WHITE PAPER

PVC Roofing Membranes: A Resilient, Sustainable Solution

SPRI PVC Environmental Task Force

ABSTRACT

THIS WHITE PAPER EXPLORES THE BENEFITS, CHEMISTRY, CRITICISMS, AND REGULATIONS SURROUNDING PVC ROOFING MEMBRANES, INCLUDING THEIR ABILITY TO MEET OR EXCEED EPA'S DEFINITION OF DURABLE PLASTICS

SPRI
SINGLE PLY ROOFING INDUSTRY

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PVC ROOFING MEMBRANES: A RESILIENT, SUSTAINABLE SOLUTION

PVC roof membranes are a resilient, high-performance plastic composite recognized for sustainability due to their exceptional durability, resiliency, versatility, and low environmental impact. With over 40 years of proven performance in North America, PVC roof membranes have provided long-lasting protection against the elements, including ultraviolet exposure (UV), extreme weather conditions, and chemical exposure[1]. As a result, PVC roof membranes are a reliable and beneficial option for various roofing applications, aligning with modern environmental standards and recycling initiatives, creating a win-win scenario for performance and eco-consciousness.

This white paper explores the benefits, chemistry, criticisms, and regulations surrounding PVC roof membranes. It concludes that they meet and often exceed applicable standards for durable plastics, making them a sustainable choice for long-term roofing needs. Unlike single-use or short-term plastic, durable plastic applications such as PVC roofing membranes warrant separate, distinct considerations. In addition, this white paper will examine the extensive use of PVC roof membranes and the industry initiatives to recycle, upcycle, and repurpose PVC roof membranes, further decreasing their environmental impact. Thus, it supports categorizing PVC roofing membranes into a separate plastic category.

PVC ROOFING MEMBRANES: RESILIENT, HIGH-PERFORMANCE PLASTIC COMPOSITES

Not all plastics are the same. Each type of plastic is designed and engineered for specific purposes, ranging from transportation to medical devices, each with different designs, life spans, and end-of-life capabilities. PVC roof membranes highlight the need to classify plastics based on their intended use, expected lifespan, sustainability, and environmental properties.

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[1] Brief History of PVC Roofing Membranes – PVC Roofing accessed 6/18/2024 available at: https://www.pvcroofing.org/brief-history-of-pvc-roofing-membranes.

CURRENT EPA PLASTIC CATEGORIES

The Environmental Protection Agency (EPA) currently categorizes plastics into three main groups[2]:

> ***"Containers and Packaging**: Containers and packaging include products such as plastic bags, containers, and wrapping material. These may be used to wrap or contain consumer goods (e.g., food, beverages, medications, cosmetic products, mattresses) and are often discarded in household waste.*
>
> ***Nondurable Plastics:** Nondurable plastics include products with a use lifespan of less than three years, such as plastic plates, cups, trash bags, disposable diapers, and clothing.*
>
> ***Durable Plastics:** Durable goods consist of products that remain in use for longer than three years, such as appliances, furniture, carpet, and consumer electronics."*

This white paper proposes a fourth category: *Resilient, High-performance Plastic Composites.* The composites in this category vastly exceed the minimal service life of 'durable plastics' and are known for their exceptional resistance to wear, impact, and degradation over time. A plausible definition for resilient, high-performance plastic composites could be the ability to withstand harsh environmental conditions, mechanical stress, and chemical exposure, making them highly durable and long-lasting. The polymers used 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 this 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 15 years or longer and a reduced need for frequent

[2] About Plastic Products and Plastic Pollution | US EPA accessed 6/16/2024 available at: https://www.epa.gov/plastics/about-plastic-products-and-plastic-pollution

replacement, promoting sustainable goals and resource efficiency. At the end of life, these can be recycled, chemically or mechanically, for reuse in other plastic products or provide feedstock for other downstream reprocessing.

PVC roof membranes are one of these composites and meet this criterion. 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 supports our premise that these materials fit in this new category.

We need to understand how the properties of plastics are created. This is accomplished 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, before the manufacturing process, vinyl chloride is a short carbon chain, highly volatile material[4], yet

[3] Brief History of PVC Roofing Membranes – PVC Roofing accessed 6/18/2024 available at: https://www.pvcroofing.org/brief-history-of-pvc-roofing-membranes.
[4] Brief History of PVC Roofing Membranes – PVC Roofing accessed 6/18/2024 available at: https://www.pvcroofing.org/brief-history-of-pvc-roofing-membranes.

when it is polymerized into long carbon chains in polyvinyl chloride (PVC), it becomes inert and certified for drinking water and is the material of choice for many applications.[5]

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 pigmentation. Combined, these enable PVC roof membrane performance as a worthy roofing material.

PVC is valued for its versatility, strength, toughness, natural fire resistance, and durability. However, when a plasticizer is added to PVC, it transforms into a remarkably flexible material.

One of the most successful applications of flexible PVC is single-ply roofing. Single-ply PVC roofing is often selected due to the combination of properties, durability, and low carbon footprint[6,7]. The inherent 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 enable various modern roofing applications. These include solar installations, green roofs, or even entertaining rooftop spaces.

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,

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[5] PVC Remains Material of Choice for Life-Saving Medical Devices (plasticstoday.com) accessed 3/1/2024 available at : https://www.plasticstoday.com/medical/medical-plastics-101-pvc-remains-material-of-choice-for-life-saving-devices

[6] An Environmental Product Declaration (EPD), accessed 7/15/2024, available at https://vinylroofs.org/wp-content/uploads/2020/04/CFFA-EPD_FINAL_210220201.pdf

[7] Life Cycle Assessment (worldsteel.org), accessed 8/13/2024, available at https://worldsteel.org/wp-content/uploads/Life-cycle-assessment-Environmental-assessment-of-roofing-systems.pdf

the incorporation of phthalate additives, and the potential creation and release of dioxins during its production processes. Each of these concerns is addressed below.

LEAD AND CADMIUM

Historically, lead and cadmium were used as stabilizers in PVC. Thankfully, the utilization of lead and cadmium as stabilizers has become obsolete, as the intentional use of cadmium and lead stabilizers was phased out in the U.S. in 2007, followed by Europe in 2015, aiding more environmentally friendly PVC production[8].

Modern PVC roofing membranes are widely considered safe, evidenced by the USEPA and ASTM/ANSI certification and a Safe Use Determination letter by the California Office of Environmental Health Hazard Assessment[9].

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.[10]

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 is 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

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[8] 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

[9] Issuance of a Safe Use Determination for Diisononyl Phthalate in Certain Single-Ply Polyvinyl Chloride Roofing Membrane Products - OEHHA (ca.gov)

[10] 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.

are chlorine-based[11,12]. 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[15].

Because chlorine is a natural fire inhibitor[16], 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[17]. The Southwest Research Institute conducted a fire resistance study demonstrating that PVC was self-extinguishing[18].

[11] Royal Society of Chemistry, Periodic Table, Chlorine, Uses and properties, Uses, Statement 3; accessed 10/05/2024 available at: https://www.rsc.org/periodic-table/element/17/chlorine#:~:text=85%25%20of%20pharmaceuticals%20use%20chlorine,they%20can%20cause%20liver%20damage

[12] Medicine.net, Health & Living Health Center, What is Chlorine Used for Article; accessed 10/05/2024 available at: https://www.medicinenet.com/what_is_chlorine_used_for/article.htm

[13] 1.9: Essential Elements for Life - Chemistry LibreTexts

[14] https://chemistry-guide.com/10-reasons-why-chlorine-is-important/ accessed 10/12/2023 available at: 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

[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] Wypych, George, PVC Degradation & Stabilization, 3rd Edition, ChemTec Publishing, 2008, pg 126.

[17] 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

[18] Testing conducted by the Chemical Fabrics & Film Association (CFFA), accessed 8/14/2024 available at: https://vinylroofs.org/durability/pvc-fire-performance/

VINYL CHLORIDE (VC) EXPOSURE TO MANUFACTURING EMPLOYEES

Strict regulations by OSHA[19] and the EPA[20] have significantly reduced vinyl chloride emissions in PVC manufacturing, ensuring worker and environmental safety. The CDC reported[21],

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

A report on vinyl chloride – PVC industry's occupational hazards that appeared in the National Library of Medicine, 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 VC exposure is associated with other cancers, a similar risk reduction would be expected."[22]

DIOXINS

It's important to note that dioxins are produced when most plastics, wood, or other materials are burned or improperly incinerated. It has been reported that over 90% of human dioxin exposure comes through our diets, primarily through meat, egg, and

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[19] 1910.1017 - Vinyl chloride. | Occupational Safety and Health Administration (osha.gov) accessed 4/10/2023 available at: https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.1017#:~:text=No%20employee%20may%20be%20exposed%20to%20vinyl%20chloride,period%20not%20exceeding%2015%20minutes.%201910.1017%20%28c%29%20%283%29

[20] Polyvinyl Chloride and Copolymers Production: National Emission Standards for Hazardous Air Pollutants (NESHAP) - 40 CFR 63 Subparts J & HHHHHHH | US EPA accessed 5/10/2023 available at: https://www.epa.gov/stationary-sources-air-pollution/polyvinyl-chloride-and-copolymers-production-national-emission-0#rule-summary

[21] https://www.atsdr.cdc.gov/toxprofiles/tp20-c5.pdf accessed 9/23/2023 available at: https://www.atsdr.cdc.gov/toxprofiles/tp20-c5.pdf

[22] Nicholson WJ, Henneberger PK, Seidman H. Occupational hazards in the VC-PVC industry. Prog Clin Biol Res. 1984;141:155-75. PMID: 6718369.

dairy[23]. Due to stringent reporting regulations, air- and water-related ambient dioxin emissions from PVC production have been reduced by 43% since 2009[24]. To bring this into perspective, the regulations governing the production of PVC resin (PVC MACT), include required reporting to the EPA National Emission Standards for Hazardous Air Pollutants (NESHAP)[25] for all industrial and utility processes that yield hazardous air pollutants (e.g., steel manufacturing, petroleum refining, electricity 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[26]. According to EPA's 2006 Dioxin Inventory of Sources Report, backyard and household trash burning dominated releases in the United States[27].

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, plastisol fishing worms, blood bags, and surgical gloves. PVC's exceptional versatility allows it to be rigid and flexible within the same application. It enables various

[23] Pacheco-Torgal, F., Jalali, S., Fucic, A., *Toxicity of building* materials, Woodhead Publishing Limited, 2012, p.46

[24] Our Sustainability Journey | 2015-2019, Vinyl Sustainability Council, available at https://vantagevinyl.com/progress-report/

[25] CFR40, Part 63, Subpart HHHHHHH

[26] Our Sustainability Journey | 2015-2019, Vinyl Sustainability Council, Appendix 2, page 26, available at https://vantagevinyl.com/wp-content/uploads/2020/04/Our-Sustainable-Journey_2015-2019_2page_FINAL-2.pdf

[27] An Inventory of Sources and Environmental Releases of Dioxin-Like Compounds in the United States for the Years 1987, 1995, and 2000, National Center for Environmental Assessment, Office of Research & Devlopment, US EPA, November 2006, available at: https://ordspub.epa.gov/ords/eims/eimscomm.getfile?p_download_id=523391

uses, such as oxygen masks, blister packaging, and complete assemblies, to deliver 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 of greater potential concern in applications where PVC encounters food or the skin. However, it's less of a concern in applications like roofing membranes. 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 roof membranes and other 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)[28] has received a Safe Use Determination (SUD) from California[29].

A 2014 study by the State of Washington reported the leaching of chemicals or other additives into water run-off collected from various roofing materials during two rounds of testing with ten rain events in each. In round 1, only one rain event reported amounts of phthalates from the PVC roofing, constituting the lowest detection percentage compared to other polymerized roofing materials tested. In round two, there were no reportable detections of phthalates in all rain events[30].

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

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[28] Jayflex™ plasticizers for advantaged performance (exxonmobilchemical.com) available at: https://www.exxonmobilchemical.com/en/resources/library/library-detail/2930/jayflex_didp_dinp_ap_en

[29] 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.

[30] Roofing Materials Assessment: Investigation of Toxic Chemicals in Roof Runoff from Constructed Panels in 2013 and 2014 (wa.gov)

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

These organizations follow consensus standard development procedures with industry experts, manufacturers, regulatory agencies, and stakeholders to develop and update standards for building materials like PVC roofing membranes that specify, among other things, performance and quality metrics for raw materials and certain end-use products made from polymeric materials.

THE ECONOMIC AND ENVIRONMENTAL IMPACT OF REPLACING PVC ROOF MEMBRANES

STRATEGIES FOR PLASTIC WASTE MANAGEMENT

Efforts to manage plastic waste include reducing, reusing, and recycling. However, taxes, quotas, and bans on plastics can negatively impact the production and use of sustainable PVC roof membranes. To reduce plastic use altogether, strategies for imposing taxes, implementing production quotas, and banning certain single-use plastic items have been proposed. Local and regional bans on single-use plastic cutlery, straws, and food containers have been implemented, but with mixed results[31].

In conjunction with 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. As a result, the benefits of these efforts may have been overlooked and should be included in environmental improvement measurements.

These approaches to reduce overall plastic consumption using taxes, quotas, or bans impact construction-grade PVC products and may adversely affect the production and

[31] The Case against paper straws, Annie Lawrey, The Atlantic

use of PVC roof membranes, which could limit sustainable choices in construction projects.

Before taking action, we must explore alternatives that would most likely replace banned or restricted items. These actions have unintended consequences, as some alternatives to PVC have higher GHG emissions. In July of 2022, McKinney & Company published an extensive study on the climate impact of plastics. The report showed that the move toward decarbonization by 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[32]. 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.

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.

LONGEVITY AND EMBODIED CARBON OF PVC ROOF MEMBRANES

With decades-long design life, PVC roof membranes have surprisingly low embodied carbon emissions. Longevity is a key component when calculating embodied carbon emissions of a product through its useful life and disposal or recycling. The longer the life span, the lower the carbon emissions are per year. 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 15 years or longer.

A 2005 study analyzed 44 PVC roofs throughout Europe and North America, testing their performance after long-term field exposure. Table 1 below shows the study's results.

[32] Climate Impact of Plastics, July 6, 2022, accessed 7/10/2023 available at: https://www.mckinsey.com/industries/chemicals/our-insights/climate-impact-of-plastics

The study considered the age and the condition of the roofs analyzed, and 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[33].

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

Table 1 - A 2005 study that analyzed 44 PVC roofs throughout Europe and North America[33]

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

[33] Beer, H. & Delgado, A. & Paroli, Ralph & Graveline, S. (2010). Durability of PVC roofing membranes - proof by testing after long term field exposure. See Table 1

Association (CFFA). (The 60-mil thickness is the most popular thickness, but this information is also available for other thicknesses in the full EPD.)

As shown in Table 2, the measured global warmth potential (GWP) of 1 sq meter of 60 mil PVC roof membrane in various phases of its life cycle is provided[34]. The production phase is A1-A3, the construction phase is A4-A5, and C1-C4 represents EOL.

Table 2 Cradle-to-construction with EOL stage (A1-A5, C1 to C4, D), EPD Results – 1 m^2 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 2 - A table from the CFFA EPD showing cradle-to-construction to EOL stage for 1 m^2 of white SPPR PVC roofing membrane (60mils).

Table 2 presents how the total embodied carbon is calculated, and Figure 1 shows the percentages of CO2 equivalent in each phase. The total CO_2 equivalent through end-of-life (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 Figure 1, we can see the percentage of each stage of CO2 eq. of the LCI.

[34] An Environmental Product Declaration (EPD), accessed 7/15/2024, available at https://vinylroofs.org/wp-content/uploads/2020/04/CFFA-EPD_FINAL_210220201.pdf

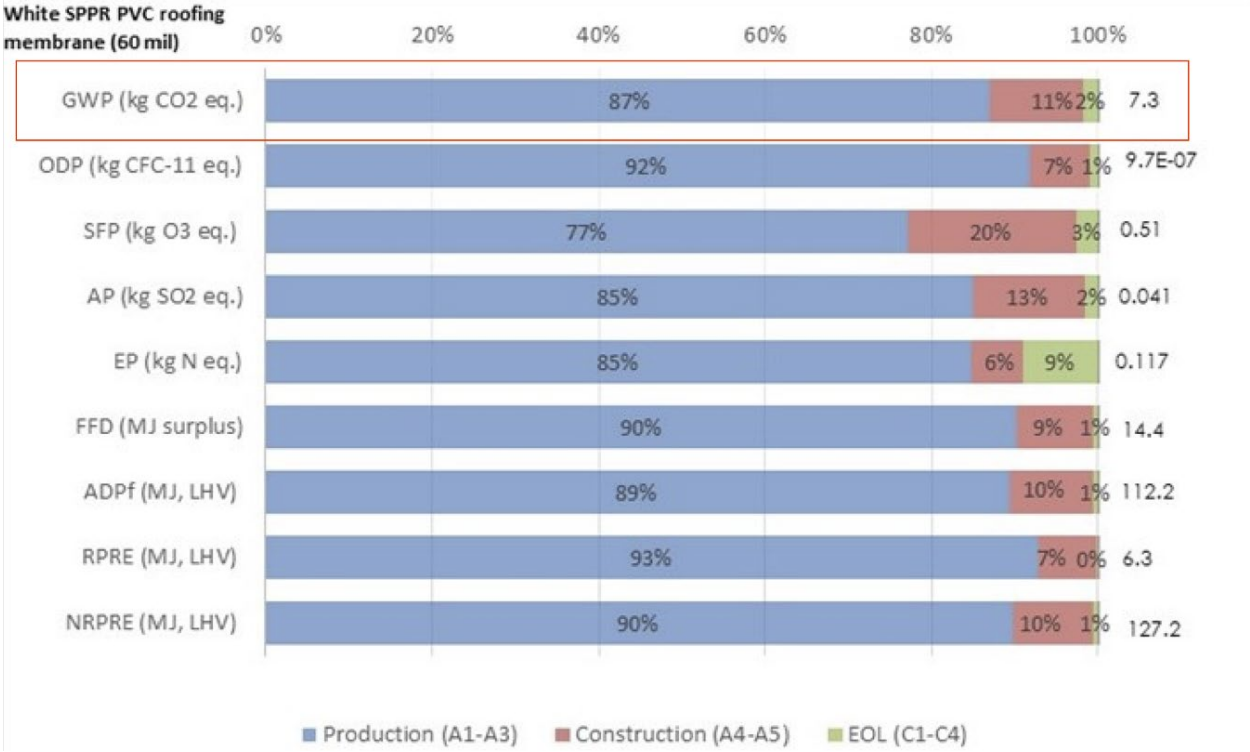

Figure 1 - Impact assessment and energy indicator results by stage – 1 m2 of 60-mil white SPPR PVC roofing membrane - % basis[35].

Figure 1 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 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. If you factor in recycling or repurposing, the total lifecycle carbon falls even lower.

OTHER SUSTAINABLE BENEFITS

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

[35] An Environmental Product Declaration (EPD), accessed 7/15/2024, available at https://vinylroofs.org/wp-content/uploads/2020/04/CFFA-EPD_FINAL_210220201.pdf

amount of embodied carbon in the material[36]. Also, because the PVC resin comprises 57% chlorine derived from NaCl, or, in other words, table salt, is one reason the embodied carbon is low.

Due to their long lifespan, PVC roof membranes are many times used as the 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[37].

PVC ROOF MEMBRANES 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 that are 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 CFFA – Vinyl Roof Division most recently recorded that 19.8 million pounds of pre-consumer thermoplastic PVC roofing membrane were recycled, a 4% growth from 2022, and 1.2 million pounds of post-consumer PVC membrane was recycled, a 23.5% growth from the calendar year 2022[38]. The vinyl industry is committed to advancing the development of more efficient feedstock recycling of post-consumer thermoplastic membranes[39]. CFFA has a well-organized initiative to accelerate PVC roof membrane recycling even more.

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[36] Making Plastics: From Monomer to Polymer | AIChE available at: https://www.aiche.org/resources/publications/cep/2015/september/making-plastics-monomer-polymer

[37] 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.

[38] https://vinylroofs.org/wp-content/uploads/2023/03/RecyclingWhitePaper.pdf

[39] 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.

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[40]. The Vinyl Institute established its $3 million VIABILITY™ Grant program in 2022 to provide funding to accelerate post-consumer PVC recycling projects[41]. Similar efforts are taking place in Europe, where efforts to foster recycling, such as Recovinyl[42] and Vinyl Plus[43], 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.

SUMMARY

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. Certifications such as 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.

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[40] Vinyl Sustainability Council Progress Report for 2021, P. 20, accessed 5/1/2024 available at https://vantagevinyl.com/progress-report/

[41] Viability: A New Post-Consumer Recycling grant program, accessed 4/30/2024 available at: https://www.vinylinfo.org/recycling/

[42] Home | Recovinyl

[43] PVC Remains Material of Choice for Life-Saving Medical Devices (plasticstoday.com)

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 15 years or more, 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 past historical production practices that no longer apply to modern PVC roofing membrane practices.

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.

Based on the findings outlined in this paper, consideration should be given to removing PVC roofing membranes from watch lists, and further consideration should be given to being exempt from any legislation or discussion of single-use plastic.

Therefore, PVC roofing membranes may be more environmentally friendly than previously thought.