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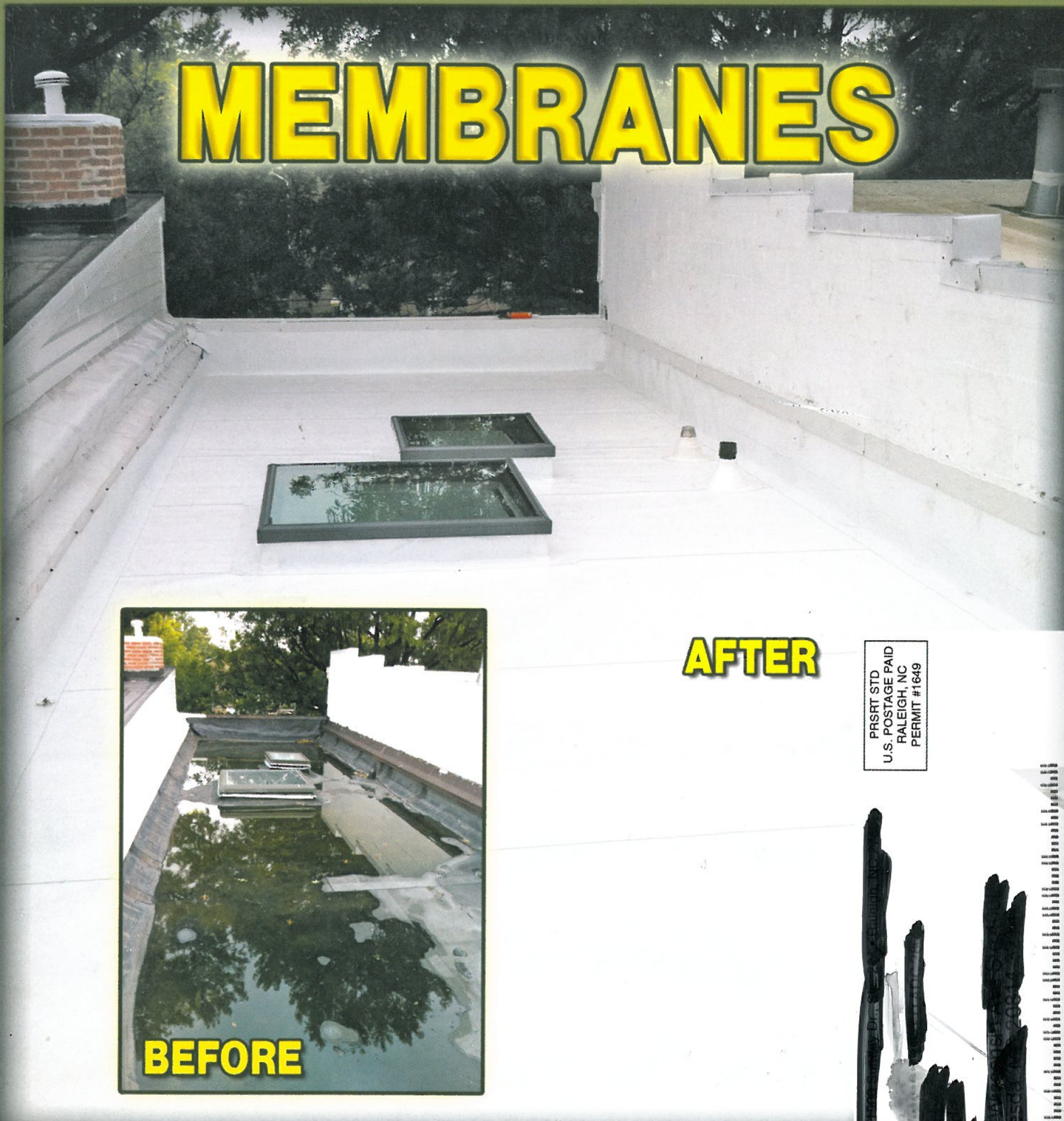

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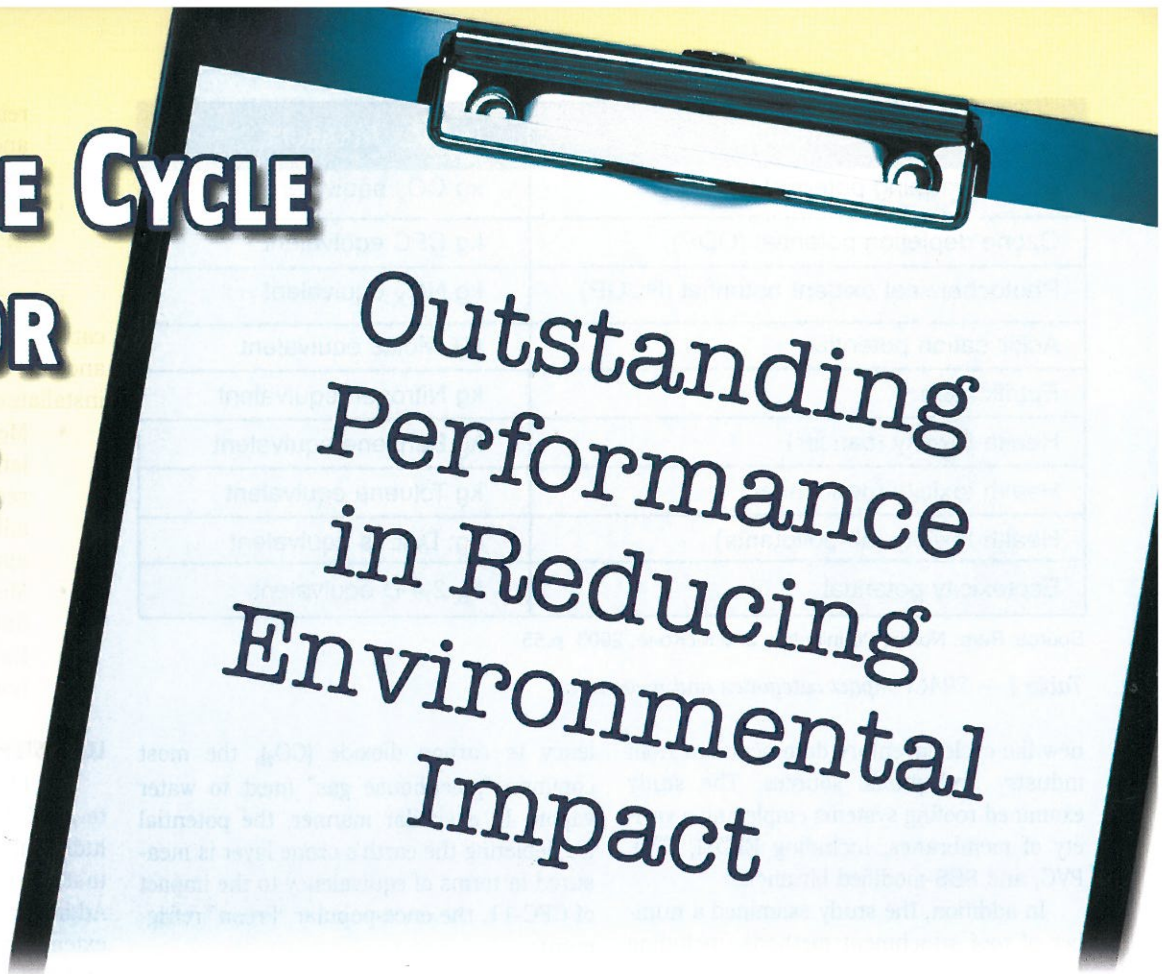
New Life Cycle Data For EPDM: Outstanding Performance in Reducing Environmental Impact



By Thomas Hutchinson, RRC, FRCI, AIA

Thanks to a number of factors—the growing emphasis on environmentally responsible building practices, the employment of increasingly sophisticated criteria for financing of construction projects, and more government regulations of public construction—the concept of life cycle assessment (LCA) has grown in importance and use. LCA is a scientific approach to evaluating the environmental impact of a product or system throughout its life cycle. In the process, significant progress has been made to establish the specific criteria for a level playing field to create effective LCA studies.

According to the U.S. Environmental Protection Agency (EPA), an effective LCA process may be divided into three basic steps (Scientific Applications International Corporation, 2006):

- Compiling an inventory of relevant energy and material inputs and environmental releases,
- Evaluating the potential environmental effects associated with identified inputs and releases, and
- Interpreting the results to help in making an informed decision.

Because the LCA process involves a final step of interpreting the results, it is employed frequently as a comparative method to make decisions among alternatives. This is particularly challenging in the arena of low-slope roofing systems with widely varying chemical components, installation methods, and expected service lives.

In addition, it is important that these new data be incorporated into the tools that have been developed to identify and summarize the effects of individual building components. These tools include the BEES® tool developed by the National Institute of Standards and Technology (NIST) in the U.S., the Athena® EcoCalculator developed by the Athena Institute in Canada, and the GaBi software developed in Europe. Although each of these tools uses different methodologies and weighting protocols, all rely on the development of a comprehensive life cycle inventory (LCI) database to provide the appropriate product inputs.

These databases, while useful, are often incomplete. The Athena® roofing database contained a larger selection of roofing materials and systems than the BEES® tool, but some of the information may be based on incorrect data and assumptions. As an example, the LCI impact data for EPDM roofing membrane is based on an assumed EPDM membrane formulation consisting of 30% carbon black, 6% clay filler, and 64% EPDM polymer (Franklin Associates, 2001). In reality, EPDM membrane produced in North America contains 47% carbon black, 28% EPDM polymer, 20% process oil, and 5% other additives (TRC Environmental Corporation, 1995).

Because the Athena® LCI values for EPDM were based on a polymer content over twice as large as actually used, the environmental effects for EPDM are significantly overstated.

With all of this in mind, a study was conducted on behalf of the EPDM Roofing Association (ERA) by the GreenTeam, Inc., a Tulsa, OK, strategic environmental consulting firm specializing in building industry issues. The study findings were also reviewed and summarized by TEGNOS Research, Inc., a firm specializing in the building envelope.

The study provides an overview of LCA as applied to selected low-slope roofing systems used widely throughout North America. Its objective was to establish up-to-date life cycle impact data based on a critical review of previous LCA studies and

TRACI Impact Category	Impact Measure
Global warming potential (GWP)	kg CO_2 equivalent
Ozone depletion potential (ODP)	kg CFC equivalent
Photochemical oxidant potential (PCOP)	kg NO_X equivalent
Acidification potential	H+ Moles equivalent
Eutrification	kg Nitrogen equivalent
Health toxicity (cancer)	kg Benzene equivalent
Health toxicity (noncancer)	kg Toluene equivalent
Health toxicity (air pollutants)	kg: DALYs equivalent
Ecotoxicity potential	kg 2,4-D equivalent

Source: Bare, Norris, Pennington, and McKone, 2003, p.55.

Table 1 — TRACI impact categories and measures.

new life cycle inventory data acquired from industry and public sources. The study examined roofing systems employing a variety of membranes, including EPDM, TPO, PVC, and SBS-modified bitumen.

In addition, the study examined a number of roof attachment methods, including ballasted, fully adhered, and mechanically attached applications. The scope of the life cycle assessment included all inputs associated with the extraction, manufacture, and installation of these roofing systems.

The key component of an LCA is to determine the environmental impact of the product or system under review. Environmental impacts are the result of the inputs and outputs over a product's life cycle. Inputs such as raw materials and energy carry with them environmental effects just as much as obvious environmental outputs such as atmospheric emissions and solid wastes.

Although the total number of different potential environmental impacts may be very large, the EPA has identified the major impact categories in its widely used Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI). These major impact categories, along with the measures employed, are listed in *Table 1*.

In addition to identifying the major threats that affect the environment and human health, the TRACI methodology also identifies specific measures for each effect. As an example, although a number of atmospheric gases—including methane and various gaseous oxides—may contribute to global warming, the TRACI scale measures all of these factors in terms of their equivalency to carbon dioxide (CO_2), the most common "greenhouse gas" (next to water vapor). In a similar manner, the potential for depleting the earth's ozone layer is measured in terms of equivalency to the impact of CFC-11, the once-popular "Freon" refrigerant.

ROOFING SYSTEMS ASSESSED

The LCA conducted by GreenTeam included the low-slope roofing membranes, thicknesses, and application methods listed below.

Membrane Types

- Nonreinforced EPDM (black and white*)
- Reinforced EPDM (black)
- Reinforced TPO (gray and white**)
- Reinforced PVC (gray and white**)
- SBS-modified bitumen (unsurfaced)

*white top layer over black bottom layer
**white top layer over gray bottom layer

Membrane Thicknesses

- 45 mil (nonreinforced EPDM, black only)
- 60 mil (nonreinforced and reinforced EPDM, reinforced TPO and PVC)
- 72 mil (reinforced TPO)
- 80 mil (reinforced TPO and PVC)
- 90 mil (nonreinforced EPDM, black only)
- 140 mil (SBS-modified bitumen)

Application Methods

- Loosely laid and ballasted (EPDM, TPO, PVC)
- Fully adhered (nonreinforced and reinforced EPDM, reinforced TPO and PVC, and SBS-modified bitumen)
- Mechanically attached (reinforced EPDM, TPO, and PVC)

In addition to the membranes and application methods listed above, the following ancillary materials necessary for system installation were also evaluated:

- Metal fasteners and plates (for insulation attachment and membrane securement as required for fully adhered and mechanically attached applications)
- Membrane bonding adhesive (for fully adhered applications)
- Ballast stone (for ballasted applications)

LCA SYSTEM BOUNDARIES

All LCAs were conducted on a "cradle-to-gate" (or cradle-to-building) basis, including all necessary inputs to complete the installation of the roofing membrane. Additional studies will be necessary to extend this research to include in-service and end-of-life impacts.

Input Sources

Sources of input used by GreenTeam included the following:

- Previous LCA studies of low-slope roofing systems (Franklin Associates, 2001; Morrison Hershfield, Ltd., 2001)
- EPDM membrane composition (TRC Environmental Corporation, 1995)
- Information supplied by the EPDM Roofing Association (ERA)
- EPA AP-42 emission factors
- Existing LCI databases (US LCI, Ecoinvent/SimaPro, Athena Institute)

LCI data for TPO, PVC, and SBS modified bitumen were derived primarily from the Athena Institute and based on the Franklin Associates and Morrison Hershfield LCA studies. LCI data for EPDM was derived from RMA compounding and manufacturing data provided by TRC Environmental, supplemented by EPA AP-42 and existing LCI database information. LCI data for metal fasteners and ballast stone were derived from existing LCI database information. LCI data for bonding adhesive was derived from generic adhesive formulation information provided by ERA.

Finally, the EPDM data used in this

TRACI IMPACT CATEGORY

SYSTEM DESCRIPTION			Global Warming (kg CO2)	Acid Rain (H+ moles)	Carcin. (kg benzene)	Non-Carcin. (Kg toluene)	Respiratory Effects (kg PM)	Eutrification (Kg N)	Ozone Depletion (kg CFC-11)	Eco-Toxicity (Kg 2,4-D)	Smog (Kg NOX)
SYSTEM	MEMBRANE	ATTACHMENT									
EPDM	60-mil nonreinf. black	Ballasted	28.3	11.9	0.17	463	0.05	0.004	< 0.00001	3.78	0.08
	60-mil nonreinf. black	Fully Adhered	29.6	12.3	0.17	514	0.06	0.005	< 0.00001	4.26	0.08
	60-mil nonreinf. white	Fully Adhered	22.4	8.8	0.17	528	0.04	0.003	< 0.00001	4.79	0.05
	60-mil reinforced black	Mech. Attached	28.7	12.0	0.17	542	0.06	0.004	< 0.00001	3.50	0.08
TPO	60-mil reinforced gray	Fully Adhered	30.5	19.2	0.15	419	0.06	0.004	< 0.00001	2.19	0.08
	60-mil reinforced gray	Mech. Attached	29.4	18.9	0.15	477	0.06	0.003	< 0.00001	1.71	0.08
	60-mil reinforced white	Fully Adhered	30.9	19.4	0.15	424	0.06	0.004	< 0.00001	2.41	0.08
	60-mil reinforced white	Mech. Attached	29.8	19.2	0.15	483	0.06	0.003	< 0.00001	1.93	0.08
PVC	60-mil reinforced gray	Fully Adhered	58.6	39.4	0.05	492	0.03	0.010	< 0.00001	6.58	0.20
	60-mil reinforced gray	Mech. Attached	54.2	38.4	0.04	528	0.03	0.008	< 0.00001	2.80	0.19
	60-mil reinforced white	Fully Adhered	73.1	49.1	0.06	606	0.04	0.010	< 0.00001	8.62	0.24
	60-mil reinforced white	Mech. Attached	67.8	47.8	0.05	650	0.03	0.011	< 0.00001	4.01	0.23
SBS	140-mil unsurfaced	Fully Adhered	81.8	52.7	0.06	998	0.04	0.160	< 0.00001	10.9	0.31

Figure 1

study, based on up-to-date product formulation, resulted in an environmental impact for EPDM significantly lower than results currently available in public databases that may not contain up-to-date EPDM formulation data. As a result, it may be prudent for building design professionals using the currently available public LCA information to be aware of the significantly reduced EPDM impact data demonstrated by this study.

METHODOLOGY

To assure that all LCA assessment activities conducted as part of this study reflect most recent industry best practice, GreenTeam, Inc., a strategic environmental consulting firm specializing in building industry issues, was selected as project assessor. Dru Meadows, AIA, FCSI, CCS, and Charles E. Bell, AIA, NCARB, LEED® AP, founding principals of GreenTeam, are nationally and internationally recognized design professionals. Meadows also serves as the chair of the recently formed ASTM Committee E60 on Sustainability.

All outputs and impacts were calculated by GreenTeam using SimaPro LCA software. Impacts were summarized using the categories and unit measures of the EPA TRACI Model (See *Table 1*). All membranes studied were assumed to provide equal service lives, so the basic impacts were not adjusted for service life. All impacts were calculated based on one square meter (m^2) of installed roofing membrane.

FINDINGS

Comparison of Widely Used Membranes and Application Types

Because of the large overall combination of membrane, thickness, and application types, this study provides a summary of the most common and widely used low-slope roofing systems.

Ballasted Systems

- 60-mil nonreinforced EPDM (black)
- Fully adhered systems
- 60-mil nonreinforced EPDM (black)
- 60-mil nonreinforced EPDM (white)
- 60-mil reinforced TPO (gray)
- 60-mil reinforced TPO (white)
- 60-mil reinforced PVC (gray)
- 60-mil reinforced PVC (white)
- 140-mil SBS modified bitumen (unsurfaced)
- Mechanically attached systems
- 60-mil reinforced EPDM (black)
- 60-mil reinforced TPO (gray)
- 60-mil reinforced TPO (white)
- 60-mil reinforced PVC (gray)
- 60-mil reinforced PVC (white)

To provide an equivalent comparison, all nonasphaltic membranes (EPDM, TPO, and PVC) were compared based on a common thickness of 60 mils. The SBS membrane is compared using the 140-mil thickness, which is typical of a modified bitumen top layer that would reasonably be compared to single-ply membranes of 60-mil thickness. A summary of the impacts for a sq ft of each of these systems is provided in *Figure 1*.

Magnitude and Relevance of Impact Categories

As illustrated in *Figure 1*, energy-related categories such as global warming appear to offer the greatest relevance. Global warming potential (GWP), as measured by kilograms of CO_2 equivalents, varied from a low of 22.4 kg per sq ft (fully adhered white, nonreinforced EPDM) to a high of 81.8 kg per sq ft (140-mil unsurfaced SBS). The relevance of the global warming category is further supported by the degree of differences exhibited by the membranes studied.

For example, the global warming potential of a white PVC or unsurfaced SBS mem-

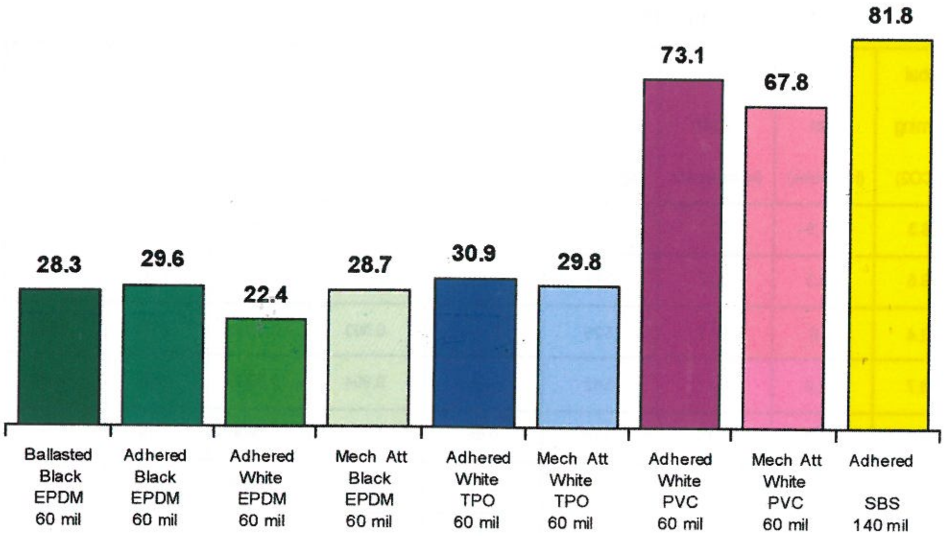


Figure 2 — Global warming potential (GWP) for widely used low-slope roofing systems Kg CO_2 equivalent per m^2 of installed membrane. (Source: The GreenTeam, 2009)

brane is over twice the potential of a black EPDM or white TPO roofing membrane for all system types studied. *Figure 2* provides a comparison of GWP for each of the widely used low-slope roofing membranes and systems.

Many other categories, including categories related to toxicity and health effects, appear to offer much less magnitude and relevance. For example, the ozone-depletion potential of every membrane and system studied as measured by kilograms of CFC equivalents was less than 0.00001 kg per sq ft. Similarly, eutrification (the process by which oxygen is removed from the water by the decomposition of large amounts of organic matter) potential as measured by kilograms of nitrogen equivalents was less than 0.01 kg per m^2 for all membranes except SBS (0.16 kg).

As suggested by other studies of the environmental impact of building materials, global warming appears to be a significant differentiating factor for making informed sustainable material evaluations and selections. And because global warming potential is closely tied to the amount of energy needed to extract, manufacture, transport, and install these building materials, it may remain a significant factor for many years, especially in a nation that relies heavily on fossil-based energy sources. Over time, as renewable energy replaces fossil sources for energy production, the importance of global warming potential may fade from the built environment, but at the present, such a situation is likely decades into the future.

The Role of Membrane Formulation

The differences observed among the various low-slope roofing membranes, especially differences in global warming potential and energy consumption, suggest a number of possible explanations. The relatively low GWP of the EPDM membranes may be attributed to the relatively high-polymer effectiveness of EPDM, which, in turn, allows a relatively low polymer content in the membrane formulation. In fact, this high-polymer effectiveness may be an even more significant factor, considering the additional energy required to cure or vulcanize a rubber material.

In contrast to the relatively high energy input required to vulcanize rubber polymers like EPDM, the TPO and PVC membranes both enjoy a lower energy input for manufacturing. However, the relatively lower GWP of TPO as compared to PVC may be attributed to the relatively higher energies required to produce a halogenated polymer such as PVC as compared to a nonhalogenated olefin polymer like TPO.

A comparison of the SBS membrane to the single-ply membranes studied also suggests a relationship between product thickness and GWP. SBS-modified bitumen requires a lower polymer content than even EPDM, but this advantage of polymer efficiency appears to be clearly offset by the greater total thickness required. And this comparative GWP disadvantage would be further magnified since a typical SBS roof installation involves the application of an additional layer of SBS material as a base layer.

The Role of Attachment Method

One of the most interesting findings in this study is the minimal role played by attachment method in determining impact. As an example, the various attachment methods studied (ballasted, fully adhered, mechanically attached) appear to affect overall GWP by less than 4% for EPDM and TPO and less than 7% for PVC. This lack of demonstrable difference suggests that the selection of the most suitable application method should be based on other factors such as potential longevity, or ease of repairability.

The Role of Membrane Color

For the TPO and PVC membranes, membrane color appears to play little or no role as a differentiating factor. As an example, the GWP for a fully adhered, gray, 60-mil TPO membrane (30.5 kg/ft^2) is essentially identical to the GWP for a similar white, 60-mil TPO membrane (30.9 kg/ft^2). For EPDM membranes, however, the difference between white and black is relatively more pronounced, with a fully adhered, white, 60-mil EPDM membrane exhibiting the lowest GWP of the study (22.4 kg/ft^2) as

System	Membrane	Attachment	Global Warming Potential (GWP) (kg CO_2 eq.)	Minimum Service Life to Achieve Equivalency[1] (years)
EPDM	60-mil nonreinforced black	Ballasted	28.3	19.0
		Fully adhered	29.6	19.8
	60-mil nonreinforced white	Fully adhered	22.4	15.0
	60-mil reinforced black	Mech. attached	28.7	19.2
TPO	60-mil reinforced gray	Fully adhered	30.5	20.4
		Mech. attached	29.4	19.7
	60-mil reinforced white	Fully adhered	30.9	20.7
		Mech. attached	29.8	20.0
PVC	60-mil reinforced gray	Fully adhered	58.6	39.2
		Mech. attached	54.2	36.3
	60-mil reinforced white	Fully adhered	73.1	49.0
		Mech. attached	67.8	45.4
SBS	140-mil unsurfaced	Fully adhered	81.8	54.8

[1]Using a conservative 15-year service life for the lowest impact system (fully adhered white EPDM).

Figure 3 — Minimum service life to distribute GWP equally.

compared to a similar black, 60-mil EPDM membrane (29.6 kg/ft^2). A possible explanation both for the similarity of white and gray TPO/PVC and the difference between black and white EPDM may be related to differences in the use of carbon black in these three membranes. Black EPDM has a relatively high carbon black content (47% by weight), and carbon black requires a higher level of production energy as compared to the titanium dioxide (TiO_2) and white clay typically used as substitutes for carbon black in white EPDM formulations. In contrast, the formulations of gray and white TPO and PVC are essentially identical, with only a minuscule amount of carbon black or similar pigment added to achieve a gray hue.

The Role of Service Life

As mentioned earlier in this study, the impact measurement of all membrane systems was based on an equivalent service life. The reasoning behind this assumption was based on several factors. First, published information and research on the estimated service life of low-slope roofing systems exhibit a significant level of variation that may be explained more by research assumptions than by specific membrane characteristics (Hoff, 2009). More important, the industry perception of the service life of established low-slope roofing alternatives such as EPDM, PVC, and SBS appears to be converging as these systems have matured in the market. And although TPO does not have as long a track record as the other membranes studied, observed performance to date has been positive.

Although this study is "service-life neutral" in scope, one important observation related to service life may be drawn from the data. Because of the relatively high variation in LCA impacts among the membranes studied (especially GWP), the implication of these variations on long-term impact and service life should be reviewed. As an example, fully adhered white EPDM (GWP = 22.4 kg/m^2) would require only a little over two-thirds the service life of adhered black EPDM (GWP = 29.6 kg/m^2) to produce an equal annual distribution of the initial embodied GWP impact. In a similar manner, an adhered white PVC membrane (GWP = 73.1 kg/m^2) would require a service life over twice as long as black EPDM to produce an equal annual distribution of initial embodied GWP impact. *Figure 3* illustrates this comparison among the widely used low-slope roofing systems in terms of the service life required to provide an equal annual distribution of GWP impact as compared to white EPDM (assuming a conservative 15-year minimum service life for white EPDM).

NEXT STEPS

Revision of LCI Databases

Because the EPDM data in this study (based on an accurate formulation of the product) produces a significantly lower overall environmental impact, it was deemed imperative to provide this information to Athena to update its Athena LCI database and Athena® EcoCalculator as quickly as possible. After its own internal review, Athena has accepted and incorporated the data into its databases. Similar steps will now take place with the US LCI database for use with the BEES® and other LCA tools. In the interim, it would be prudent for building design professionals using the Athena® EcoCalculator to be aware of the significantly reduced EPDM impact data demonstrated by this study.

Importance of Service Life Estimates

The data in this study suggest that service life estimation is a critical element in the development of an accurate and dependable life cycle assessment of any building or roofing system. As a consequence, building designers should not assign an estimated service life for a building or any major building system without conducting a sensitivity analysis of the comparative consequences of that service life. For example, if a roofing system with a relatively low initial GWP is being compared against a roofing system with a significantly higher GWP, the data in this study suggest that it would be prudent for the designer to be confident that the higher GWP system can provide a significantly longer service life to be considered an equivalent in terms of global warming impact.

Importance of Life Cycle Management

As stated previously, the LCA conducted for this study was based on a cradle-to-building approach. As a consequence, no impacts were identified or measured for activities that occur during the service life of the roofing system (routine maintenance and periodic repair or renovation) or at the end of service life (removal, disposal, and possible recycling). Although many of the activities not addressed by this study (such as routine maintenance and periodic renovation) generate relatively small environmental impacts, their value in extending service life may be much more important than their incremental impact contribution.

For the roof system designer, the opportunity to reduce overall environmental impact by extending useful service life implies that material or design features that support this opportunity should receive considerable attention. Such features may include the possibility of accurately predicting maintenance and repair requirements, relative ease of repair of the roofing membrane, and the possibility of removing and replacing selected roof system components.

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Model Green Building Ordinance

A Model Green Building Ordinance for use by municipalities intending to promote the construction and design of new buildings that make efficient use of energy, water, and materials has been released by the Center for Climate Change Law at Columbia Law School. The model ordinance, the result of over a year of work and consultations with dozens of stakeholders, is designed to be readily adopted by local jurisdictions.

" With 40% of all energy consumed in the U.S. used by buildings, it is clear that a large part of the effort to mitigate the impact of climate change will have to come from efficiency gains in the built environment, particularly through the use of green construction, design, and operating practices," said Michael Gerrard, director of the Center for Climate Change Law, and Andrew Sabin, professor of professional practice.

Current municipal green building ordinances vary widely in content, coverage, and quality of drafting. Many small localities cannot devote sufficient resources to form a fully developed green building ordinance. To this end, the model ordinance compiles the best aspects of green building ordinances nationwide and is structured to avoid the legal pitfalls encountered by some municipal ordinances.

The ordinance is designed for New York State municipalities but with minor revisions can be readily adopted in other states, if not around the world, Gerrard said. The model ordinance, together with extensive commentary, legal analysis, and other supporting documentation, is available for download at the Center for Climate Change Law' s Web site, www.columbiaclimatelaw.com.