Life-Cycle Assessment of Architectural Coatings

A WORLD WITHOUT PRESERVATIVES[1]

The primary goals of the Life-Cycle Assessment were to determine the environmental impacts and benefits that wet-state and dry-film preservatives play in architectural coating systems and see how reducing, eliminating, or replacing certain preservatives impacted the coating's overall sustainability profile.

OVERVIEW

An industry study was conducted to assess the environmental performance of 10 architectural coating preservation scenarios using a Cradle-to-Grave Life-Cycle Assessment (LCA). This article is an update of a study conducted in 2017 and was revised to incorporate improved manufacturing data and consider some additional preservation strategies.

Preservatives themselves play a crucial role in enhancing shelf life, ensuring the product does not spoil before being used, and protecting the dried coating film from biologic growth. The primary goals of the LCA were to determine the environmental impacts and benefits that wet-state and dry-film preservatives play in architectural coating systems and see how reducing, eliminating, or replacing certain preservatives impacted the coating's overall sustainability profile.

Representatives of several major coating, chemical, and trade associations were involved with the creation and completion of this study.

METHODOLOGY

The LCA was performed using best practices and developed to conform with ISO 14040[2], ISO 14025[3], ISO 21930[4], as well as the calculation rules outlined in American Coating Association's Product Category Rule (PCR) for Architectural Coatings[5].

The functional unit from the Architectural Coating PCR (covering and protecting $1m^2$ of substrate for 60 years) was used in this assessment. The performance values in this study were developed through industry consensus and are consistent with the values found in publicly available literature and/or based on actual field data.

Both the water-based and solvent-based formulas came from industry sources and represent actual products commercially available for purchase today or in the past (in the case of the historic solvent-based formula). Each formula was modeled to at least 99.9% of its composition (by weight) and all major flows and processes were accounted for in the LCA models.

The following 10 preservative scenarios were considered, and each is labeled with an acronym for easy reference throughout this article and the charts:

1. A typical water-based architectural coating with preservative level adequate to prevent spoilage **(WB)**
2. A typical high-quality water-based architectural coating with preservative level adequate to prevent spoilage **(WBH)**
3. A typical water-based coating using a natural preservative (citric acid) requiring a higher dose relative to a conventional preservatives **(WB-N)**

4. A typical water-based coating with no preservatives **(WB-NP)**
5. A typical water-based coating with no preservatives, but assumed to be refrigerated once formulated **(WB-NPR)**
6. A historic solvent-based formula **(SB)**
7. A typical water-based coating with no preservatives, but assumed to be treated with ionizing radiation for sterilization **(WB-ION)**
8. A modified water-based coating with no preservatives, but with an added buffer greatly increasing the pH of the final coating. **(WB-pH)**
9. A modified water-based coating with less preservatives but some solvent added **(WB-S)**
10. A modified water-based coating using formaldehyde donors versus conventional coating preservatives **(WB-FD)**

The first two scenarios (WB and WB-H) were chosen as they represent the current industry status quo of water-based architectural coatings, which have become the norm given the VOC reductions across the industry in order to enhance product sustainability and to help improve indoor-air quality.

The results clearly illustrate that any of the non-baseline preservation scenarios led to a substantial increase in the environmental impact of the coating.

The next seven scenarios (WB-N, WB-NP, WB-NPR, WB-ION, WB-pH, WB-S, and WB-FD) were chosen as likely alternatives if the coating industry were forced to abandon its current preservation strategy through regulatory or market pressures.

The final scenario—SB—is a legacy solvent-based formula to show the significant improvement in environmental impact across the industry in moving from legacy solvent-based chemistries to water-based chemistries for architectural products.

Each of these scenarios was modeled in the GaBi 9.2 software using the most current and appropriate Life-Cycle Inventory (LCI) databases as well as industry assumptions regarding product performance, lifespan, spoilage, and rework. The LCI databases used were commercially available, third-party-validated datasets, including ecoinvent, Sphera, and CEPE's coating industry LCI.

Table 1 identifies the key assumptions of the study, while *Table 2* examines other considerations of the product scenarios not captured by the LCA models[6].

The summary results of the study are shown in *Figure 1* and in *Appendix A* in *Table 3*. *Figure 1* provides a comparison of the relative impact of the scenarios: the larger the bar, the greater the impact.

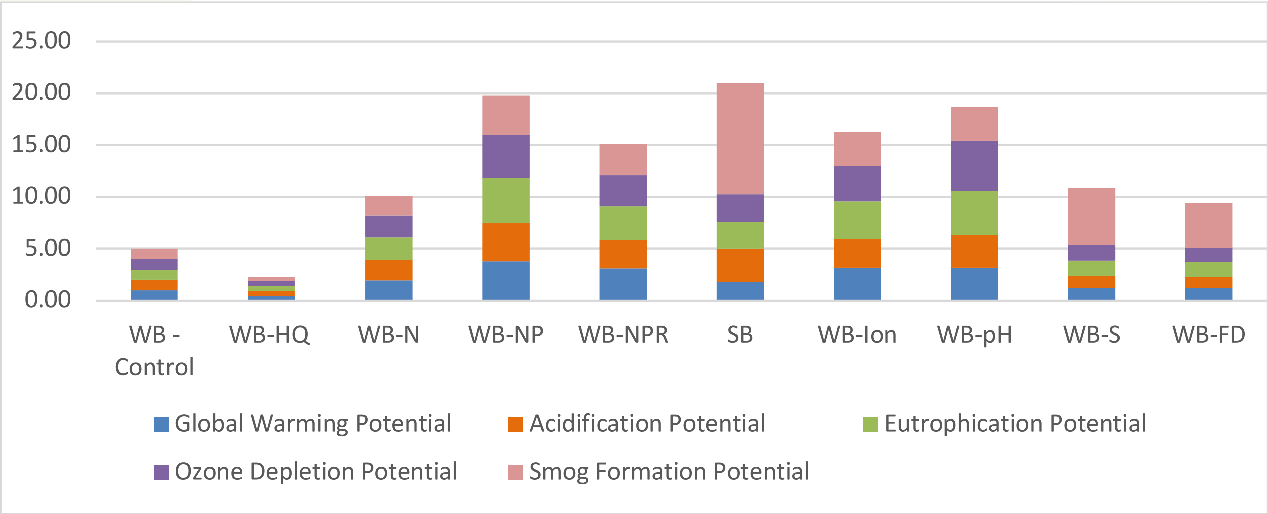
TABLE 1—Key Assumptions in the LCA

SCENARIO	DRY FILM LIFETIME	WET FILM THICKNESS	PRODUCT SPOILAGE	ADDITIONAL PURCHASE FOR TOUCH-UP	VOC CONTENT	ADDITIONAL ENERGY NEEDS
WB-CONTROL	7 years	4 mils	0.05%	0%	<5 g/L	
WB-H	15 years	4 mils	0.05%	0%	<5 g/L	
WB-N	4 years	4 mils	10%	10%	<5 g/L	
WB-NP	3 years	4 mils	50%	10%	<5 g/L	
WB-NPR	3 years	4 mils	10%	10%	<5 g/L	2 MJ electricity burden per kg
SB	7 years	4 mils	0%	0%	324 g/L	
WB-ION	3 years	4 mils	10%	10%	<5 g/L	0.3 MJ electricity burden per kg and additional transportation
WB-PH	3 years	4 mils	5%	10%	<5 g/L	
WB-S	7 years	4 mils	0.10%	0%	200 g/L	
WB-FD	7 years	4 mils	5%	10%	150 g/L	

TABLE 2—Other Considerations of the Product Scenarios

SCENARIO	OTHER CONSIDERATIONS AND/OR CONCERNS NOT CAPTURED BY THE LCA MODELS
WB-CONTROL	N/A—baseline scenario
WB-H	Higher cost to consumers
WB-N	Significant spoilage; more frequent repaints; mildew growth in many climates; need to purchase additional product for touch-up
WB-NP	Higher cost to consumers; quality control issues; significant spoilage; more frequent repaints; mildew growth in many climates; need to purchase additional product for touch-up
WB-NPR	Additional capital costs for infrastructure; increased product costs; quality control issues; significant spoilage; more frequent repaints; mildew growth in many climate; need to purchase additional product for touch-up
SB	Not possible in certain markets with strict VOC measures; increased smog formation; possible air-quality concerns
WB-ION	Technology does not currently exist; additional capital costs for infrastructure; increased product costs; quality control issues; significant spoilage; more frequent repaints; mildew growth in many climates; need to purchase additional product for touch-up
WB-PH	Poor product quality; cannot tint paint; skin irritation; mildew growth in many climates; significant spoilage; need to purchase additional product for touch-up
WB-S	Not possible in certain markets with strict VOC measures
WB-FD	Not possible in certain markets that do not allow use of such preservatives; increased VOC and product spoilage. will not pass emissions tests needed for Green Building Standards.

FIGURE 1—Relative Cradle-to-Grave LCA Results of Different Preservative Scenarios in Architectural Coatings (Water-Based Coating Normalized to 1.00 for Each Indicator)[7].



RESULTS

The results clearly illustrate that any of the non-baseline preservation scenarios led to a substantial increase in the environmental impact of the coating. The relative environmental impact was determined by comparing the baseline—WB—to the other coating scenarios.

The environmental indicators assessed in the LCA were global warming potential, acidification, eutrophication, ozone depletion, and smog formation. Relative to the baseline scenario, changing the preservation strategy increased the environmental burden of the system ranging from a 50% higher impact to almost a 400% higher impact depending on the specific scenario.

The LCA models also showed that the preservatives themselves were typically responsible for <1% of the total impact in each impact category. This pales in comparison to their importance in the environmental performance and sustainability benefit of the entire coating system.

Finally, the legacy solvent-based system—which would not require a wet-state preservative—was the worst overall environmentally and shows how much of an improvement the industry has made by moving from solvent-based to water-based chemistries for architectural products.

This study clearly shows that the actual environmental impact of preservatives is extremely modest relative to their benefit and the tradeoffs associated with preservative substitution are severe compared to the other parts of the coating formulation.

This study showcases that preservatives play a tremendously important role in coating formulation and how overall product performance must be considered when making formulation changes, as substitutions without considering the impact on product efficacy can greatly increase the environmental burden of the product.

Additionally, it is important for regulators to consider the impact on downstream users when reviewing preservatives. The decrease in shelf life and increase in spoilage rates not only creates a substantial environmental impact, but also would place a significant financial burden on the downstream user through product loss.

Preservatives are key for the low-VOC, water-based formulations that are used in the marketplace today. For example, if you examine the increase in smog formation when moving away from the baseline water-based coating you see increases ranging from 75% (WB-N) to almost 500% (SB).

This study clearly shows that the actual environmental impact of preservatives is extremely modest relative to their benefit and the tradeoffs associated with preservative substitution are severe compared to the other parts of the coating formulation.

OTHER CONSIDERATIONS

- It is also important to consider economic and/or possible health issues that could arise from the alternative preservation scenarios. For example, raising the pH may lead to significant skin irritation issues and spoilage and/or needing more paint to do the same job would lead to significantly higher costs for coating products to consumers. Likewise, in humid environments uncontrolled mildew growth could be a concern to environmental quality.

- The significant amount of spoilage from improper preservation would lead to a staggering increase in waste generated by the coatings industry.
- Many of the assessed alternative scenarios would require longer job times, more repaints, and/or significantly increase costs of coating products.
- Reports from consumers regarding sensitization following exposure to coatings products is very rare and these reports have not been conclusively demonstrated to be caused by the preservatives in the coating product. Reports of sensitization are extremely rare in occupational settings and can be easily avoided with proper PPE.
- There will be additional capital needed to accommodate for any of the other scenarios which will represent additional environmental impact not captured by the LCA. Generally, capital costs are modest over a long period of time, but there would be significant impacts when to make and install any such equipment such as refrigeration systems, ionization equipment, etc. Given this, the above LCI assessment results are likely underestimates for the alternative scenarios. ❊

GLOSSARY

- **Adequate Preservation Level:** A product with the minimum level of preservation to avoid significant product spoilage and/or early failure**.**
- **Citric Acid:** A weak organic acid that occurs naturally in citrus fruits.
- **CEPE:** The European Council of the Paint, Printing Ink and Artists' Colours Industry.
- **Dry Film:** The fully cured coating film after painting.
- **Dry Film Preservative:** Additive that contributes to reduction and prevention of molds and mildew.
- **ecoinvent:** A life cycle inventory database that contains international industrial life cycle inventory data on energy supply.
- **Film Thickness:** Thickness of applied coating.
- **GaBi:** Created by PE INTERNATIONAL GaBi Databases are LCA databases that contain ready-to-use Life Cycle Inventory profiles.
- **LCA**: Life Cycle Assessment. A technique to assess environmental impacts associated with all the stages of a product's life from cradle to grave (i.e., from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling), as defined in ISO 14040.
- **LCI**: Life Cycle Inventory. A central source of critically review, consistent, and transparent data.
- **LCIA:** Life-Cycle Impact Assessment—The LCA phases involving the identification, compilation, and quantification of inputs and outputs associated with the product's life-cycle. For this study, the LCIA is quantified in *Table 3* of *Appendix A*.

Life-Cycle Impact Assessment—The LCA phases involving the identification, compilation, and quantification of inputs and outputs associated with the product's life-cycle. For this study, the LCIA is quantified in Table 3 of Appendix A.

- **Lifetime:** The number of years before the product is expected to experience any failures.
- **Natural Preservative:** A substance added to products to prevent decomposition by microbial growth. This substance exists nature and not made or caused by humans. An example of a natural preservative would be citric acid.
- **Organic Solvents:** Solvents that contain at least one carbon atom and one hydrogen atom, low molecular weight, and they exist in liquid form at room temperature.
- **PCR**: Product Category Rule. A PCR defines the rules and requirements for creating EPDs of a certain product category, as described in ISO 14025.
- **Product Spoilage:** Product that is unusable due to biologic growth.
- **Product Touch-Up:** Application of paint on small areas of painted surfaces to repair mars and scratches.
- **Shelf Life:** The period in which a material may normally be stored and still be in a usable condition.
- **Solvent-Based Coating:** Coatings which contain only organic solvents, if water is present it is only in trace quantities**.**
- **thinkstep**: A life-cycle inventory database that contains critically reviewed energy and transport data.

- **Volatile Organic Compound (VOC):** Any organic compound which participates in atmospheric photochemical reactions; that is, any organic compound other than those which the EPA designates as having negligible photochemical reactivity[8].
- **Water-Based Coating:** Coatings in which the volatile content is predominantly water. These include latex paints, emulsion paints, and water paints.
- **Wet-State Preservative:** Preservative that combats the growth of microorganisms during the prior to the use of the product.

Appendix A

TABLE 3—Summary Results

SCENARIO	GLOBAL WARMING POTENTIAL (KG CO2E)	ACIDIFICATION (KG MOL H+E)	EUTROPHICATION (KG NE)	OZONE DEPLETION (KG CFC-11E)	SMOG FORMATION (KG O3E)
WB-CONTROL	2.60	3.38E-02	3.46E-03	1.46E-07	0.13
WB-HQ	1.21	1.58E-02	1.62E-03	6.81E-08	0.06
WB-N	5.05	6.70E-02	7.69E-03	3.00E-07	0.25
WB-NP	9.90	1.23E-01	1.53E-02	5.99E-07	0.50
WB-NPR	8.14	9.13E-02	1.13E-02	4.40E-07	0.39
SB	4.79	1.07E-01	9.04E-03	3.88E-07	1.41
WB-ION	8.34	9.41E-02	1.25E-02	4.95E-07	0.43
WB-PH	8.32	1.04E-01	1.50E-02	7.00E-07	0.43
WB-S	3.20	3.83E-02	5.25E-03	2.20E-07	0.72
WB-FD	3.10	3.69E-02	4.91E-03	1.97E-07	0.57

ENDNOTES

1. This report was created by the American Coatings Association Life Cycle Assessment Drafting Team, a subgroup of the American Coatings Association Preservation Product Stewardship Working Group.
2. ISO 14040:2006: Environmental management–Life-cycle assessment–Principles and framework. July 2006; reviewed and confirmed 2016. International Organization for Standardization, Geneva, Switzerland. *https://www.iso.org/standard/37456.html* (accessed Mar 29, 2021).
3. ISO 14025:2006: Environmental labels and declarations–Type III environmental declarations–Principles and procedures. July 2006; reviewed and confirmed 2020. International Organization for Standardization, Geneva, Switzerland. *https://www.iso.org/standard/38131.html* (accessed Mar 29, 2021).
4. ISO 21930:2007: Sustainability in building construction—Environmental declaration of building products. Oct 2007; updated with ISO 21930:2017. International Organization for Standardization, Geneva, Switzerland. *https://www.iso.org/standard/40435.html* (accessed Mar 29, 2021).
5. Product Category Rule (PCR) for Architectural Coatings. June 2020. NSF International, Ann Arbor, MI. *https://standards.nsf.org/apps/group_public/document.php?document_id=28098* (accessed Mar 29, 2021).
6. The scenarios were developed by the ACA Preservation Product Stewardship Working Group.
7. Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI). U.S. Environmental Protection Agency. *https://www.epa.gov/chemical-research/tool-reduction-and-assessment-chemicals-and-other-environmental-impacts-traci* (accessed Mar 29, 2021).
8. Protection of Environment: Definitions. Code of Federal Regulations. 40 C.F.R. 51. 100(s) *https://ecfr.federalregister.gov/on/2021-03-29/title-40/chapter-I/subchapter-C/part-51/subpart-F/section-51.100* (accessed Mar 29, 2021).