C4 represents EOL.

Table 11 Cradle-to-construction with EOL stage (A1-A5, C1 to C4, D), EPD Results – 1 m² of white SPPR PVC roofing membrane (60 mils)

Impact category and inventory indicators	Unit	A1-A3	A4	A5	C1-C4	D
Global warming potential, GWP 100[1)]	kg CO_2 eq	6.3	0.18	0.65	0.13	-1.0
Ozone depletion potential, ODP[1)]	kg CFC-11 eq	8.9E-07	7.4E-12	7.1E-08	9.4E-09	-1.5E-07
Smog formation potential, SFP[1)]	kg O_3 eq	0.39	0.060	0.042	0.013	-0.016
Acidification potential, AP[1)]	kg SO_2 eq	0.035	0.0023	0.0032	0.0007	-0.0034
Eutrophication potential, EP[1)]	kg N eq	0.099	0.0001	0.007	0.011	-0.0020

Table 11 presents how the total embodied carbon is calculated, and Table 6 shows the percentages of CO2 equivalent in each phase. The total CO_2 equivalent through EOL is 7.3 kg per square meter of PVC roof membrane. The production phase (A1-A3) is 6.3kg, which converts to approximately 13 Lbs. of CO2 equivalent.

Looking at Table 6, we can see the percentage of each stage of CO2 eq. of the LCI. Table 6 identifies that the production phase represents 6.3kg or 87% of CO2 produced in the entire life cycle through EOL. 11% of CO_2 or 0.803 kg from the Construction phase (A4-A5) and 2% or 0.146 kg from the EOL (C1-C4), totaling 7.3 kg. or 16 Lbs. of CO_2 eq.

Stretched out for 30 years equals 0.53 Lbs. of CO_2 eq. per year per square meter of PVC

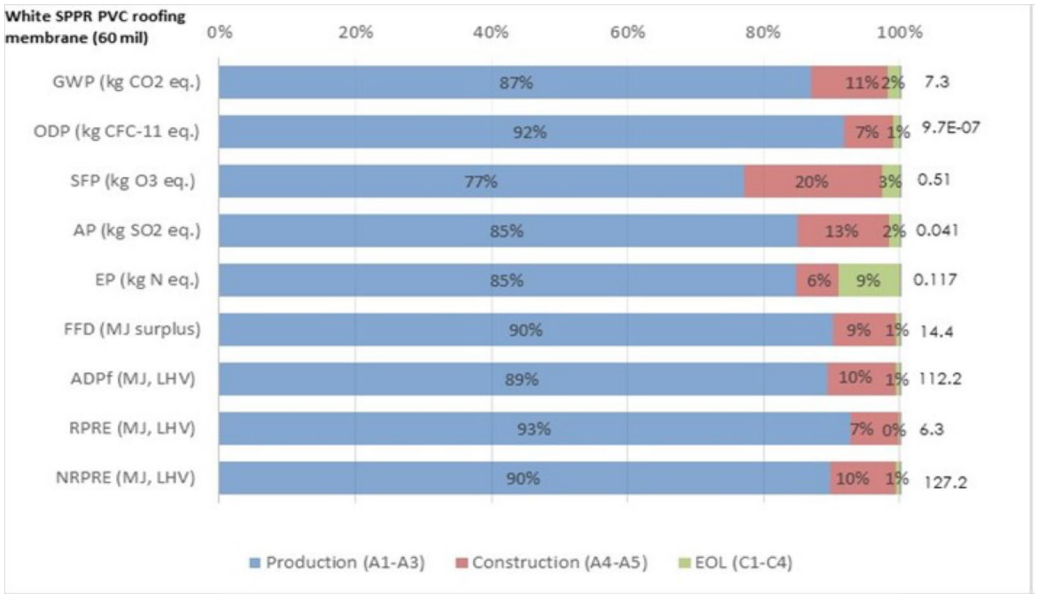


Figure 6 Impact assessment and energy indicator results by stage – 1 m_2 of 60 mils white SPPR PVC roofing membrane – % Basis

roof membrane through its entire lifecycle, including EOL. This number gets even lower when you analyze the environmental benefit of using a reflective color in hotter climates. Or allow the PVC roof membrane to be the foundation for soil and plants, providing significant insulation value and mitigating the water run-off on a vegetative roof or the electricity produced from solar panels. Then, factor in recycling or repurposing, and the total lifecycle carbon falls even lower.

Compare this to a popular, less expensive, petroleum-based asphaltic product of 11.1 kg or 26 Lbs per square meter of CO_2eq through the same lifecycle analysis.[28]

[28] chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.asphaltroofing.org/wp-content/uploads/2019/10/APP-Torch-EPD.pdf

A typical warranted lifetime of 10 years would equal 2.6 Lbs per square meter per year, a 20% increase in CO_{2eq}. Longevity is a critical component of a product's entire lifecycle.

Other Sustainable Benefits

Most non-plastic alternate roof materials are formed by higher quantities of petroleum-based materials and energy during their lifecycle. PVC roof manufacturing relies on catalysts that, in small amounts, lower the energy required to string together the monomers into a polymer, thus resulting in a lower amount of embodied carbon in the material.[29] Also, because the PVC resin comprises 57% chlorine derived from ordinary table salt, its embodied carbon is even lower.

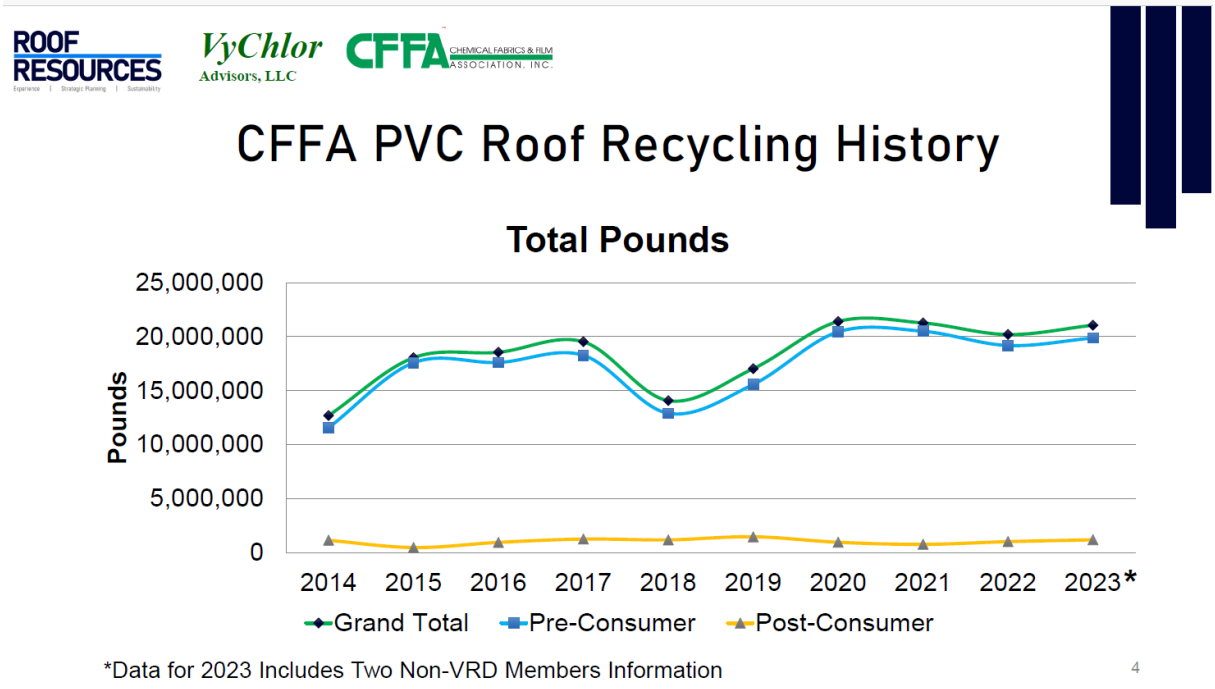
Due to their long lifespan, PVC roof membranes are an excellent foundation for solar arrays and vegetative roofs. The life span and highly reflective colors of PVC roof membranes aid in preventing the urban heat island effect, saving energy, especially in hot summer months where peak demand is a problem, as shown by the Cool Roof Rating Council (CRRC)[30].

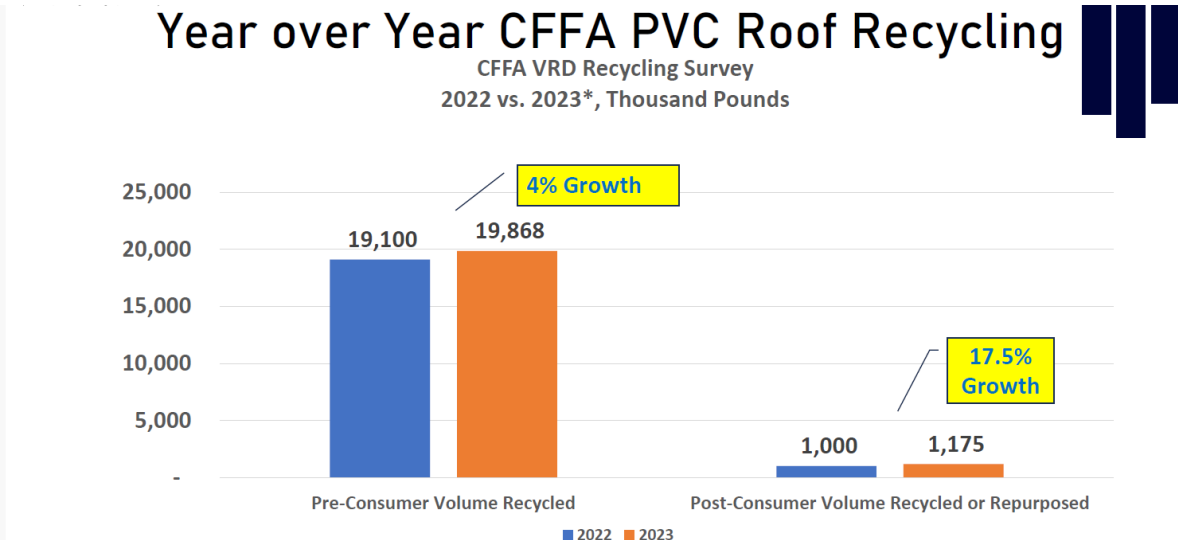
[29] Making Plastics: From Monomer to Polymer | AIChE available at: https://www.aiche.org/resources/publications/cep/2015/september/making-plastics-monomer-polymer
[30] The cool roofing movement | Professional Roofing magazine accessed 2/10/2024 available at: https://www.professionalroofing.net/Articles/The-cool-roofing-movement--01-01-2004/392#:~:text=Cool%20roofs%20have%20an%20additional%20benefit%20aside%20from,that%20cause%20roofing%20components%20to%20expand%20and%20contract.

7. PVC Roof Membrane Recycling

The PVC roof industry has made great strides in recycling and upcycling pre and post-consumer membranes in the last few years. The industry is quickly moving in this direction by creating long-term mechanisms showing great results. Additional tax or legislation may slow this process, taking away vital capital to develop mechanisms that guarantee more efficient end-of-life solutions.

Recycling has been a critical component of the PVC roof industry's lifecycle management. Post-consumer PVC roof membrane recycling first started in 1999. The Chemical Fabrics and Film Association (CFFA)—Vinyl Roofing Division began tracking pre- and post-consumer PVC membrane recycling by its members in 2014.





They most recently recorded that 19.8 million pounds of pre-consumer thermoplastic PVC roofing membrane were recycled, a 4% growth from 2022 and 1.1 million pounds of post-consumer PVC membrane were recycled, a 17.5% growth from the calendar year 2022[31]. The vinyl industry is committed to advancing the development of more efficient feedstock recycling of post-consumer thermoplastic membranes.[32] CFFA has a well-organized initiative to accelerate PVC roof membrane recycling even more. The U.S. Vinyl Institute' 's Vinyl Sustainability Council has tracked other PVC product recycling in the U.S. and Canada since 2013, and its most recent update reported that 958 million pounds of pre-consumer and 142 million pounds of post-consumer PVC materials for a combined total of 1.1 billion pounds recycled in 2020[33]. The Vinyl Institute established its $3 million VIABILITY™ Grant program in 2022 to provide funding to accelerate

[31] https://vinylroofs.org/wp-content/uploads/2023/03/RecyclingWhitePaper.pdf
[32] Lewandowski K, Skórczewska K. A Brief Review of Poly(Vinyl Chloride) (PVC) Recycling. Polymers (Basel). 2022 Jul 27;14(15):3035. doi: 10.3390/polym14153035. PMID: 35893999; PMCID: PMC9332854.
[33] Vinyl Sustainability Council Progress Report for 2021, P. 20, available at https://vantagevinyl.com/progress-report/

post-consumer PVC recycling projects.[34] Similar efforts are taking place in Europe, where efforts to foster recycling, such as Recovinyl[35] and Vinyl Plus,[36] were established more than two decades ago. The European efforts are also showing remarkable progress, with nearly two billion pounds (1M tons) recycled annually. In summary, PVC recycling is a robust industry and is receiving greater support than ever as a critical sustainability parameter for the growth of the entire PVC industry.

[34] https://www.vinylinfo.org/recycling/
[35] Home | Recovinyl
[36] PVC Remains Material of Choice for Life-Saving Medical Devices (plasticstoday.com)

8. Summary Points

PVC (polyvinyl chloride) roof membranes represent a sustainable choice for building construction and maintenance due to several key factors: Longevity, energy efficiency, waterproofing performance, and recyclability. But there is more; regulatory requirements to stringent industry standards ensure that PVC roof membranes are environmentally sustainable.

In addition, manufacturers adhere to guidelines regarding additives, emissions, and waste management practices to minimize environmental impact throughout the product lifecycle. Additionally, certifications such as ENERGY STAR, Green Globes, and LEED (Leadership in Energy and Environmental Design) recognize PVC membranes for their sustainable attributes, further reinforcing their credibility as a sustainable, lower-environmental-impact building material.

Enough compelling evidence suggests that PVC roof membranes do not belong in the durable plastic category but need to be placed in a suggested category of Resilient, High-performance Plastic Composites.

As PVC roofing has an expected service life of more than ten years, it should be considered independently of current Extended Producer responsibility regulations, primarily concerned with single-use plastic applications with much shorter service life expectations.

Concerns about PVC's environmental impact have been discussed. These concerns are typically based on historical production practices that no longer apply to modern PVC roofing membrane practices.

In conclusion, PVC roof membranes are a sustainable choice for modern building projects. By incorporating PVC membranes into construction practices, we can

contribute to environmental conservation, energy efficiency, and long-term sustainability in the built environment. PVC roofing membranes should remain a potential solution that can be selected for waterproofing applications from other possible options in the marketplace.