THE ROLE OF PVC RESINS IN SUSTAINABLE DESIGN

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Abstract:

The concept of sustainability is often stated in a number of ways but four core principles appear throughout: Protect the environment, promote human health, conserve resources, and assure social and economic well-being to the global population. PVC resin has intrinsic properties that allow finished products to meet all four of these objectives. PVC resin and products compare favorably to other materials in life cycle assessments when reviewing key impacts of resource and energy conservation, and greenhouse gas emissions. Sustainability assessments at the business level are excellent tools to promote these principles and track performance. This paper was prepared for the Society of Plastics Engineers Annual Technical Conference (SPE ANTEC) Vinyl Session, April 22, 2013 in Cincinnati, Ohio.

Introduction: Defining Sustainability

One of the most talked about subjects in our industry in recent years is the concept of 'sustainability'. The focus on sustainability stems from the growing awareness by many experts that the earth and its fragile climate and ecological systems are being stressed due to unintended consequences of rapid population growth, economic growth and consumption of its natural resources. Activist groups and regular citizens alike have become increasingly vocal in their belief that these pressures need to be dealt with before irreparable harm is done to the earth, its climate and its living environments.

These issues have been confused, however, by the frequent use of ‘green’ as a short-hand for ‘sustainable.' Green is hard to define, but is generally intended to convey some form of environmental benefit, especially when compared with alternative, conventional practices which presumably are ‘not green.’ For some it is a vague idea meaning 'natural' such as houses built of hay bales with solar collectors on the roof. For others, green simply means products made from bio-based, and wherever possible, rapidly-renewable materials. And still others, including regulators, want a more systematic approach to labeling something as ‘green’. Indeed, the term has such broad and confusing meanings, from the standpoint of environmental and sustainable performance that the Federal Trade Commission views its use in environmental marketing claims with disfavor. [1] Nevertheless, because buildings consume a high percentage of the materials and energy we use, “being green” is of great interest to the professionals responsible for the design and construction of buildings. Since building and construction applications represent about three fourths of the uses of PVC (polyvinyl chloride) resins, this topic is of keen interest to the PVC industry as well.

Sustainability is a broader term, encompassing not only environmental notions, but also social welfare considerations. Notions of sustainability generally are better defined than green, but just as widely debated, and bearers of significant preconceptions. Curiously, in a random survey of U.S. consumers on the meaning of the term, the FTC found that 36% of respondents interpreted the term sustainable to mean durable or long-lasting. Only seven percent of the admittedly small sample said the term suggested a product that is good for, helps or befits the environment. As a result, the FTC declined to issue guidance on whether sustainability claims complied with U.S. advertising law. [2]

As we discuss below, the FTC’s view arguably is an outlier within the U.S. Federal Government, but points to the need for a working definition of sustainability.

Table 1 summarizes various definitions of sustainability, including by the Office of the President, the U.S. Environmental Protection Agency (EPA), the United Nations Environmental Protocol, and others.

These varying formulations reflect very similar goals: Protect the environment, conserve resources, and promote human health, all as affordably and equitably as possible. For purposes of this article, however, we find the best working definition to be from *PVC: Reaching for Sustainability*, by Dr. Mark Everard:

“Sustainability is enabling our growing human population to live equitably within the

supportive capacities of the natural world on an indefinite basis."[3]

Table 1: Definitions of Sustainability

	Definition	Source
1	"Improving the quality of human life while living within the carrying capacity of supporting ecosystems."	IUCN, UNEP, WWF (1991): Caring for the Earth. A Strategy for Sustainable Living.
2	"Meeting the needs of the present without compromising the ability of future generations to meet their own needs."	Brundtland Commission of the United Nations, March 20, 1987
3	"Sustainable development is often thought to have three components: environment, society, and economy. The well-being of these three areas is intertwined, not separate." Modern perspectives on this consider economy as a subset of society, which is then a subset of the environment.	McKeown, R. (2002), The ESD Toolkit 2.0.
4	"Sustainability creates and maintains the conditions under which humans and nature can exist in productive harmony that permits fulfilling the social, economic and other requirements of present and future generations."	(EO 13423, Section 9 and EO 13514, Section 19(l)).
5	"Sustainability is important to making sure that we have and will continue to have, the water, materials, and resources to protect human health and our environment."	USEPA Sustainability Webpage

In the built environment, sustainability is about energy use, land use, site and resource utilization, indoor air quality, using natural daylight in spaces that people occupy, and many other factors, too. It's also about building materials, where they come from, how they are made and their end-of-life disposition.

Federal Government Sustainability Initiatives

As the preceding discussion indicates, the U.S. Federal Government has long sought to promote sustainability both in government activities and the private sector. Absent broader authority from the U.S. Congress, however, the Federal Government is best able to focus on its own practices as evidenced by two recent Executive Orders (EO).

EO 13423 "Strengthening Federal Environmental, Energy, and Transportation Management", signed by President Bush on January 24, 2007 sets goals in the areas of energy efficiency, acquisition, renewable energy, toxics reductions, recycling, renewable energy, sustainable buildings, electronics stewardship, fleets, and water conservation. In addition, the order requires more widespread use of Environmental Management Systems as the framework in which to manage and continually improve these sustainable practices. [4]

EO 13514 "Federal Leadership in Environmental, Energy, and Economic Performance ", signed by President Obama on October 5, 2009 sets sustainability goals for Federal agencies and focuses on making improvements in their environmental, energy and economic performance. The EO is known as the 'Guiding Principles' and requires Federal agencies to set a 2020 greenhouse gas (GHG) emissions reduction target, increase energy efficiency, reduce fleet petroleum consumption, conserve water, reduce waste, support sustainable communities, and leverage Federal purchasing power to promote environmentally-responsible products and technologies.[4] It also requires that 15 percent of the existing federal capital asset building inventory as of the end of fiscal year 2015 incorporate the sustainable practices contained within the Guiding Principles.

Citing these Executive Orders, the U.S. EPA has begun establishing policies to make sustainability the next focus of environmental protection by drawing on advances in science and technology to protect human health and the environment, and promoting innovative green business practices. [5]

> "Historically, environmental programs have focused on how to reduce air and water pollution, and how to identify and monitor chemical and environmental risks to human health and the environment. Today's challenges depend on the sustainable use of natural resources, and require solutions that stress the

linkages between energy use, water use, land use, material consumption, environmental protection, human health, quality of life, and the global economy. In 2011, the National Academy of Science published its study entitled "Sustainability and the U.S. EPA," also known as the Green Book, to direct EPA policies in this area. [6]

One Key Recommendation (5.1) in The Green Book is that EPA should include risk assessment as a tool, when appropriate, as a key input into its sustainability decision making to support comparisons of chemicals as part of an alternatives analysis for Green Chemistry applications.

EPA lists Green Chemistry as one of its approaches to sustainability to help it manage when risk assessments become more uncertain, particularly at low exposure levels. One aspect of Green chemistry is to design chemical products and processes that reduce or eliminate the use or generation of hazardous substances. But an equally stated goal of Green Chemistry is to reduce uses of energy and resources, and to reduce waste across the life cycle of a chemical product. [7] These goals can conflict, and a measured approach to sustainability requires acknowledging the trade-offs in emphasizing one goal over another.

Matching Sustainability Characteristics of PVC Resins with Federal Policies

One question asked by many activists is "How can PVC be more sustainable than some other obvious choices for a building material?"

To begin with, in the U.S., PVC is derived from co-products of abundant resource production. Wet gas extraction for energy yields natural gas liquids (NGL) (ethane through hexane) that are ideal for petrochemical manufacture, and are the primary feedstock for ethane conversion to ethylene, a building block raw material for PVC. NGLs save conversion steps to derive ethane from either methane or petroleum based naphtha.

PVC resin is 57% chlorine which is derived from common salt, another abundant mineral in the earth's crust. Chlor-alkali production from NaCl salt produces two co-products. For each mole of caustic (NaOH) produced, a half mole of chlorine is produced. There are hundreds of chemicals made directly from chlorine and caustic and even thousands more that are further derived from these building blocks. Caustic is an important chemical in the production of many products including aluminum, textiles, pulp and paper, water treatment, and others vital to the economy. Chlorine is equally important as a chemical in the manufacture of basic organic chemicals and acids widely used in polymeric materials, solvents, pigments and inks, pharmaceuticals, cleaning and disinfection agents, water treatment, and other important life-enhancing uses. PVC accounts for the largest use of chlorine, consuming approximately 40% of yield and without the manufacture of PVC, demand for chlor-alkali co-products would become unbalanced. [8] The use of ethane and chlorine, both co-products of other necessary chemical manufacture helps minimize natural resource depletion, a key sustainability principle. Creating a polymer with inherent flame resistance and strong and stiff physical properties in just a few steps further reduces ingredients when compared with polymers that are compounded using flame retardant additives, which again conserves resources.

Table 2: PVC Attributes to Meet EO 13423 & 13514

Environmental Protection • Low ecotoxicity • Low eutrophication • Low ozone depleting chemical emissions • Low photochemical smog • Reduced GHG emissions	**Resource Conservation** • Low embodied energy • Low natural resource depletion • Uses co-products from abundant production of energy (gas) and chemical (chlor-alkali) • High atom economy • Recyclability
Human Health Protection • Low exposure to criteria emissions • Does not compete with food supply • Inert resin product • Safe manufacturing methods	**Economic Well Being** • Efficient large scale manufacturing • High product yield, little waste • Widespread availability • Long service life • Worker employment

Beyond the preceding considerations, PVC resin also meets the more specific criteria of the Executive Orders and many of EPA's 12 Principles of Green Chemistry. Table 2 illustrates how PVC meets a number of the sustainability factors put forth in the Executive Orders on the basis of life cycle information (LCI) prepared for the Plastics Division of the American Chemistry Council [9, 10].

Beyond the general principles of EO 13423 & 13514, PVC also performs excellently under EPA's sustainability criteria. Among the U.S. EPA's initiatives for accomplishing sustainability in the manufacture of chemicals are the "Green Chemistry" practices listed in Table 3. Those principles designated with an '*' illustrate at least seven areas with which PVC resin production conforms

Table 3: The 12 Principles of Green Chemistry [11]

1. Prevention
*2. Atom Economy
*3. Less Hazardous Chemical Syntheses
4. Designing Safer Chemicals
5. Safer Solvents and Auxiliaries
*6. Design for Energy Efficiency
7. Use of Renewable Feedstocks
*8. Reduce Derivatives
*9. Catalysis
10. Design for Degradation
*11. Real-time analysis for Pollution Prevention
*12. Inherently Safer Chemistry for Accident Prevention

*Indicates a principle that PVC production conforms with.

Principle No.2, "Atom Economy", refers to the conversion of raw materials into finished products. Overall conversion efficiency for ethylene dichloride to vinyl chloride to PVC is estimated to be 94% [12], which puts it among the highest for polymer resins. Key to achieving this is steam stripping of PVC resin that removes unreacted monomer and recycles it back to the front of the polymerization process which drives the polymerization (step 5) to nearly complete utilization of monomer feedstock.

As shown in Figure 1, PVC has one of the lowest embodied energy profiles for a polymer because of its composition with chlorine, use of catalysts in feedstock preparation, and exothermic monomer polymerization reaction, which all combine to adhere to Principle No.6 "Design for Energy Efficiency."

A further look at embodied energy is warranted since it should be basic to any material sustainability evaluation due to the amount of GHG emitted to produce the material. In the case of PVC, replacement of ethylene with chlorine in the polymer matrix creates an interesting tradeoff between the electrical energy intensive derivative chlorine (total energy for process and transportation = 17.67 MJ/Kg including salt mining) [9] versus the fuel and electrical energy intensive derivative ethylene (total energy for process and transportation = 17.73 MJ/Kg), [9] with the net result of PVC having a low total embodied energy. It should be pointed out that comparisons of polymers or other materials on a unit basis would only be an indication of certain intrinsic attributes, and may not be representative of actual impacts of any material when a complete cradle to grave life cycle assessment (LCA) is performed.

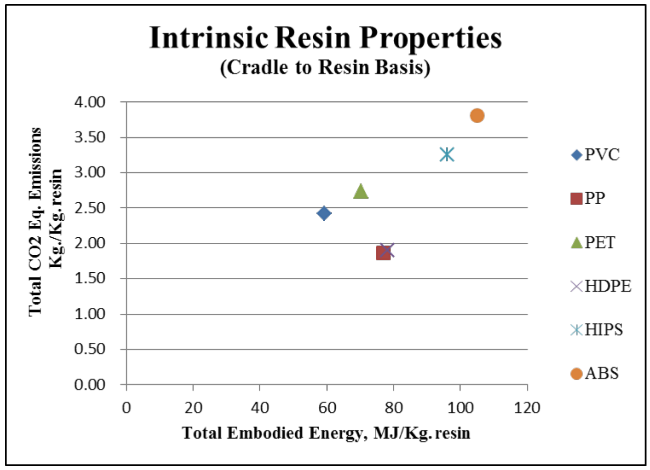

Figure 1: Resin GHG Emissions vs. Embodied Energy, Data Reference: ACC Cradle to Gate LCI Report [9]

Principles No. 3 and 12, "Less Hazardous Chemical Syntheses" and "Inherently Safer Chemistry for Accident Prevention" intend to reduce environmental and workplace hazards through chemical selection. But all organic raw materials, whether in a solid or liquid form, can present combustible dust or flammable liquid hazards which require responsible care during handling and processing, and whether derived from biomaterials or fossil fuels, cause issues when released into the environment. Alternatively, process safety practices and workplace monitoring are ways to accomplish the same end result. The PVC industry has a history of implementing safeguards and a proven record of achieving both of these aforementioned green chemistry principles through sophisticated process monitoring and controls. Year over year reductions in criteria emissions for vinyl chloride and dioxin are shown in Figures 2 and 3 respectively. These improvements have been accomplished by implementing many technology improvements such as large self-cleaning reactors that reduce openings, robust monomer recovery from all equipment that prevents release and exposure to vinyl chloride, and quick quench of high temperature impurity oxidizers that reduce formation of criteria pollutants. It should be noted that these emission reductions have occurred over a period of time when industry-wide PVC production has grown dramatically, demonstrating a history of continuous improvement and reduction of environmental impact.

PVC plants are equipped with an elaborate array of continuous air samplers that alert employees quickly in the event of any monomer leak. These monitors and the continual emphasis by the industry for safety has resulted in an illness and injury rate that is one-third that of the overall chemical industry, and one-sixth that of overall manufacturing, as recorded in Figure 4.

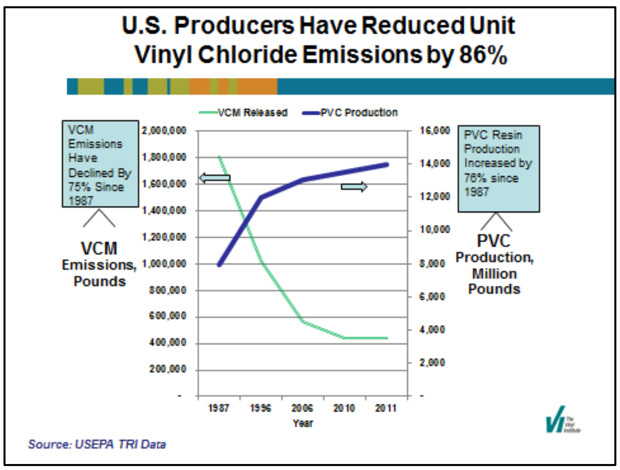

Figure 2: PVC Industry Cradle to Resin Vinyl Chloride Emissions

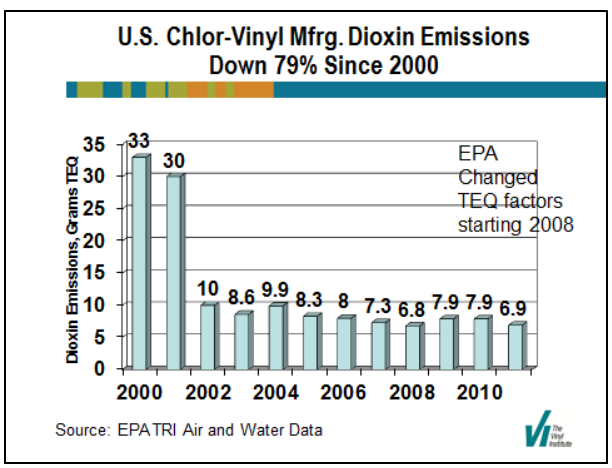

Figure 3: PVC Industry Cradle to Resin Dioxin Emissions

Principle No. 8 "Reduce Derivatives" can be shown to be met by the examining the block flow diagram in Figure 5 which depicts the relatively simple route to manufacture PVC resin in just 5 steps.

Several steps incorporate catalysts which drive reactions more effectively as required by Principle No. 9 "Catalysis."

Each step is computer controlled and continuous process parameter monitors assure optimal operations, which meets the requirement of Principle No.11 "Real-time Analysis of Pollution Prevention."

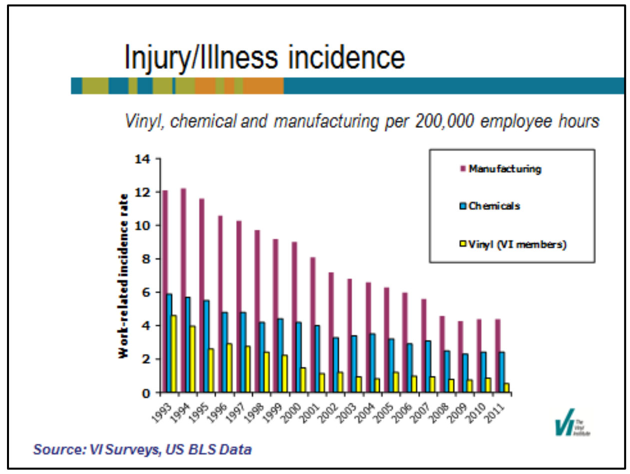

Figure 4: Illness and Injury Rate, PVC Resin

An effective sustainability program must include goals directed toward measuring and improving performances. The Vinyl Institute revised its health, safety, and environmental survey in 2002 and challenged VI member EDC/VCM and PVC producers to achieve the 6 goals listed in Table 4. These challenges in part are responsible for the industry-wide improvements in emissions and safety illustrated in Figures 3, 4, and 5. For the 2010 and 2011 periods, the VI presented 19 different facilities with a total of 45 awards for meeting the following safety and environmental criteria.

Everard points out the necessary relationship between assumptions and values related to sustainability, and about taking the steps necessary to achieve sustainability. [3] There has been substantial progress within the PVC industry on the sustainability front; and while continual improvement is the guiding principle, the industry's progress to date can serve as a model to other industries.

Table 4: Vinyl Institute Annual HSE Survey Goals

1.	Fewer than 1 reportable quantity release of 1 pound or more of vinyl chloride as required by the VC National Emission Standard for Hazardous Air Pollutants to the National Reporting Center;
2.	Year over year reduction in criteria pollutants released to the environment as air, water or land pollutants as reported in EPA's Toxic Release Inventory;
3.	Year over year reductions in reported wastes as reported in EPA's TRI;
4.	100% compliance with the VC NESHAP;
5.	Demonstrated reductions in energy and water consumption;
6.	Zero reportable injuries based on OSHA criteria.

Sustainability Characteristics of Vinyl Products

Let's further examine how the sustainability attributes of PVC resin translate into benefits in finished products. In an era when material science has made available new products that are durable and perform well in the applications for which they are intended, it is hard to defend a return to purely 'natural' materials made from plants and other bio-mass sources as some green design and construction proponents advocate. Depending on the intended application, those products may not be as durable and may in fact cause more impact on the environment than the synthetic materials that originally displaced them. And who should determine what is more sustainable, what that should mean in the marketplace, and how sustainable attributes should be measured? Most reasonable design professionals recognize that all human activity carries with it some impact on the environment. All materials have issues and there really are no 'good' or 'bad' materials, just better and worse ways of using the materials available to us. The goal therefore should be to choose the materials that perform well in their intended applications with the lowest overall environmental impact.

Three-fourths of the PVC resin produced is used in building products that last for many years if not decades, so it makes sense to focus in on this market segment. Qualitative sustainable attributes for building products made from PVC are listed in Table 5, which further demonstrate how U.S. federal sustainability guidelines are being achieved.

Table 5: Sustainability Attributes of PVC Building Products to Meet EO 13423 & 13514

Environmental Protection • Energy conserving characteristics in functional use reduce environmental burdens • Reclamation at end of life eliminates environmental emissions characteristic of other reclaimed non-polymeric building materials. • Inert behavior in landfill disposal • Reduced GHG emissions
Resource Conservation • Reduced weight, and therefore transportation fuel consumption, when compared with heavier alternative material applications • Thermal insulating quality reduces energy use in buildings • Low maintenance finishes saves cleaning and resurfacing • Rot and pest resistant, colorfast, and retention of strength and impact-resistance in outdoor use enables longer service life • Ability to recycle PVC at its end of life into many different uses conserves resources and minimizes environment burden
Human Health Protection • Proven performance with decades of safe use • Meets indoor air quality limits • Inert and inherently cleanable products help control spread of bio hazards (such as fungus, bacteria). • Safe conversion to finished products • Inherent fire resistance and low heat release minimizes losses in accidental fires • Electrical insulation properties enable durable safe power distribution to homes, and appliances • Water pipe applications resistant to bio contamination • Positive worker safety record
Economic Well Being • Efficient large scale manufacturing • High product yield, little waste • Widespread availability • Long service life reduces replacement costs • Extensive and positive employment impact

It is worth noting that the number of end-of-life solutions for PVC building materials is growing. Several flooring, wallcovering, and roofing manufacturers using PVC materials have instituted or expanded their take-back programs for products when being replaced with their brands. VI estimates this accounts for over a hundred million pounds of post-consumer material annually. After separating and cleaning the reclaimed materials, the PVC can be reprocessed into new products for useful lifetimes often equivalent to the original product. This substitution of a reclaimed PVC molecule for a new one effectively eliminates a large portion of the emissions burden associated with new PVC manufacture, a quality not able to be achieved by non-polymer materials e.g. aluminum, ductile iron, wood, etc. that must go through the front end reprocessing and its associated energy and emissions burdens in order to be recycled. A material with persistent plastic molecules can be recycled because its structure does not biodegrade or corrode and dissolve but rather stays locked up within the product itself. Durability is an asset in supporting human needs, and persistence in fixed and recoverable infrastructure can be a virtue in sustainability terms. Delivery of human value from a limited pool of molecules is well served by durable, relatively maintenance-free products, whether they are window frames, water pipes, flooring tiles, or any other product. [3]

For a more quantitative perspective, environmental and health impacts can be determined through life cycle assessment (LCA). According to the American Center for Life Cycle Assessment, an LCA can assess many different impacts (Table 6) but all of them should be part of an attempt to evaluate the environmental and human health aspects of a product or a service in a ‘cradle-to-grave’ fashion. There are now international standards such as ISO 14040 and others, which have uniform procedures about how to perform an LCA. The determination of the functional unit and the useful life of the product are more complicated than it sounds for various building materials that have certain desirable attributes depending on the needs of the installation. A Product category rule (PCR) is one of the first steps in identifying those crucial aspects of an LCA that make them more comparable for a specific application across a spectrum of materials. The flooring industry is one of the first to come together and work with NSF International to develop a PCR according to ISO 14025 guidelines.

Table 6: Typical Life Cycle Assessment Impact Categories

- Global Climate Change
- Stratospheric Ozone Depletion
- Photochemical Smog
- Natural Resources Depletion (habitat, water, fossil fuels, minerals, biological resources)
- Acidification
- Eutrophication
- Ecotoxicity
- Human Toxicity

Human toxicity is a more challenging determination for LCAs, but U.S. federal and state regulations on manufacturing attempt to reduce occupational exposures to a zero-risk level. Most interior vinyl products are designed to meet indoor air quality standards whereby volatile and semi-volatile organic compound emissions are tested to be below chronic reference exposure levels.

Using data from publicly available LCA’s, (NIST BEES) it is possible to compare two critical sustainability attributes, resource conservation and GHG emissions, for similar products made from various materials. An attempt is made in Table 7 to normalize the impacts for material weight, embodied energy, and CO2 emissions for each type of material in an application. Only the cradle-to-installation data was examined because Product Category Rules are not in place yet for each application which would provide impact data over an identical useful life for each material considered. Once the maximum impact for a material in an application was identified, the impacts of the other materials were divided by the maximum to determine a material in a product category that may be more optimal than the others, using the criteria selected. For simplification purposes, only three impacts were studied, but a more thorough assessment would consider as many impacts as the availability of data would make possible. In only one application and one impact does PVC reach the maximum, and that is for weight of DWV pipe. Other considerations come into play in that application, such as chemical and stress resistance that gives PVC an advantage over the life of the application. In the other applications, PVC has some of the lowest impacts and generally has substantially lower impacts than the maximum for that application.

To the extent a given product has any real or perceived environmental issues (and all products have issues) it is good to have LCA studies available to support the good aspects and refute negative perceptions. PVC applications serve many basic human needs, but environmental and health issues associated with the material have received much press and discussion over the years. There is little consensus about the magnitude of some of the perceived risks. Few equivalent questions are asked about alternative materials, which may in fact share the same issues often highlighted for PVC and that could be associated with additional issues and lead to regrettable substitutions. In February 2007, the U.S. Green Building Council PVC Task Group stated in its final report, "No single material shows up as the best across all the human health and environmental impact categories, nor as the worst." [13] As part of their deliberation and research, the task group members expressed concern that guiding decision makers away from PVC could steer them toward using materials that perform worse over their life cycles with respect to the bulk of the impact categories. Similarly, a 2001 Entec and Ecobalance study for the DETR (Department of the Environment Transport and the Regions) study [14] in the United Kingdom and a 2004 study published by the European Commission [15] demonstrated that PVC was no more environmentally unacceptable than the alternatives.

Sustainability Assessments and Information Management

Green building projects continue to be a popular choice in both the public and private sectors. Green certification and assessment systems like Green Building Initiative's Green Globes® and the USGBC LEED® rating systems help to determine the degree to which buildings can be designed to perform better in terms of energy consumption, water use, site utilization, indoor air quality and other measures, aspects that have come to be known as 'whole building sustainability.' Both of these leading rating systems have their supporters, and other rating systems are available. It should be noted that in 2005, GBI became the first green building organization accredited as a standards developer through the American National Standards Institute (ANSI). GBI has since developed the Green Globes for New Construction protocol into the first ANSI standard for green commercial buildings.

The design of the building is not the sole determinant of its sustainability however; the products used to implement the design should also be considered. Therefore it is important for design professionals to be able to understand their options, the choices they ultimately make, and for suppliers to respond by clearly describing the salient sustainability features of their products. So how should design professionals identify the best building product for their projects? How and where can product suppliers communicate sustainability features? As product sustainability information becomes more important to design professionals, manufacturers are under increasing pressure to identify and communicate the sustainability features of their products and materials.

To compound this challenge, the term 'sustainability' means different things to different people and, as a result, industry segments need standards for measuring sustainability features of products. One such tool is the NSF certified sustainability assessment. These standards are developed through an ANSI process that is open, and engages stakeholders and intends to provide transparency into the performance of individual products, their manufacturers (and their distributors in the case of wallcoverings), and establish a consistent and comprehensive approach to the evaluation of environmentally preferable and sustainable products.

Certified sustainability assessments allow designers, specifiers, and consumers to make informed decisions when it comes to understanding and purchasing products. Market segments that put years of effort into recently completed sustainability assessment standards and use PVC in their products include resilient floor coverings, carpet, wallcoverings, and single ply roofing. NSF/ANSI 332 Sustainability Assessment Standard for Resilient Floor Coverings has been approved for floor covering manufacturers to use in certifying resilient flooring products for sustainability attributes. [16] NSF/ANSI 140 Sustainability Assessment for Carpet rates commercial carpet products such as broadloom and carpet tiles. [17] NSF/ANSI 342 evaluates all types of wallcovering products across the entire life cycle of the product, from raw material extraction through end of life disposal. [18] NSF/ANSI 347 Sustainability Assessment for Single Ply Roofing Membranes is the leading consensus standard for evaluating and certifying sustainable attributes for this type of roofing product over their entire life cycle. [19] Each of these standards use point-based systems to achieve various certification levels that include prerequisite requirements as well as performance criteria and quantifiable metrics in five key areas: 1) Product Design, 2) Product Manufacturing, 3) Long-term Value, 4) Corporate Governance and 5) Innovation. NSF/ANSI 332, 140, and 342 also include an additional end of life metrics in their assessment rating while 347 considers end of life as part of the product design metric. Not all product segments and manufacturers have come together to establish sustainability assessment standards similar to what the resilient flooring, carpeting, roofing, and wallcovering industries have done.

Recognizing how confusing all this can be for both designers and suppliers, The Construction Specifications Institute (CSI) has applied their industry experience to develop a solution by providing a format that can help to organize and manage the large amount of sustainability-related product data available to practitioners and producers alike. GreenFormat™ is an information organizing tool developed by members of CSI to communicate the sustainability features of building products. [20] GreenFormat is designed to organize and structure product sustainability information in a manner consistent with other CSI formats such as MasterFormat®. GreenFormat's systematic approach provides manufacturers with a way to communicate not only their product's sustainability features but their company's attributes as well, which will allow design professionals to make informed decisions. Manufacturers of all building products, including those made with vinyl will be encouraged to provide their information to design professionals using GreenFormat.

Conclusion

Over time we have learned that all human activity carries with it a range of environmental impacts. As we become more informed about the ways in which the economic, social and environmental systems of the world work together, the implication for architects, engineers, specifiers, and other design professionals is that sustainability should be assessed across whole life cycles. Well-informed specifiers with a solid foundation in all aspects of what makes building products, systems, and technologies sustainable are in a powerful position to reward manufacturers who share their vision and thereby make good decisions by specifying sustainable, low-impact products.

Therefore, how we select products and services has a significant impact on achieving sustainability. It becomes clear that there are no 'good' or 'bad' materials. There are only more or less sustainable ways to use materials. Because buildings have such a large impact on the environment, the goals of sustainability demand that their impact be reduced, partly through better design, but also through better material choices. The real objective then should be reducing the collective environmental impact of all building materials, so that sustainable design decisions can be made to the greatest beneficial effect.

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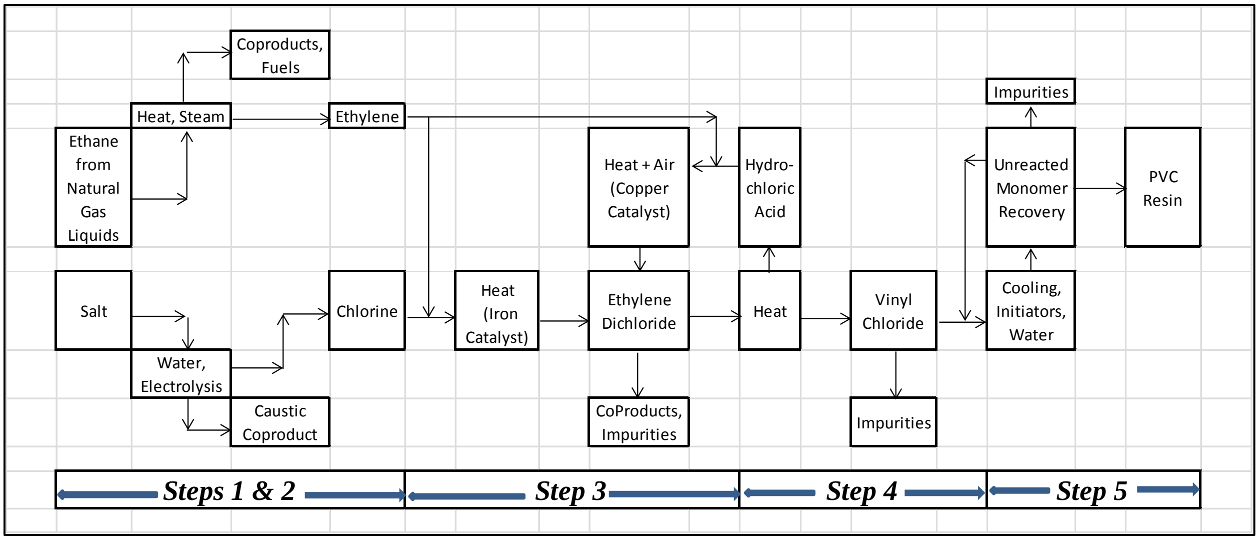

Figure 5: Cradle-to-Resin Flow Diagram of PVC Production

Table 7: Cradle-to-Installation Comparison of Resource Consumption and GHG Emissions for Various Materials used in Building and Construction Applications

Application	Data Source	Functional Unit Description	Material	Weight of Functional Unit Kg	% of Max. Value for Application	Total Embodied Energy MJ	% of Max. Value for Application	Net CO2 Equivalents Emissions g	% of Max. Value for Application
Window	1	1. Residential (1 m^2) 0.61 m x 1.65 m (24" x 65")	PVC	9.76	53%	643	81%	29,906	43%
			Aluminum	6.93	38%	576	73%	70,323	100%
			Wood	18.31	100%	793	100%	2,915	4%
Cladding	2	2. Residential 0.093 m^2 (1 ft^2)	PVC	0.18	1%	12	19%	552	12%
			Aluminum	0.15	1%	13	20%	1,538	34%
			Wood	0.53	3%	23	37%	85	2%
			Brick	15.76	100%	63	100%	4,513	100%
			Fiber Cement	1.45	9%	22	34%	2,391	53%
Pipe - Entrance	3	3. Residential 9.1 m x 25 mm (30 ft. x 1" diam.)	PVC	4.45	39%	253	65%	11,032	43%
			Copper	11.44	100%	390	100%	25,651	100%
			Polyethylene	2.18	19%	179	46%	5,403	21%
Pipe - DWV	3	4. Residential 409 m^2, (4,402 ft^2) 112.8 m, (370 ft)	PVC	208.46	100%	13,293	75%	597,010	86%
			ABS	160.25	77%	17,724	100%	698,252	100%
Pipe - HCWD	3	5. Residential 409 m^2, (4,402 ft^2) 168.6 m, (553 ft)	CPVC	33.99	34%	2,289	65%	107,598	47%
			PEX w/brass	29.96	30%	2,796	80%	113,954	50%
			Copper	101.45	100%	3,503	100%	227,454	100%
Flooring	4	6. Composite 0.09 m^2, (1 ft^2)	PVC	0.61	24%	22	58%	1,141	42%
			Linoleum	0.27	11%	29	77%	1,042	39%
			Ceramic Tile w/recycled glass	2.53	100%	32	84%	2,641	98%
			Terazzo	2.22	88%	38	100%	2,698	100%

1. Functional Unit from NFRC report [22], weight from Assoc. Labs unit profile Info. [23], energy and CO2 scaled from NIST BEES Siding Energy and Siding Data [21]
2. NIST BEES Siding Data [21], Wood siding Western Red Cedar Association weight data (24)
3. PPEF LCI Report [25]
4. NIST BEES Flooring Data [21]