

BETTER BUILDING MATERIALS

UNDERSTANDING HUMAN HEALTH
AND ENVIRONMENTAL ATTRIBUTES



BETTER BUILDING MATERIALS: UNDERSTANDING HUMAN HEALTH AND ENVIRONMENTAL ATTRIBUTES

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ABBREVIATIONS.

BADGE	bisphenol A diglycidyl ether
BIFMA	Business and Institutional Furniture Manufacturers Association
BPA	bisphenol A
CARB	California Air Resources Board
CAS	Chemical Abstracts Service
CBI	confidential business information
CDC	Centers for Disease Control and Prevention
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFC	chlorofluorocarbon
CFL	compact fluorescent lightbulb
CO₂	carbon dioxide
CSR	corporate sustainability report
DDT	dichlorodiphenyltrichloroethane
EB	Existing Buildings (a LEED rating system)
EPA	U.S. Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
EPD	environmental product declaration
EPEAT	Electronic Product Environmental Assessment Tool
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FRP	fiber-reinforced polymer
GHS	Globally Harmonized System (for classification and labelling of chemicals)

HFR	halogenated flame retardant
HPD	Health Product Declaration
HVAC	heating, ventilation, and air-conditioning
IARC	International Agency for Research on Carcinogens
IBC	International Building Code
IGCC	International Green Construction Code
IMDS	International Material Data System
ISO	International Organization for Standardization
LCA	life cycle assessment
LD₅₀	median lethal dose
LED	light-emitting diode
LEED	Leadership in Energy and Environmental Design
MDF	medium-density fiberboard
MR	Materials and Resources (a LEED credit category)
MSDS	material safety data sheet
NO_x	nitrogen oxides
OIA	Outdoor Industry Association
OSHA	Occupational Safety and Health Administration
PBDE	polybrominated diphenyl ether
PBT	persistent, bioaccumulative, and toxic
PCB	polychlorinated biphenyl
PCR	product category rule
PEL	permissible exposure limit

PFC	perfluorinated chemical
PPE	personal protective equipment
PV	photovoltaic
PVC	polyvinyl chloride
RCRA	Resource Conservation and Recovery Act
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RSL	restricted substances list
SCAQMD	South Coast Air Quality Management District
SDS	safety data sheet
SO_x	sulfur oxides
SPF	spray polyurethane foam
SVHC	substance of very high concern
SVOC	semivolatile organic compound
TCE	trichloroethylene
TDCPP	tris(1,3-dichloro-2-propyl) phosphate
TLV	threshold limit value
TRI	Toxics Release Inventory
TSCA	Toxic Substances Control Act
UNEP	United Nations Environment Programme
v4	version 4 (LEED)
VOC	volatile organic compound
WEEL	workplace environmental exposure level

EXECUTIVE SUMMARY.

The built environment is the stage for our lives. Materials make that built environment possible, and collectively, the effects of millions of materials choices have massive consequences for the ecosystem and human health at local, regional, and global scales.

The breadth of materials-related issues extends far beyond familiar factors, such as aesthetics, cost, durability, availability, performance, emissions of volatile organic compounds (VOCs), or the percentage of recycled content. Increasingly, we understand that materials choices are complex and multifaceted, affecting the health of manufacturing and construction workers and building occupants, and the sustainability and quality of natural resources across the life cycle of each building product.

For most building professionals, the array of considerations is daunting, and navigating the issues requires new knowledge and skills. This guide defines the core information—including fundamental issues, major tools, and best practices—needed by the professionals who specify and procure building products to understand the consequences of building materials for human health and the environment. This knowledge will empower project teams and related professionals, such as facilities managers, product designers, manufacturers, and scientists, to take leading roles in using materials selection to promote human health and protect the environment.

EVOLUTION OF GREEN BUILDING PERSPECTIVES ON MATERIALS

Selecting “preferable” materials—those with desirable human health and environmental attributes that deliver comparable or improved function, durability, and maintainability—has always been an important component of green building. Until recently, the focus within green building rating systems like the U.S. Green Building Council’s Leadership in Energy and Environmental Design™ (LEED) was on single attributes, such as recycled content, locally sourced materials, and VOC content, covering a limited part of the materials life cycle.

Growing understanding of the health and environmental impacts of materials, as well as better access to tools and data, has allowed LEED to pursue an alternative approach. This is reflected in LEED v4 by new Materials and Resources credits that emphasize information disclosure and materials optimization. The new credits will enable project teams to choose preferable products based on more robust, multifaceted information, including ingredient lists, human health hazards, and environmental impacts across the life cycle of materials, and they provide incentives for manufacturers to improve their products.

ENVIRONMENTAL AND HUMAN HEALTH CONSEQUENCES OF BUILDING MATERIALS

A systems-based, life cycle approach to the selection of building materials requires an appreciation for the human health and environmental consequences of materials choices beyond the operational phase of a project. Building professionals must consider implications from each life cycle stage, aggregate information from multiple sources, and apply the resulting knowledge to make better decisions in the context of myriad practical constraints. This requires them to have a working understanding of the underlying concepts and issues.

The contents of building materials are extracted from a variety of natural resources and transformed into products through manufacturing processes that use large amounts of energy and water and emit pollutants to the air, water, and soil. Because systems are nested, impacts on one part of the environment often propagate to others. These impacts can be local or global and short- or long-lived. They can affect the air and atmosphere, water, soil and land, natural resource availability, and habitat and biodiversity. Each stage of the materials life cycle—raw materials extraction and processing, manufacturing, construction and installation, use and maintenance, and end of life—presents an opportunity to mitigate these impacts.

In addition, building materials are increasingly recognized as a significant source of chemical exposures to building occupants, as well as to those who come in contact with these materials or their raw ingredients through manufacturing, construction, installation, and recycling, reuse, or disposal. The chemical contents of building materials are virtually all new in the past seven decades, and some can be linked to increased incidence of chronic diseases, such as asthma, diabetes, and certain types of cancer. Rather than being static or inert, building materials release their constituent chemicals into workplaces, ecosystems, water sources, and food chains. People are exposed to chemicals in building materials via air, food, water, and even dust and skin contact. Although some health consequences of chemical exposure, like skin irritation, are short-lived, others, such as cancer or neurodevelopmental effects, have implications for a lifetime.

TOOLS FOR CHANGING THE BUILDING MATERIALS MARKET

Project teams often lack the information about human health and environmental attributes of materials they need to make informed product decisions. Consequently, these attributes cannot be factored into decisions, contributing to the misallocation of capital (e.g., purchasing inferior products when superior substitutes are available) and unanticipated exposures to hazards.

The current situation arose in part because of the patchwork nature of policies affecting building materials, which has left various aspects of life cycle impacts under- or unregulated. U.S. policies aimed at protecting air, water, and land, as well as consumers' health and safety, tend to be fragmented and poorly coordinated and do not provide a holistic and nuanced consideration of relative hazard, exposure, and risk. Policy gaps are natural places for leadership in improving building materials.

The green building movement seeks to improve and accelerate change in the status quo by defining a goal for superior performance, then implementing a series of targeted interventions that enable markets to function efficiently by systematically addressing information gaps and internalizing costs and impacts. These interventions include reporting, evaluation, preferential selection, and innovation coupled with awareness, education, and advocacy. If successfully applied to building materials, these interventions will contribute directly to a transformed market with products that are optimized for human health and environmental attributes.

Timely and relevant information disclosure on materials options and implications is a first step to improving decision making. Disclosure can provide even greater benefits when the reported information is evaluated and distilled into actionable recommendations or judgments, such as third-party labels or certifications. The results of such evaluations allow decision makers to differentiate among products and select those matching their values and requirements. However, the extent of disclosure and level of evaluation for products vary considerably, and it is important for project teams to understand this landscape, including strengths and limitations in the provision and interpretation of building product information. Fortunately, a practical toolkit is emerging to serve this purpose.

Life cycle-based environmental tools, such as life cycle assessment (LCA) and environmental product declarations (EPDs), are grounded in a holistic approach that includes multiple attributes and impacts and covers the entire life cycle of a product. LCA quantifies the inputs and outputs from all life cycle stages and identifies their potential impacts or burdens on the environment. Product-level LCA is used to identify and quantify potential impacts that occur throughout a product's life cycle; whole-building LCA tools enable project teams to explore interactions among building systems and develop optimal combinations of materials and assemblies, as well as compare entire building designs and the impacts of a new building with renovation of an existing building. EPDs distill the findings from the LCA and, by describing environmental characteristics in a consistent way, help product teams compare products and make informed decisions.

In recent years, increased demand for information about the human health attributes of materials has created the need for more robust and standardized methods for assessing, distilling, and reporting health information. For instance, the Health Product Declaration® Open Standard is a disclosure tool, providing a standardized format for reporting building product contents and their known associated hazard data. The GreenScreen® for Safer Chemicals, a hazard assessment method for individual ingredients and more complex mixtures, helps manufacturers prioritize chemicals of concern and plan for phaseout or find alternatives. Cradle to Cradle Certified™, another program with a health-focused component, is a multiattribute standard that promotes continuous improvement in a product through five levels of certification. The European Union's REACH regulation also plays a role by addressing substances of very high concern that are being considered for regulation requiring authorization for some or all uses.

Although each of these tools and programs provides some information about some products, none can be considered a complete resource. Over time, practitioners can expect these tools to improve and become more coordinated and aligned.

MATERIALS OPTIMIZATION AND INNOVATION

Both project teams and manufacturers play important roles in improving the status quo. As the designers and makers of products, manufacturers have a clear responsibility to optimize their processes and ingredients for human health and environmental protection. At the same time, building practitioners, as the consumers of these products, can drive optimization and innovation by demanding more robust product disclosure and evaluation and by preferentially selecting products designed with improved human health and environmental attributes in mind.

LEED v4 aims to accelerate this process by helping to reorient materials design and selection from a reactive approach that addresses problems as they arise to a proactive approach that encourages inherently safer life cycle design and product specification. This convergence of interests around preferable materials provides an opportunity to bring together the expertise of manufacturers, project teams, and scientists around common goals of healthful, environmentally preferable, high-performing, and cost-effective materials. Several scientific and technological concepts and processes support this goal, such as cleaner production and alternatives assessment, which underlie strategies such as reformulation, redesign, and new materials discovery.

FUTURE OUTLOOK

The building industry is not alone in driving improved materials and products. Most sectors have established restricted substances lists, and some have created approaches and tools to collect chemical information, evaluate substitutes, and measure progress toward more preferable chemicals and materials. Greater public pressure, increased focus on supply chain impacts, regulatory reform, enhanced intra- and cross-sectoral collaboration, and new analytical tools will increase access to materials information and improve products in multiple sectors.

Although the movement toward more sustainable building products is far from complete, the building industry and allied industries have made progress. The past two decades have seen a significant increase in scientific, government, industrial, and consumer concern about the human health and environmental impacts of materials and products across multiple industries. These concerns have led manufacturers to develop products that avoid or reduce impacts.

The efforts currently under way to increase materials information and improve products in multiple sectors have created momentum that will drive future change and, ultimately, superior products benefiting people and the environment. Realizing this vision for the future will require the combined efforts of all stakeholders—from manufacturers, engineers, and construction workers to architects, specifiers, contractors, and building owners. We hope this guide will empower you to take on a greater role in the ongoing efforts to enhance the human health and environmental aspects of our shared built environment.

INTRODUCTION.

Vision for this guide

This guide defines the core information that building project teams need to know to understand the consequences of building materials for human health and the environment. This knowledge will empower practitioners to explicitly consider the health and environmental attributes of building materials during building design, construction, operation, and demolition. Thoughtful consideration of these factors will contribute to buildings and communities that benefit people and the environment.

MATERIALS CHOICES MATTER

The built environment is the stage for our lives. According to the U.S. Environmental Protection Agency, we spend 90% of our time—living, learning, working, playing—indoors.¹ The construction, operation, and disposal of our shared built environments contribute to a large fraction of world economic activity and have both positive and negative effects on human health and the environment.

Materials make our built environment possible, and the resources required and processes used to create those materials affect our ecosystems—communities of flora and fauna and the land, air, and water on which they depend—and ourselves. Each materials choice makes a difference, and collectively, the effects of millions of choices have massive consequences at local, regional, and global scales.

Decisions about building materials go far beyond aesthetics, finish, function, and cost. They also have direct implications for:

- the health of manufacturing workers, construction teams, and building occupants;
- the sustainability of the natural resources required to extract, refine, transport, process, install, use, and ultimately recycle or dispose of building products; and
- the quality of natural resources, including air, water, soils, and ecosystem services, across the life cycle of each building product.

The breadth of these issues extends far beyond familiar, single factors, such as emissions of volatile organic compounds (VOCs) or the percentage of recycled content. Increasingly, we understand that materials choices are complex and multifaceted, with considerations spanning multiple spatial dimensions (buildings, regions, ecosystems) and temporal scales (minutes, years, decades).

¹ Report to Congress on indoor air quality, vol. 2, EPA/400/1-89/001C (Washington, D.C.: U.S. Environmental Protection Agency, 1989).

For most building professionals, the array of considerations is daunting, and navigating the issues requires new knowledge and skills. This guide will help build a foundation of understanding about the fundamental issues, major tools, and best practices needed to help bring the consideration of human health and environmental attributes into the materials selection process. This knowledge will empower project teams to take leading roles in using materials selection to promote human health and protect the environment across the entire life cycle of a building.

CURRENT STATE OF BUILDING MATERIALS PRACTICE

Over the past several decades, buildings have become intricate systems composed of hundreds or thousands of materials, many of them produced from complex, resource-intensive manufacturing processes. The incredible proliferation and diversification of building materials and manufacturing techniques have helped the industry create relatively safe, comfortable built environments. However, these modern materials and buildings come at a cost. We can no longer intuitively understand the nature of most commercial building materials. Moreover, the scope of the industries involved in planning, design, construction, operations, and demolition long ago reached the point at which the cumulative impact of decisions made on thousands of projects has global implications for human health and the environment.

Most people do not give much thought to what buildings are made of and how materials are chosen. Building professionals, however, make several major materials decisions (e.g., concrete versus steel structure) and many small choices (e.g., tile versus laminate flooring) for each building. Such decisions are often based on aesthetic and functional requirements, like color, texture, strength, and durability. Information about these attributes is readily available for any building product. The green building movement has motivated project teams to consider basic human health and environmental information as well, like VOC emissions, recycled content, and local sourcing. However, these isolated, single-factor considerations leave many issues unaddressed. Ensuring human health and protection for the environment across a material's life cycle involves much deeper and broader considerations.

The challenges related to materials selection are important, but specific solutions are often unclear because of the complexities of supply chains, building life cycles, and the underlying science. There are almost always trade-offs to consider (e.g., between embodied energy and chemical toxicity), missing scientific information (e.g., the absence of toxicology data), and limited ingredient information (e.g., the inability to obtain complete data from complex, multitier supply chains).

The result is an inadequate supply of timely, relevant, actionable information. At the same time, demand for this critical information is weak because decision makers across the supply chain are unfamiliar with the consequences of their choices. The deficiencies in both supply and demand mean that the market fails to systematically account for human health and environmental impacts associated with building materials.



Asbestos and lead paint are well-documented hazards to human health.
Courtesy: Brasil2/Getty Images (top); westphalia/Getty Images (bottom)

OPPORTUNITIES TO IMPROVE MATERIALS CHOICES

We know from experience that the selection and specification of building materials can contribute to either tangible benefits or significant economic, health, and environmental risks. Wood, stone, and brick illustrate beneficial choices: these are beautiful, durable, nontoxic materials with low life cycle environmental impacts, used in many historic structures that have served generations.² Lead in paint,³ asbestos,⁴ and VOCs,⁵ on the other hand, are familiar examples of how the absence of information about human health and environmental attributes can lead to unintended consequences. Each of these substances had a well-intended functional purpose, yet information about the product's human health and environmental harms came to light only after widespread use.

Information about the human health and environmental attributes of building materials matters—and its absence represents a failure of the market to value these attributes. A similar market failure, involving energy efficiency, is already being addressed by the green building movement. Leadership in Energy and Environmental Design™ (LEED) certifications and ENERGY STAR® labels helped to remedy a lack of information on absolute and relative energy efficiency

that would enable buyers to choose green buildings or differentiate relatively high performers. By increasing the supply of information about energy performance, LEED and ENERGY STAR make it possible to identify energy-efficient properties, and now, after nearly two decades, buildings with these labels are in demand: they command higher rents and sales prices and have better tenant retention. The effort is nowhere near complete, however, and it requires diligence from a broad coalition to build on this success and promote the availability of relevant, actionable information on energy-efficient buildings.

2 L.M. Gil-Martin et al., Toward the production of future heritage structures: Considering durability in building performance and sustainability—A philosophical and historical overview, *International Journal of Sustainable Built Environment* 1 (2012): 269–73.

3 E. Gould, Childhood lead poisoning: Conservative estimates of the social and economic benefits of lead hazard control, *Environmental Health Perspectives* 117 (2009): 1162–67.

4 D. Gee and M. Greenberg, Asbestos: From “magic” to malevolent mineral, in Late lessons from early warnings: *The precautionary principle 1896–2000*, Environmental Issue Report 22 (European Environment Agency, 2001), 52–63.

5 G. Maddalena et al., Formaldehyde and other volatile organic chemical emissions in four FEMA temporary housing units, *Environmental Science and Technology* 43 (2009): 5626–32.

We can envision a similar trajectory for increasing transparency and driving innovation in building products. Today, specifiers in most developed countries commonly select products with low VOCs and high recycled content, yet both the supply of and the demand for more comprehensive information about the full life cycle effects of building products are insufficient. We can do better. The challenge is to understand the roots of this situation and take coordinated action to create built environments with benefits for and reduced risks to people and the ecosystem by:

- making human health and environmental information more accessible and relevant;
- integrating human health and environmental considerations into decision making;
- designing products with intrinsically preferable attributes throughout their life cycles; and
- promoting the specification of such products.

PURPOSE OF THIS GUIDE

The green building community can play a role in transforming the market for products that improve human health and environmental outcomes. This guide aims to aid that goal by building awareness of the concepts underlying multiattribute approaches and life cycle thinking about materials. It is not a how-to guide. Rather, it describes the core knowledge needed to make the consideration of human health and environmental issues a systematic part of building materials specification, purchasing, and use. Armed with health and environmental information and the knowledge to interpret that information, building project teams will be able to consider these dimensions during building design, construction, operations, and demolition.

This guide will be particularly useful to the community of professionals who specify and procure building products, including building designers, architects, specifiers, engineers, contractors, facility managers, and facility planners. Other members of the green building community will also find it useful, including product designers and manufacturers, scientists, and individuals responsible for analyzing, documenting, and communicating the human health and environmental characteristics of building products.

The guide is only the beginning of an education on the issue: it introduces the fundamental ideas and provides references to sources of additional information. It emphasizes policies and market conditions in the United States while recognizing that conditions vary widely in other parts of the world. Building professionals may not have the training, incentives, or time to devote to the underlying science—and all the data, ecolabels, policies, and tools in the marketplace can complicate rather than facilitate their research on building products. Consequently, the guide focuses on principles and actionable information.

OVERVIEW

[Chapter 1](#) introduces the history of thinking about materials as they relate to human health and the environment. This includes the evolution toward multiattribute, life cycle considerations that underpin current tools, notably the LEED rating systems of the U.S. Green Building Council.

[Chapter 2](#) highlights human health and environmental impacts across the life cycle of the built environment, with emphasis on their breadth and importance.

[Chapter 3](#) describes the green building movement's theory of change, the role of policy, and the concept of market transformation through a cycle of disclosure, evaluation, preferential selection, and innovation. It also introduces the tools of life cycle assessment, environmental product declarations, materials health assessments, and Health Product Declarations.

[Chapter 4](#) takes the selection and innovation discussion a step further by explaining the principles and goals of materials optimization and innovation and associated approaches. It also highlights examples of how other industries are tackling similar issues as they address human health and the environment.

[Chapter 5](#) provides personal perspectives: insights from each of the guide's main authors, and [Chapter 6](#) consists of case studies from leading practitioners and manufacturers on how they are using human health and environmental information.

Resource lists are available at the end of each chapter, and at the end of the guide readers, will find a [glossary of terms](#).

1.

CHAPTER 1. EVOLUTION OF GREEN BUILDING PERSPECTIVES ON MATERIALS

- How does materials selection contribute to the broader green building movement?
- How have Leadership in Energy and Environmental Design (LEED) rating systems addressed materials in the past?
- What is new for materials in LEED version 4 (v4) and why were these changes made?
- How will LEED v4 drive change in the building industry?
- What do these changes mean for a building project team? For a manufacturer?

From the time of stone, bronze, and iron, the relationship between humans and building materials has reflected our history and culture. The materials we use and the buildings we construct tell the story of who we are and what we value. Advances in science and technology, beginning with the industrial revolution and mechanized production, have allowed us to engineer materials to meet our needs in unprecedented ways. New materials with new capabilities have increased levels of performance but also raised questions:

- What is this new building material made of, where did it come from, and what are its properties? One can't tell just by looking at it.
- What are the sources of its ingredients? Its contents may be difficult to trace.
- What happens if one touches it, ingests it, burns it, combines it with another material, or pulverizes it? The answers have implications for human health and the environment.
- How do its production, use, and disposal affect the local and global environment? The potential harms of complex products with components sourced from global supply chains are hard to identify.

Answering those questions—and ultimately acting on the answers—requires new professional knowledge, new tools, and in some cases, new decision-making processes. We need the skills and wisdom to ensure that materials selected for building projects reflect our values and aspirations, as well as functional, aesthetic, and financial goals.

CHANGING PERSPECTIVES ON BUILDING MATERIALS

Over the past 25 years, the building industry has been rewriting the conventions used to design, construct, and operate buildings and neighborhoods. With growing understanding of the ramifications of the built environment, both positive and negative, building designers and operators and product manufacturers and their suppliers have collaborated to expand and improve the available information about buildings and use it to transform decision making.

Selecting “preferable” materials—those with desirable human health and environmental attributes that deliver comparable or improved function, durability, and maintainability—has always been an important component of green building. In the early 1990s, the American Institute of Architects published detailed materials reports in its *Environmental Resource Guide*,¹ and BuildingGreen’s *Environmental Building News* began more than 20 years of reporting on materials and other topics. From the beginning, the focus was not just on environmental attributes of materials but also on human health aspects, particularly as sick building syndrome became an issue with new and renovated buildings, including the U.S. Environmental Protection Agency (EPA) headquarters at Waterside Mall in Washington, D.C.²

Green building certification systems, which were developed in North America and Europe in the late 1980s and 1990s, sought ways to accelerate efforts to promote preferable materials. The earliest versions of the LEED rating systems contained credits on topics like recycled content, locally sourced materials, salvaged and reused materials, and low-emitting materials. Over time, details of the credits were refined, but the topics they addressed remained stable until [LEED v4](#).

LEED v4 significantly shifted the [Materials and Resources \(MR\) credits](#) to encourage a more complete picture of materials and their impacts on human health and the environment across their life cycles. The new credits will enable project teams to choose preferable products based on more robust, multifaceted information, and they provide incentives for manufacturers to improve their products.

These shifts were made for several reasons:

- Previous versions of the MR credits dealt with limited materials information, which made it challenging for project teams to fully consider the impacts of their choices. A locally sourced product might not be as durable as one from a more distant company, or a recycled product might contain hidden hazardous ingredients.
- Single attributes referenced in previous MR credits were proxies, or stand-ins, for desired outcomes. For instance, materials with recycled content were assumed to reduce impacts from raw materials extraction and waste disposal, and locally sourced materials were assumed to reduce transportation impacts and promote local economies. These assumptions are reasonable in many circumstances; however, they were not rigorously tested for specific materials and products.
- Previous credits did not adequately address human health attributes. Although volatile organic compounds (VOCs) have been addressed since the first version of LEED, the systems to address many other potentially harmful substances did not yet exist.
- Tools and data have developed and become more widely available, allowing LEED to pursue an alternative approach.

¹ <http://www.aia.org/practicing/groups/kc/AIAS077347>.

² <http://www.epa.gov/region1/enforcement/fedfac/iaqbroc.html>.

Before addressing the details of the credits, it is important to understand the conceptual shifts they seek to drive:

- from single-attribute to multiattribute assessments;
- from snapshots in time to life cycle thinking; and
- from work in discrete silos to systems thinking.

FROM SINGLE ATTRIBUTES TO MULTIPLE ATTRIBUTES

LEED v4 shifts the focus from single human health or environmental attributes of materials, such as recycled content, to approaches that consider multiple health and environmental attributes at once. Project teams already make multiattribute decisions when they compare products based on aesthetics, cost, durability, availability, and performance. The new LEED credits promote adding multifaceted health and environmental attributes to this mix. The credits also reference tools that support teams in weighing these new attributes and incorporating them into materials specification decisions.

FROM SNAPSHOTS IN TIME TO LIFE CYCLE THINKING

Life cycle thinking³ is a core green building concept that involves consideration of the entire life of a product, not just a single snapshot in time. It begins with extracting and refining raw materials, encompasses all stages of fabrication and manufacturing, installation, use, and maintenance, extends to final disposal, reuse, or recycling, and includes transportation and energy consumption throughout these stages (Figure 1-1). This type of thinking is sometimes called “cradle to grave,” to indicate the whole “life” of the product, or “cradle to cradle,” to emphasize recycling and reuse.

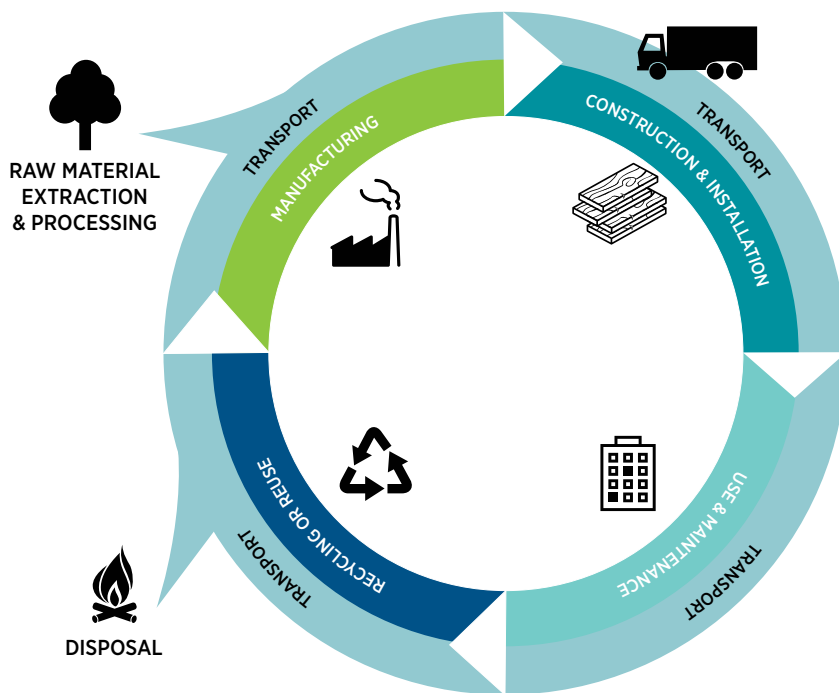


Figure 1-1. Materials life cycle

³ Life cycle thinking is a conceptual framework that all building professionals should be familiar with. It is different from life cycle assessment, which is a formal process (see Section 3.4).

Life cycle thinking enables consideration of human health and environmental consequences across all life cycle stages. This mindset is particularly important because the most critical impacts might occur outside the traditional perspective of the project team or product manufacturer, such as at the point of raw material extraction or end of life. The scope and complexity of product attributes may appear daunting, but understanding the materials life cycle will enable project teams to compare products and select those with superior characteristics overall.

LIFE CYCLE ASSESSMENT

Life cycle thinking is an informal thought process for considering all of a material's impacts across all phases of its life cycle. *Life cycle assessment* is a standardized process to quantify this information. Comprehensive, multicriteria LCA thus contrasts with single-attribute approaches that indicate only the presence or absence of particular ingredients or characteristics. It identifies processes and their associated inputs (e.g., energy, water, materials) and outputs (e.g., wastes, by products), from the earliest stages of materials production through the end of a product's service life. LCA quantifies these inputs and outputs and calculates their potential impacts on the environment and human health. LCA cannot address all possible impacts, however, and it is currently more effective in quantifying potential environmental impacts than human health impacts.

LCAs can be performed for individual products or whole buildings. Product-level LCAs are typically performed by manufacturers and enable comparisons of materials. Whole-building LCAs are generally done by individuals with expertise in building science to enable optimization of structural and enclosure systems. In either case, LCA is data intensive and generally requires specific training and experience.

LCA methods and standards have been developed by international organizations to ensure objectivity, quality, and comparability among results. Additional information on LCA is presented in Section 3.4.

FROM SILOS TO SYSTEMS

In the design and development process used over the past century, a building was treated as a set of parts—shell, heating and cooling systems, interior, landscape—each designed, constructed, and maintained by different practitioners far too often working independently in separate, specialized silos. The silos have created efficiencies but also inefficiencies. For example, an HVAC engineer who has information on the building envelope but not on the lighting plans (which affect heat load) may specify incorrectly sized equipment that will not perform well.

The green building movement increasingly appreciates that buildings are more than standalone entities composed of lots of parts; they are nested sets of interconnected systems. By integrating not only the various parts of the building but also the building itself into its larger context of location, function, and interaction with people and infrastructure, practitioners can identify and

address inefficiencies and externalities and create places that promote human health and protect the environment. Materials choices can support the project's health and environmental goals and create a place that connects to local culture and values.

THE MASTER BUILDER

“Master builders were schooled through local apprenticeships, and the techniques and technologies they learned were developed from an understanding of local issues and passed down through generations. Mechanized transportation was limited, so people possessed an intimate knowledge of local materials as well as workforce skills, economies, cultural imagery and traditions, microclimates, and soil conditions. They understood the flow of local resources and what local conditions could be limiting. The built environment was designed and constructed from a deep connection to each individual place. . . . What resulted were buildings and communities that truly were integrated with their environment and that lived, breathed, and grew to become timeless elements of their place.”

— *The Integrative Design Guide to Green Building*, 7 Group and Bill Reed, p. 1

By understanding the interconnections among materials and systems, project teams can be more strategic, solving for multiple goals at once in a cost-effective way. Often there are opportunities to reimagine or redesign systems in ways that reduce or eliminate the use of potentially hazardous and environmentally damaging materials while supporting the local infrastructure.

The LEED rating systems assume that there is no single “right” solution. Rather, there are better and worse choices of materials and other systems, depending on how a project team prioritizes a series of interconnected outcomes. LEED credits and prerequisites aim to establish market conditions that give teams the tools and information they need to evaluate choices.

MATERIALS AND RESOURCES IN LEED v4

The new LEED v4 MR credits are intended to create change at two scales:

- **PROJECT SCALE.** LEED v4 encourages project teams to go beyond single-attribute thinking, learn more about materials, and make more intentional decisions based on information about the human health and environmental attributes across a material's life cycle. These decisions address the selection of preferable products as well as promote the use of less material or no material at all (e.g., if finishes are not needed).
- **INDUSTRY SCALE.** LEED v4 creates an incentive for manufacturers to disclose product ingredients and their associated human health, environmental, and ecosystem impacts and to optimize their products to reduce negative impacts.

The life cycle approach to the evaluation of building products and whole buildings taken by LEED v4 seeks to identify and, when possible, fill gaps in available information. LEED also recognizes important limitations of existing life cycle assessment (LCA) tools. Currently, LCAs of building products do not provide robust information associated with two key areas:

- ecosystem impacts of raw materials extraction; and
- human health impacts of materials ingredients.

In addition, the insufficiency of data to inform decisions is a problem across all facets of building product manufacture and use.

To compensate for these blind spots and information gaps, LEED v4 augments the LCA approach with credits that address materials extraction and human health, recognize release of information by manufacturers, and reward use of this information by project teams to select products with improved human health and environmental attributes (Figure 1-2).

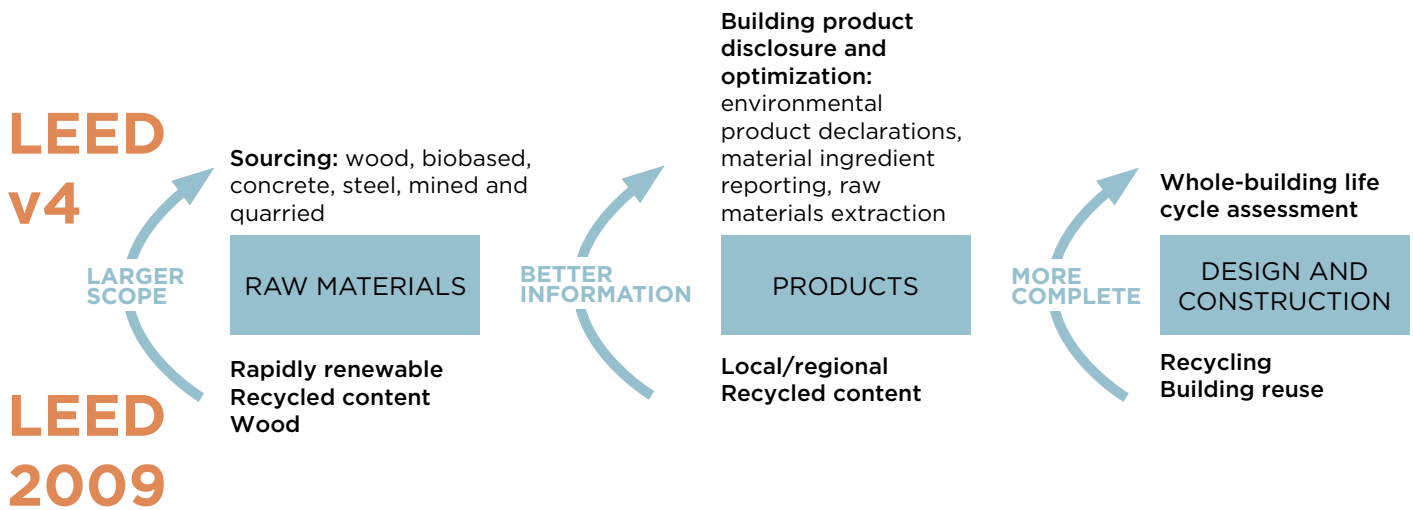


Figure 1-2. Summary of updates to MR credits in LEED v4
 Courtesy: U.S. Green Building Council

LIFE CYCLE–BASED MATERIALS AND RESOURCES CREDITS IN LEED v4

BUILDING LIFE CYCLE IMPACT REDUCTION

To encourage adaptive reuse and optimize the environmental performance of products and materials. Project teams must demonstrate reduced environmental effects during initial project decision-making by reusing existing building resources or demonstrating a reduction in materials use through whole building life cycle assessment.

BUILDING PRODUCT DISCLOSURE AND OPTIMIZATION—ENVIRONMENTAL PRODUCT DECLARATIONS

To encourage the use of products and materials for which life cycle information is available and that have environmentally, economically, and socially preferable life cycle impacts. Project teams are rewarded for selecting products from manufacturers who have verified improved environmental life cycle impacts.

BUILDING PRODUCT DISCLOSURE AND OPTIMIZATION—SOURCING OF RAW MATERIALS

To encourage the use of products and materials for which life cycle information is available and that have environmentally, economically, and socially preferable life cycle impacts. Project teams are rewarded for selecting products verified to have been extracted or sourced in a responsible manner.

BUILDING PRODUCT DISCLOSURE AND OPTIMIZATION—MATERIAL INGREDIENTS

To encourage the use of products and materials for which life cycle information is available and that have environmentally, economically, and socially preferable life cycle impacts. Project teams are rewarded for selecting products for which the chemical ingredients in the product are inventoried using an accepted methodology and for selecting products verified to minimize the use and generation of harmful substances. Raw materials manufacturers are rewarded for producing products verified to have improved life cycle impacts.

For more information on LEED v4 credits, see <http://www.usgbc.org/credits/new-construction/v4>.

CATALYZING IMPROVEMENT AND INNOVATION

LEED is a tool for market transformation, empowering project teams to create better buildings and communities. As part of this process, LEED gives a competitive advantage to materials with superior human health and environmental attributes.

For example, because LEED credits have historically encouraged the use of materials with particular health and environmental attributes, such as low-emitting finishes or recycled content, project teams responded by asking manufacturers to verify their products' characteristics.

The demand for information has not only encouraged manufacturers to document and report on the attributes of their materials, it has also spurred them to develop materials with better performance (Figure 1-3).

This cycle has resulted in new products with desirable characteristics:

- reflective roofing and paving materials;
- salvaged, reused, and recycled materials;
- locally produced materials;
- rapidly renewable materials;
- sustainably extracted materials; and
- low-emitting materials.



Figure 1-3. Market transformation cycle

The LEED v4 credits are built on two market transformation concepts that are the foundation of the process illustrated above:

- **DISCLOSURE:** reporting by manufacturers about product ingredients or impacts to the public or to third parties.
- **OPTIMIZATION:** use of this information by project teams to select preferable materials and products, and by manufacturers to improve materials and products.

DISCLOSURE

Perhaps the greatest problem facing project teams seeking to build and operate buildings that are more healthful and have less harmful environmental impacts is lack of information. Manufacturers commonly provide some information through material safety data sheets (MSDSs). These documents include certain information required by law and any additional data selected by the manufacturer. This information can be useful but is often inconsistent and does not systematically cover human health and environmental attributes. Addressing this lack of information is the first component of three new v4 credits.

To support disclosure, two credits in LEED v4 promote the use of the environmental product declaration (EPD) and the Health Product Declaration® (HPD) Open Standard. These tools are described briefly here and in more detail in Sections 3.4 and 3.5. Both require manufacturers to provide standardized information about their products so that project teams and others can compare products based on the same set of environmental and health information.

EPDs are based on the results of LCAs performed in accordance with international standards for data requirements and communication of data. EPDs address the potential impacts of a product's life cycle in categories such as global warming potential, acidification potential, and ozone depletion potential. They have been used in Europe and elsewhere for years in building certification systems and consumer product information.

HPDs report on product contents and each ingredient's relationship to the bigger picture of human health. HPDs are not based on life cycle thinking or LCA, as they address only the contents of the final product in its use phase. The HPD is a relatively new tool, so the specific information it provides is continuing to evolve. The Health Product Declaration Collaborative, which manages the HPD, will release an updated version of the format in mid-2015.

Neither of these tools adequately addresses issues of raw materials extraction. LEED v4 therefore also gives credit for using products from manufacturers that obtain and publish reports from their raw materials suppliers. Each report must verify the extraction location and commit the supplier to long-term, ecologically responsible land use; reduction in environmental impacts from extraction and manufacturing processes; and achievement of applicable standards or compliance with voluntary programs with responsible sourcing criteria.

OPTIMIZATION

Reliable, standardized data on building materials enable other key steps that lead to materials optimization. At the project level, tools distill this new information and help project teams consider

trade-offs among different products and the best “mix” of products, since it is rare for one product to perform best on all health and environmental aspects. These tools help teams identify products that are optimized for human health and environmental aspects—that is, they have the best performance, given a project’s goals. At the manufacturer level, optimization takes place in product development efforts, as companies respond to demand for products with these preferable attributes and performance characteristics. Of course, optimization is an ongoing process. As new products that are safer and more environmentally friendly reach the market, the cycle of reporting, evaluation, and preferential selection begins again, iteratively leading to further innovation and more preferable products.

SUMMARY

- The materials used to construct our built environment have implications for human health and the ecosystem. Selecting “preferable” materials reduces negative impacts and incentivizes the market to produce better products.
- Previous versions of LEED dealt with limited information about the health and environmental attributes of materials, which made it challenging for project teams to fully consider the impacts of their choices.
- LEED v4 significantly changed the MR credits to encourage a more complete picture of materials and their impacts on human health and the environment across their life cycles. This shift included an emphasis on information disclosure and materials optimization.
- LEED and other green building efforts have a track record of incentivizing better products. LEED rewards manufacturers that develop better products and share information, thereby contributing to a positive feedback loop in which reporting, evaluation, and preferential selection spur further innovation.
- The new credits will enable project teams to choose preferable products based on more robust, multifaceted information, and they provide incentives for manufacturers to improve their products.

CHAPTER 1. RESOURCES

WEBSITES

- [BuildingGreen Environmental Building News](#)
- [GBIG Insight blog](#)
- [LEED v4](#)
- [Videos from USGBC's materials and health event series](#)

CONTINUING EDUCATION

- [Education @USGBC](#)
- [AIA online course directory](#)
- [BuildingGreen continuing education](#)

2.

CHAPTER 2. ENVIRONMENTAL AND HUMAN HEALTH CONSEQUENCES OF BUILDING MATERIALS

2.1 Navigating the complex scientific landscape

- In what ways have materials decisions become more complex?
- Why is it important to navigate these complexities?
- Which scientific specialties are involved in developing and assessing materials, and what complications do scientists face in assessing materials?

A systems-based, life cycle approach to the selection of building materials requires an appreciation for the human health and environmental consequences of materials choices beyond the operational phase of a project. Building professionals must consider implications from each life cycle stage, aggregate information from multiple sources, and apply the resulting knowledge to make better decisions in the context of myriad practical constraints.

The issue is not whether the selection of materials has local, regional, or global consequences for people and the environment. Clearly, it does. The concern is how to better understand the nature of these effects and take action to promote human health and protect environmental resources. This is a complex and constrained task. Every building material has a range of potential health hazards and environmental and ecosystem impacts. Every building material is the product of resource extraction, manufacturing, and transportation. Every building material presents some degree of hazard to human health. There are no “perfect” products, yet we must make decisions. Building materials will be specified, purchased, installed, used, and ultimately disposed of. Practically speaking, the best we can do is inform and guide the course of decision making toward solutions that benefit people and the environment.

THE COMPLEXITY OF MATERIALS DECISIONS

Architects, engineers, and allied professionals are deeply interested in materials attributes and have an intuitive appreciation for color, texture, durability, weight, cost, and many other factors. They can access and use information to navigate trade-offs among these factors to make decisions in many different circumstances. Health and environmental attributes are different. They are typically intangible and invisible. Handling a sample does not reveal the chemical composition, just as studying an installation will not convey the amount of embodied greenhouse gas emissions. Moreover, complete health and environmental information for building products is almost always unavailable.

Health and environmental attributes are not only intangible and invisible, they are also multifaceted and interrelated. Consideration of the entire life cycle of a material requires building professionals to ask a new chain of questions:

- Where do the raw materials come from? Which extraction processes cause the least harm to workers, the local population, and the ecosystem?
- What consequences do transportation of raw ingredients and manufacturing processes have for the local, regional, or global environment? How might manufacturing workers be exposed to potentially hazardous substances?
- What products will minimize hazards for construction workers and building occupants?
- What happens to the product at the end of its life in a building? Can it be recycled? Does it generate toxic or environmentally damaging impacts as it degrades or breaks down?

The answers to those questions may or may not lead to clear choices and immediate opportunities for action. A product that has minimal health and environmental impacts during use may require enormous resources to manufacture. Decisions may be constrained by available products, cost, or competing priorities. This is a clear and understandable potential source of frustration. However, simply asking the questions and bringing these issues into the decision-making process is the first step toward driving change.



All stages of the materials life cycle have implications for human health and the environment.
Courtesy: Echo/Getty Images (left); hsvrs/Getty Images (middle); Oxford/Getty Images (right)

The answers to the questions will also underscore the complexity of issues involved. The considerations frequently intertwine matters of human health and environment. For example, many building products emit VOCs during manufacturing, installation, operation, or disposal. Large-scale release of these substances during manufacturing can induce “acid rain,” causing widespread damage to aquatic ecosystems. Release of VOCs within buildings can also expose occupants to potential cancer-causing substances. The life cycle stage at which VOCs are of most concern varies for different materials and products, and stakeholders are likely to place different levels of importance on personal well-being, public health, and regional environmental impacts. LEED Indoor Environmental Quality credits focus on reducing occupants’ exposures to VOCs but do not directly address potential exposures during manufacturing or installation. This additional consideration could be used to inform specification and purchasing decisions.

Although there are rarely easy answers, building professionals are increasingly being asked to help stakeholders navigate these topics. Project teams therefore need a working understanding of the concepts, issues, and trade-offs.

SCIENTIFIC DISCIPLINES INVOLVED

Many scientific disciplines have contributed to our current understanding of how materials affect human health and the environment, yet we have significant knowledge gaps—and no quick fixes. In part, this is because the science is multifaceted and does not always provide definitive answers. Although some impacts are immediate (e.g., a chemical spill polluting a river), others may take years to become apparent (e.g., mesothelioma from asbestos exposure). And in complex environments, it is difficult to determine a direct relationship between a human health or environmental outcome and the substance of origin.

Distinguishing the scientific specialties involved in developing and assessing building materials is important for understanding where certain information comes from and who has the expertise to solve a problem. It may also be helpful for identifying potential sources of advice.

- **CHEMISTS AND CHEMICAL ENGINEERS** develop new chemicals as well as processes for making chemicals with particular attributes and functionalities. They understand substances at the atomic and molecular levels, the role of individual chemicals, and how to select or design substitutes for chemicals of concern. A chemist would be able to design a less toxic flame-retardant chemical, for example.
- **MATERIALS SCIENTISTS AND ENGINEERS** develop new materials and processes for making materials with particular attributes and functionalities. They can manipulate materials properties across a range of scales, including nano-, micro-, and macroscopic levels, and they understand how physical and chemical properties combine to create useful materials. A materials scientist might develop lighter-weight, more durable structural materials or more energy-efficient lightbulbs.
- **TOXICOLOGISTS** study the harm a specific substance causes to living organisms. They evaluate exposure and physiological responses. A toxicologist could test the impact of a particular substance, like bisphenol-A, on an organism. Most often, toxicological experiments are done using living cells or animals, and a safety factor is incorporated into the toxicity results to estimate the impact on humans. Computer models may also be used to predict a substance's toxicity to a particular organism.
- **PUBLIC HEALTH EXPERTS**, such as epidemiologists, study the patterns, causes, and effects of disease in human populations. They might, for instance, study the patterns of chronic disease in miners or construction workers.
- **ECOLOGISTS AND ENVIRONMENTAL SCIENTISTS** study the structure, function, and dynamics of ecological systems. They understand ecological responses to the introduction of pollutants or environmental stressors, so they can examine things like ozone depletion and nutrient pollution of waterways resulting from manufacturing and building-related activities.

Scientists typically operate within their own field. For instance, a materials scientist or chemist would not usually consult a toxicologist when considering which raw ingredients to combine into a product. Likewise, a public health expert would be unlikely to work with an engineer on how to improve a chemical process to reduce the likelihood of work-related illness. The siloed approach that scientists and engineers take to their work reflects tradition and training: those who are not trained in toxicology or public health are unlikely to consider health effects in their work.

As described in Chapter 1, green building strives for an integrative design process that breaks down barriers between traditional professional specialties, helping create higher-performing buildings at lower costs by revealing synergies. Scientific silos, like building professionals' silos, can result in inefficiencies and information that is not passed along to those who may benefit. Just as integrative design is making headway in the building industry, interdisciplinary approaches to science are gradually becoming more common, but they are not yet the norm.

The rest of this chapter will highlight some of the most important environmental and human health considerations for materials. It is not comprehensive; rather, it provides examples and context for understanding environmental and human health impacts. The way we treat these two issues is different because the nature of the question and the scope of the subject differ. As complex as human health is, we are fundamentally looking at one species, so it is possible to get into very fine detail. When looking at the ecosystem and environment, we are concerned about millions of species as well as the physical surroundings.

SUMMARY

- Every building material has a range of potential health hazards and environmental impacts. The concern is how to better understand the nature of these effects and take action to promote human health and protect environmental resources.
- Health and environmental attributes are typically intangible, invisible, multifaceted, and interrelated. Understanding how a material affects health and the environment across the life cycle may or may not lead to clear choices and immediate opportunities for action.
- Building professionals are increasingly being asked to help stakeholders navigate these topics. That requires them to have a working understanding of the concepts and issues. Project teams need expert guidance to navigate these complex issues and trade-offs.
- Just as navigating complex life cycle considerations and trade-offs is difficult for a building professional, assessing the human health and environmental impacts of materials is complicated for scientists. In part, this is because the science is multifaceted and does not always provide definitive answers. Although some impacts are immediate, others may take years to become apparent. And in complex environments, it is difficult to determine a direct relationship between a human health or environmental outcome and the substance of origin.

- Chemists, materials scientists, toxicologists, public health experts, ecologists, and environmental scientists are some of the specialists who are involved in developing and assessing building materials. Although scientists typically work in silos, just as integrative design is making headway in the building industry, interdisciplinary approaches to science are gradually becoming more common.

2.2 Environmental impacts of building materials

- What are the connections between building materials and environmental impacts?
 - What are the major types of environmental impacts?
 - How are environmental impacts created at each stage of the life cycle?
-

CONNECTIONS BETWEEN BUILDING MATERIALS AND THE ENVIRONMENT

All materials must come from somewhere. Their contents are extracted from mines, oil wells, forests, and fields and transformed using varying amounts of energy and water in manufacturing processes that emit pollutants to the air, water, and soil. These emissions occur because extraction and manufacturing processes are never 100% efficient, and they use chemicals and resources that are not incorporated into the final material. For example, the pesticides applied to cotton and the acid used to extract metals from mineral ores both end up as environmental pollutants. It was Antoine Lavoisier in the 18th century who first proved that matter cannot be created or destroyed. Instead, all chemicals and materials undergo physical and chemical transformations as they move through the environment.

Because systems are nested, impacts on one part of the environment often propagate to others. This is most easily demonstrated in a natural ecosystem, such as a forest, but it applies to all aspects of the environment, including people. A forest comprises many interacting systems: soil microorganisms, local topography and climate, regional plants and animals, flows of water through the watershed, and global cycling of carbon, phosphorus, and nitrogen.

Disruptions at any of these scales can have cascading effects throughout the larger system. For instance, clear cutting removes the plants that form the basis of the forest ecosystem, resulting in ripple effects: soil erosion can inhibit regeneration of the forest, and runoff of silt can clog streams and kill fish and aquatic insects. These changes can destabilize the larger forest system, leading to a loss of biodiversity. At the same time, the regional watershed can gradually lose the ability to infiltrate and filter stormwater, leading to poor water quality and exacerbating the effects of drought; and the carbon stored in the plants and soils can be released into the atmosphere, contributing to global climate change.

Disruptions need not be catastrophic. Responsible forest management can prevent many of these problems by respecting and accommodating the complex relationships of the physical, chemical, and biological components and responding to the whole system in ways that enable regeneration and sustain diversity of both organisms and functions.

Some materials can actually have environmental benefits. The use of waste materials, such as recycled metals, wood, or cotton, both avoids impacts associated with materials extraction or harvesting and reduces the amount of material sent to landfills. For example, straw bales are made from agricultural waste that would otherwise be burned. They can be assembled with minimal

processing and can provide both structure and insulation for buildings while also reducing a waste stream, storing instead of releasing carbon, and offsetting the amount of other materials required. This benefit, however, is captured only in places where there is a nearby supply of straw and where high levels of building insulation are appropriate. Using straw bales on a tropical island, for example, where the climate is mild and local sources of straw are limited, would undermine this benefit.

Finally, materials extraction and production can create jobs and support local economies. Project teams must carefully consider all factors related to materials not only to reduce environmental and human health harms but also to generate benefits.



Responsible forest management and use of agricultural waste in construction materials are two ways to mitigate environmental impacts.
Courtesy: iStock.com/georgeolsson (left)

Since all building materials have embodied energy and environmental impacts, the challenge is to make more intentional and thoughtful materials choices based on an understanding of what types of impacts there are, where they occur in the life cycle, how severe they are, and how they compare with the impacts of alternatives. The proverbial dilemma of paper versus plastic bags is a microcosm of the issues: both paper and plastic have environmental pros and cons. To evaluate which is better requires a full analysis across the life cycle of each product. In most cases, an even better solution is to bring your own bag. Although the plastic, cotton, bamboo, or other material used to make reusable bags has impacts as well, the difference is one of scale. Ultimately, one must consider how the materials and processes used to make a reusable bag compare with its disposable (or recyclable) counterparts, how many times will the bag be used, and what will happen at the end of its life.

The trade-offs we face when choosing between paper and plastic bags may seem complicated at first, but each of us finds the answer that makes sense for our individual situation. The trade-offs involved in making decisions about building materials and products can be far more complicated. Fortunately, there are tools that can help project teams identify pros and cons of alternatives to help them make the best decisions for a particular project. This section provides a foundation of knowledge for teams to understand the science underlying these tools so that they can use them effectively.

HARDWOOD VERSUS BAMBOO FLOORING: WHICH IS BETTER FOR THE ENVIRONMENT?

Bamboo flooring is touted as an environmentally friendly alternative to hardwood flooring and is becoming increasingly popular in the United States and other countries. Both materials are aesthetically pleasing and can have similar cost and durability (depending on the type of hardwood). A primary attraction of bamboo is that it is rapidly renewable: it's ready for harvest in less than five years, compared with decades for hardwood, and can regrow without replanting. But are the environmental aspects as simple as they appear?

Most bamboo for flooring is sourced in Southeast Asia, whereas hardwoods can be found around the world. Depending on where the flooring will be installed, the resources required to transport the bamboo may outweigh other environmental benefits. Waiting decades for a tree to grow may not mean it's any less renewable than bamboo. Some hardwood trees can produce as much biomass per year as bamboo. Depending on the harvesting practices used, the less frequent harvest of hardwood may require fewer overall resources for the same amount of material. Bamboo, which grows as a hollow stalk, also requires more resources and binders to manufacture it into flooring compared with hardwood.

Arriving at a "best" choice for a particular project requires comparing the sources of the materials and types of transport used, the impacts of the harvesting practices, the durabilities of the final products, and the resources required to manufacture the products.

Many environmental impacts can also affect human health. Human health issues are addressed separately, in the next section, but it is important to keep in mind that the lines between environmental and human systems are conceptual rather than actual. Ultimately, we are all part of the same system.

HOW BUILDING MATERIALS AFFECT THE ENVIRONMENT

Environmental impacts can be the result of processes that occur at any point in the life cycle of a material, including creation, use, and disposal, as well as energy use and transportation at any of these stages. They can involve physical disruption of a system, depletion of a resource from a system, or chemical inputs into a system beyond what that system can assimilate. They can be highly local, regional, or global in nature, are often interrelated, and may have cascading effects. Materials selection requires a general level of familiarity with the major types of environmental impacts: air and atmosphere, water, soil and land, natural resources, and habitat and biodiversity.

TYPES OF IMPACTS

AIR AND ATMOSPHERE. Atmospheric emissions result from the use of energy and processes involved for resource extraction, manufacturing, transport, installation, and disposal of building materials. The impact of atmospheric emissions can be local (e.g., inducing ground-level haze or smog) and global (e.g., contributing to global climate change). Air pollutants can also fall to the surface with precipitation, leading to pollution of water and land.

COMMON EMISSIONS TO THE AIR AND ATMOSPHERE

Greenhouse gases trap heat in the earth's atmosphere. The largest source is carbon dioxide, which results from burning processes, particularly the burning of fossil fuels for energy production. Other greenhouse gases, including methane, nitrous oxide, ozone, and chlorofluorocarbons (CFCs), can also result from energy production and other industrial chemical processes.

Sulfur oxides (SO_x) result from the burning of coal or petroleum and other industrial processes and contribute to acid rain and smog.

Nitrogen oxides (NO_x) result from high-temperature combustion and are a major component of smog, giving smog its characteristic brown haze.

Carbon monoxide results from incomplete burning of fossil fuels and is a major component of vehicle exhaust. It is a colorless and odorless gas that is toxic to humans and animals in high concentration, and it is a major component of smog.

Particulates and aerosol emissions can result from burning of fossil fuels in vehicles, mining operations, and industrial processes. There are many types of particulates, and their size and source determine what kinds of impacts they can have, from causing respiratory problems for humans and animals to changing the albedo of the earth and thereby playing a role in climate change.

WATER. Impacts include pollution of surface water (rivers, streams, lakes, oceans) and groundwater, as well as depletion of water resources.

Pollution can change both the chemical and the physical properties of water and can include acidification, which can kill corals and other sea life; increased nutrients, which lead to oxygen deficiency; contamination with toxic or hazardous substances; changes in the temperature of water, which can disrupt natural systems; and increased turbidity (cloudiness) of the water, which can block sunlight from penetrating. These changes can result in further impacts on aquatic communities, including changes in productivity, reduced reproduction, disease, and death, as well as impacts on human health. All of these impacts can degrade the quality not only of natural ecosystems but also of human systems and can diminish the supply of drinking water. Water availability, an issue of increasing concern as droughts affect more areas worldwide, can also be affected by processes that use groundwater or surface water for cooling or other purposes.

MAJOR CATEGORIES OF WATER POLLUTION

Nutrient pollution occurs when excess amounts of nutrients, such as nitrogen and phosphorus, enter waterways from stormwater runoff, agricultural fertilizers, polluted air, or other sources and trigger blooms of algae, which in turn die and decay and deplete the water of oxygen; this process is called eutrophication.

Inorganic chemicals and substances, including acids, salts, and heavy metals, can be emitted during mining and industrial and manufacturing processes, as well as energy production. These materials can harm fish and wildlife, depress crop yields, and harm human health. Heavy metals can bioaccumulate up the food chain as contaminated plankton are eaten by fish, which are then eaten by larger animals as well as humans. In addition, mining and construction and other earth-moving activities can flush sediment into streams, degrading the aquatic habitat.

Organic chemicals include petroleum hydrocarbons (from fuels and lubricants), pesticides, industrial solvents, and other chemicals. Some of these substances are known carcinogens, causing cancer in both humans and wildlife.

SOIL AND LAND. Air and water pollution can also degrade soil, as can erosion and changes in topography, soil compaction, and alteration of soil chemistry (including depletion of nutrients). This category also includes the conversion of land for landfills or other storage of solid waste and sludges, or alteration of land such that its productivity or habitability is changed. Land itself is a nonrenewable resource. Land that has become contaminated or degraded beyond its ability to support life can take centuries to recover.

NATURAL RESOURCES. Both nonrenewable resources and supposedly renewable resources can be depleted. Nonrenewable resources include fossil fuels, metals, and other minerals. Since many of the resources used in the life cycles of building products are finite, their depletion diminishes worldwide resource availability. For example, demand for nonrenewable resources can lead to increasingly invasive extraction techniques, which can not only deplete resources but cause a wide range of other environmental problems as well.

Many resources, such as wood or agricultural products, are considered renewable, but this is actually the case only if the rate of harvest is less than the rate at which that material can regenerate. For example, some types of forestry prevent forests from recovering, decreasing the size and quality of wood available for harvest over time. Rainforests are particularly vulnerable to depletion because the nutrients reside in the plants and not in the soil, and therefore removal of trees can cause the ecosystem to collapse. On the other hand, responsible forestry practices ensure the overall sustainability of the forest ecosystem, removing resources at a rate that allows them to fully regenerate.

HABITAT AND BIODIVERSITY. All of the impacts listed above can also harm habitat, the natural home or environment of an animal, plant, or other organism, and biodiversity, the variety of species and habitat types found in a place. Both individual species and their habitats can be destroyed and ultimately can become extinct as a result of processes associated with building materials production. These impacts may be irreversible and are important to humans not only for the intrinsic value of the species that are lost but also for their role in maintaining healthy ecosystem functioning, such as water purification.

IMPACT CHARACTERISTICS

Impacts to air and atmosphere, water, soil and land, natural resources, and habitat and biodiversity are further defined by their source type and emission type.

LOCAL VERSUS GLOBAL. Emissions released into the air or water can travel. How far they go and what impacts they have depend on physical and chemical characteristics, such as how heavy the pollutant is and how it reacts with other pollutants, naturally occurring chemicals, or sunlight. In most cases, air and water pollution are worst near their sources, such as factories or mining operations. On the other hand, carbon dioxide has little local effect but contributes to global climate change, and CFCs, which are otherwise inert, cause ozone depletion, which increases the planet's exposure to damaging ultraviolet light.

SHORT-TERM VERSUS LONG-TERM. Impacts can be immediate and short-lived (acute) or long-lasting (chronic or persistent). Some chemicals break down quickly when released into the environment; others can bioaccumulate in the environment and the food chain over thousands of years, posing a risk to human health and ecosystems and demonstrating the links between environmental and human health impacts. Persistent, bioaccumulative, and toxic (PBT) substances include mercury, dioxin, and polychlorinated biphenyls (PCBs). PBTs can transfer easily among air, water, and land, and they can travel and spread to different geographical locations and span generations. For example, a fish that feeds on mercury-contaminated smaller fish or plants ingests the toxic element. This effect continues through many cycles, with mercury levels increasing further up the food chain. For this reason, mercury levels are high in large fish like albacore tuna, and lower in smaller fish like salmon and pollock. When humans or other animals eat fish, the mercury is transferred to them.

ENVIRONMENTAL IMPACTS ACROSS THE LIFE CYCLE

The life cycle of a product typically includes a wide variety of potential impacts that occur before or after a building's construction and use, and are therefore outside the conventional purview of project teams (Figure 2-1). The extent to which potential impacts happen in reality depends to some extent on where the processes take place, since some countries have more stringent regulations than others as well as more effective enforcement.

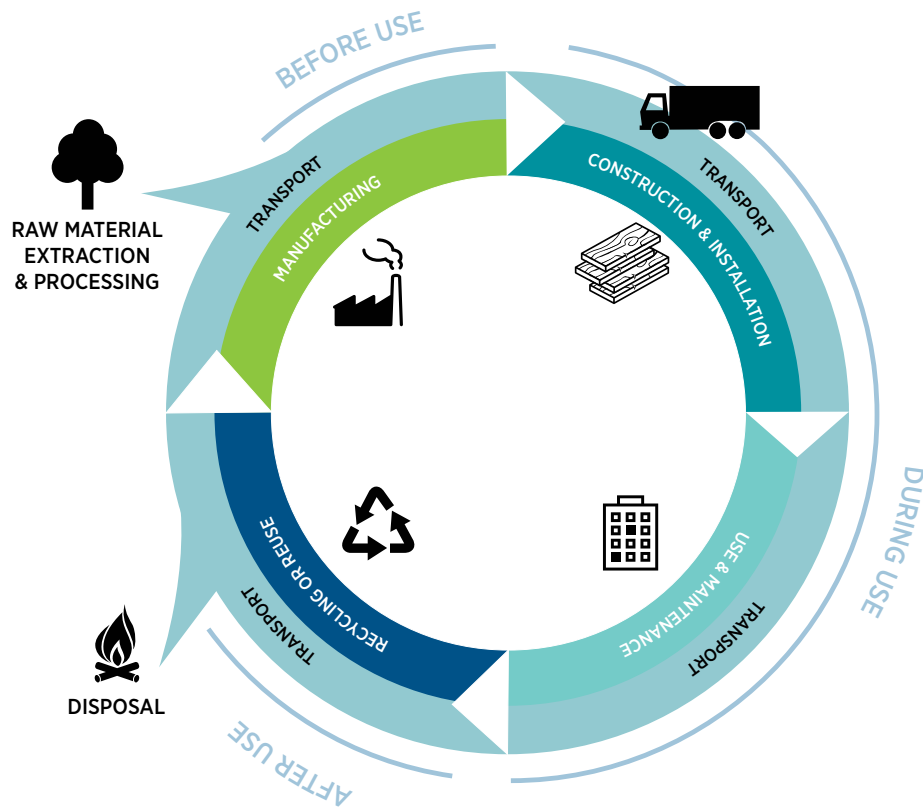


Figure 2-1. Materials life cycle

Often the most significant impacts of a material are outside the normal purview of the project team, occurring either before or after construction and use.

The challenge to the building professional is to identify the products that result in fewer and less severe negative impacts throughout the life cycle. The challenge to the manufacturer is to design products and manufacturing processes and use supply chains that meet the demand for benign products. Some common examples of potential environmental impacts during each life cycle stage are outlined below.

RAW MATERIALS EXTRACTION AND PROCESSING

The removal of raw materials from the earth is necessary, but some extraction practices are more harmful than others. The goals of sustainable extraction are to ensure that impacts are minimized and that renewable resources are not harvested faster than they can be replaced. This stage of the life cycle includes mining of ores, minerals, and rocks; extraction of petroleum and natural gas; growing and harvesting of trees and agricultural products; and raising and slaughter or shearing of animals. It includes processing of these raw materials into products needed by the manufacturer. This can include crushing, grinding, and processing of minerals and rocks; beneficiation of ores; refining of petroleum; production of chemicals; and manufacture of intermediate products. Because of the significant impacts that can occur at this stage, green building materials have often been designed to incorporate salvaged or recycled content, thus avoiding many impacts caused by the processes of extraction or harvesting, processing, and transporting raw materials.

Examples of potential impacts of several common extraction processes used in building materials follow.

MINING. Mining can be done through underground or surface methods. The impacts are somewhat different, but both types can affect large areas of land, destroying existing vegetation and habitat. Once degraded, many habitats take centuries to regenerate; once endangered, many species will not recover. Most mining involves extraction of large quantities of “waste” material that surrounds the specific ore that is sought, and this waste can contain harmful substances and require storage and disposal. Discharge and leakage from settling tanks and waste storage cause surface and groundwater pollution; acid drainage threatens animals and plants by polluting water and habitat. Blasting, grinding, and crushing generate dust and emissions that can contain harmful substances. Equipment operation releases pollutants and carbon dioxide (CO₂), which contributes to climate change.

WOOD HARVESTING. Trees form the backbone of many forest systems, provide habitat, store carbon, and filter air and water. Therefore there are many benefits to growing wood for building materials, but not all forestry operations enable the trees to perform these valuable functions. From an economic perspective, a “sustainable” harvest rate is one that maximizes yields over time. However, many other aspects of forestry contribute to its relative environmental impact and ecological sustainability, such as the diversity of tree species, the rate that trees grow, the protection of habitat and soil, the use of chemicals, and the invasiveness of forestry practices. For example, clear-cutting forested slopes and cutting close to waterways increase particulate water pollutants, damaging aquatic ecosystems. Logging on steep slopes can cause erosion. Roads through the forest compact soils. Unsustainable cutting depletes the forest as a resource and is a major cause of species extinction. The logging of old-growth forests or slow-growing species such as tropical hardwoods is particularly disruptive.

AGRICULTURE (BIO-BASED PRODUCTS). Bio-based materials have the advantage of being renewable, but they may require fertilizers, pesticides, and large quantities of water for irrigation. Some fertilizers contribute nitrous oxide, a potent greenhouse gas, to the atmosphere. Insecticides and fertilizers can leach into groundwater and run off into surface water. Runoff from fertilizers and other nutrients can cause algal blooms and “dead zones” in surface waters. Some crops deplete soil nutrients or contribute to erosion because of cultivation practices. Organic and sustainable farming can avoid some of these impacts.

INDIGENOUS AND NATURAL MATERIALS. Many building materials can be obtained directly by a project team at or near a project site and used with minimal processing. Indigenous materials might include mud, straw, cordwood, rock, or grasses that may be fashioned into bricks, woven into mats, or sculpted directly into walls. These materials are typically abundant in particular places, and local populations may have long histories of using them in ways appropriate to climatic conditions and cultures. Such materials generally have minimal environmental impacts, and some may even offset waste streams or other environmental problems. Their use can be limited by performance considerations, such as wall thickness or structural limitations (or in some cases by code restrictions), but when used as part of a well-designed building system, they can be some of the best alternatives available.

MANUFACTURING

This stage includes product fabrication as well as all the processes that convert feedstock into the materials for fabrication. It also includes packaging of the product and shipment to the job site. Each manufacturing process may require energy to generate heat or electricity and to run machinery, which generates emissions to air. The manufacturing facility may also emit airborne waste through stacks. Some manufacturing processes may require large quantities of water and may emit water that is heated or contaminated. Pollutants might also be released into surface water or leach into groundwater. Some processes generate large quantities of solid waste that may contain hazardous constituents. Areas around manufacturing facilities can become inhospitable to local plants, humans, and other animals if emissions are not controlled or if there are accidental releases.

Environmental laws and regulations, where they are in place, up to date, comprehensive, and enforced, have significantly reduced emissions from some manufacturing processes. Manufacturers have incentives to develop energy-efficient processes to reduce costs as well as emissions. Depending on the costs and availability of waste disposal in the area, manufacturers may be encouraged to reduce solid waste, recycle it into the process, compost it for agricultural or other purposes, or find another valuable use for it. Manufacturers also have incentives to use material ingredients with lower environmental and human health burdens, as customers increasingly demand greener products. Certification systems and labels also provide incentives.



Feedstock conversion, material and product fabrication, waste disposal, packaging, and transportation are among the activities that contribute to environmental impacts during the manufacturing phase.

Courtesy: iStock.com/EyeMark (right)

CONSTRUCTION AND INSTALLATION

This stage includes installation of the product into the project. Air emissions from trucks delivering materials and construction equipment can be significant, particularly if these vehicles are left idling when not in use. Installation of some insulation materials involves blowing agents that can contain ozone-depleting substances. Paints and coatings can release VOCs, which off-gas at high rates in new materials; the rate typically declines over time. The pollutants in liquid wastes that are disposed of improperly—dumped on soil, into drains, or into surface water—can affect plants and

animals. Construction can produce large quantities of solid waste for disposal. Packaging, from pallets to cardboard to plastic wrap, can also become solid waste that requires recycling or disposal.

In the United States and some other countries, construction practices have evolved to emphasize minimizing waste and recycling as much waste as possible. Separation of wastes for recycling is mandatory in many areas. Because VOCs in many materials have been reduced or eliminated, environmental effects of these emissions have been reduced. Use of ozone-depleting agents in products such as insulation has also been reduced or eliminated. Federal and local regulations reduce soil runoff and siltation of surface water.

USE AND MAINTENANCE

The use stage for building products can dominate the rest of the life cycle because of its potential duration: building products can stay in place and in use for hundreds of years. Energy consumption is a significant component. Durability is an important consideration because products that require frequent replacement can generate solid waste unless they are designed for recovery, reuse, or recycling, and production of the replacements can duplicate the upstream life cycle impacts of the original products. Products that require frequent maintenance, particularly if the maintenance involves harmful chemicals for cleaning or coating, have environmental impacts. Products whose finishes do not require recoating avoid the associated future emissions and other environmental impacts. Green cleaning practices can reduce some of the toxicity impacts related to the use and maintenance phase for humans and ecosystems.

END OF LIFE

Construction and demolition waste accounts for roughly 40% of the total waste produced in the United States.¹ The typical end-of-life scenario for building products and materials has been landfilling, which once cost less than other end-of-life strategies. However, with the scarcity of new sites for landfills, coupled with mandatory recycling and new technologies, landfilling of construction waste is declining.

Decomposition of some materials in a landfill produces harmful gases, such as methane, a gas that contributes 25 times the global warming effect of CO₂.² Low-temperature fires in landfills can release toxic materials, such as dioxin, to the atmosphere. Over time, landfills can leach toxicants into groundwater and other sensitive areas. Depending on the way the landfill is constructed, substantial amounts of materials may remain intact and sequestered indefinitely, leading to long-term storage issues and degradation of valuable land.

¹ Estimating 2003 building-related construction and demolition materials amounts, EPA530-R-09-002 (Washington, D.C.: U.S. Environmental Protection Agency)

² S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.), *Climate change 2007: The physical science basis*, contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Cambridge and New York: Cambridge University Press, 2007).

To mitigate the effects of landfilling, green building practices encourage alternative end-of-life uses for building materials, such as recycling, reuse, or using the waste to generate energy, although waste-to-energy practices create pollution that must be managed. EPA has developed a hierarchy for preventing and managing waste. The most preferable approach is source reduction—not generating waste in the first place. Design methods such as prefabrication and modular construction are effective means to achieve source reduction early in a project.

Second best is reuse of a product or material for the same or equal purpose. Once a building has ended its useful life, deconstruction and salvage of the building components recover reusable materials. Materials from older buildings are often highly prized, with beautiful wood, interesting details, and fine craftsmanship.

Third is recycling, a common end-of-life scenario that is considered environmentally beneficial because it reclaims already extracted materials and puts them back into the manufacturing stage, thereby avoiding the extraction of virgin raw material, or recycles them into another product. Recycling is not “free,” however: it can require energy to make a used product into a new one. For example, steel beams are recyclable, and today steel used in construction may contain up to 90% recycled content. However, a lot of energy is needed to melt the metal and re-form it into new beams. Recycling can also involve “downcycling”: recovered materials that cannot be used for original purposes are used to make products of reduced quality and/or reduced functionality. Because building materials are frequently bound up in assemblies, recovery, reuse, and recycling are often not as straightforward as recycling of some consumer products, such as newspaper and plastic.

Last is energy recovery from materials that cannot be reused or recycled. The embodied energy in wood or plastics can be extracted through waste-to-energy processes. This is the least beneficial end-of-life scenario because the materials are incinerated, making them unavailable for future use and releasing odor, particulates, and potentially such substances as dioxins. It is not used widely in the United States.



Although some materials must ultimately be disposed of in a landfill, environmental impacts are reduced by recycling or reusing materials and products.
Courtesy: iStock.com/Ralph125 (left); iStock.com/hillwoman2 (middle); Helena Wahlman/Getty Images (right)

SUMMARY

- The contents of building materials are extracted from a variety of natural resources and transformed and manufactured into products using large amounts of energy and water, emitting pollutants to the air, water, and soil. Because systems are nested, impacts on one part of the environment often propagate to others.
- Understanding ecosystem relationships assists in responsible resource management and can result in materials and processes with environmental benefits.
- Environmental impacts related to building materials can be local or global and short- or long-lived. They can affect the air and atmosphere, water, soil and land, natural resource availability, and habitat and biodiversity.
- Each stage of the materials life cycle—raw materials extraction and processing, manufacturing, construction and installation, use and maintenance, and end of life—presents an opportunity to mitigate these impacts.

2.3 Human health considerations for building materials

- Why should building professionals be concerned with the contents of materials?
 - How do substances move from materials into the environment, and how are humans then exposed to them?
 - How do certain substances affect human health?
 - What are the human health considerations across the materials life cycle?
-

BIOLOGICAL BASIS FOR CONCERN

Humans are the product of nearly 4 billion years of biological evolution. The chemicals that now constitute the material basis of our built environment are virtually all new in the past seven decades, emerging with the petroleum-based inventions of the Second World War. The result is an unprecedented volume and diversity of exposures to substances that people had not historically experienced. We do not understand the implications of many of these exposures. In fact, given the complexity of real-world conditions, we may never fully understand these interactions. Yet we know enough to be cautious and, in some cases, concerned.

Over the same time span that these chemicals have come into widespread use—less than a century—the incidence of some chronic diseases with hypothesized links to chemical exposures has risen sharply. For example, asthma rates have been growing steadily since U.S. recordkeeping began in 1980. After nearly doubling between 1980 and 1996, the percentage of children with asthma has continued to increase, although at a slower rate. In 1997, one in nine U.S. children had been diagnosed with asthma; by 2012, the rate had increased to one in seven.¹ Although many factors come together to produce asthma, including genetics and environmental exposures, it is now known that exposure to some chemicals can directly contribute to new cases of asthma. Other chemicals may not cause asthma directly, but may—after prenatal exposure or exposure during early childhood—predispose children to asthma by altering how their lungs and immune systems develop.² Some of these chemical asthmagens are present in paints and finishes, resins, insulation, wallboard, adhesives, and flooring products.³

Other chronic diseases, such as diabetes and some types of cancer, are also on the rise, and exposure to some substances commonly found in building materials may be contributing factors. Understanding these links motivates a precautionary approach to chemicals and materials use and offers opportunities for prevention: identifying safer alternatives to hazardous chemicals in building materials provides manufacturers and project teams with the information to promote health for occupants and decrease risks to health across the life cycle of building products.

¹ Federal Interagency Forum on Child and Family Statistics, Asthma: Percentage of children ages 0–17 with asthma, selected years 1980–2012, <http://www.childstats.gov/americaschildren/tables/health8a.asp> (accessed July 2014).

² S. Lott and J. Vallette, Full disclosure required: A strategy to prevent asthma through building product selection (Healthy Building Network, December 2013), <http://www.healthybuilding.net/content/asthma-report>.

³ For a full list, see Lott and Vallette, Full disclosure required.

HOW SUBSTANCES MOVE FROM MATERIALS INTO THE ENVIRONMENT

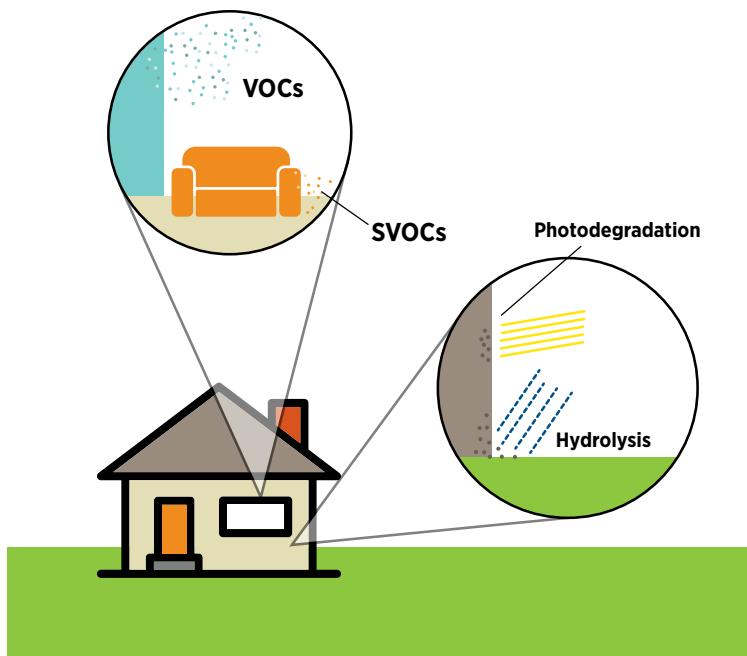


Figure 2-2. Migration of substances from building materials

Many of us think of building materials as static, unreactive, and unchanging, but the reality is much more dynamic and nuanced. If we were able to see into materials at the molecular level, we would observe chemicals emanating from many common building materials. Volatilization, leaching, oxidation, and various types of degradation are some of the processes that release substances from materials into the surrounding environment (Figure 2-2). Even seemingly inert materials like concrete are undergoing molecular rearrangements throughout their lifetimes. Bonds are formed and broken, releasing water, changing strength profiles, and even reacting with glues or other materials that are in contact with the concrete.

The following sections discuss the most common processes that release materials' contents into the environment, exposing people and the ecosystem through a variety of pathways.

VOLATILIZATION. Vapor pressure is a measure of how readily a substance will change from solid or liquid form into a gas. Substances that have high vapor pressures have low boiling points and are readily released into the air in a process also referred to as off-gassing. Chemicals classified as volatile organic compounds all have relatively high vapor pressure. Formaldehyde is an example of a VOC used in many building materials, such as paints, sealants, adhesives, plywood, composite wood, and insulation. Other examples include ethyl acetate and acetone, found in coatings and paints. Whenever these chemicals are used in construction, a significant amount can be released into the air, exposing construction workers as well as building occupants. Although the amount of chemical in the air depends on local ventilation rates and often decreases significantly after the initial application, residuals may remain long after a product's application or installation. VOCs are also a major source of chemical exposure during materials manufacturing, since many manufacturing processes use solvents and other volatile compounds.

Semivolatile organic compounds (SVOCs) evaporate through the same process as VOCs but at a much slower rate. Chemicals that fall into the SVOC category include some types of phthalates, bisphenol A (BPA), and halogenated flame retardants (HFRs), which may be found in flooring, wall coverings, furniture, and electronics. Even small amounts of these chemicals, once released into the air, can pose health risks. Many SVOCs adhere to dust particles (adsorption), which can then be

lofted into the air and inhaled, or they may settle on surfaces and transfer to hands, where they are absorbed through the skin or ingested through food contact. Because of their slow rate of release, SVOCs can persist for years in indoor environments.⁴

VOC CONTENT VERSUS VOC EMISSIONS

VOCs in paints and other wet-applied products can be measured by content or by emissions. VOC content is the amount of VOCs present in a product, generally reported as a percentage or weight per unit volume, whereas VOC emissions are a measure of the amount of VOCs released into the air from the product. In the United States, VOC content has been the main method for evaluation because of VOC content regulations, such as the limits created by the South Coast Air Quality Management District (SCAQMD) and California Air Resources Board (CARB) to improve outdoor air quality (e.g., reduce smog, outdoor pollution, and ground-level ozone). Recently, the green building industry, particularly in the European Union, has been shifting to the VOC emissions method because air concentration measurements from chamber testing are a much better predictor of emissions over time and VOC exposure. VOC content in a product does not directly translate to VOCs that will be emitted, and reactions taking place during application mean that some products with no VOC content emit VOCs under real-world conditions. However, chamber emissions testing is generally more expensive, less widely adopted for wet-applied products, and more difficult for evaluating emissions generated at the time of application.

LEACHING. Whereas vapor pressure controls the release of chemicals into the air, a compound's solubility in water or oil determines its ability to transfer through skin and migrate into the water or food supply. In the same way that small amounts of chemicals are released from materials into the air, water-soluble compounds can migrate from materials into water sources through leaching. Oil-soluble compounds, on the other hand, are more likely to be absorbed into skin or end up on dust or in the food chain. Metals found in pipes, coatings, fittings, or soldered joints can contaminate the water supply as they dissolve and wear over time. The same process that transports metals and other contaminants from pipes also transports pollutants from landfills and mines into the environment.

OXIDATION. Oxidation is one of the most common ways that materials are transformed. Burning and rusting are two familiar examples. Oxidative processes are also ubiquitous in biological systems. For example, humans breathe oxygen to oxidize sugars, fats, and proteins. This metabolic process releases energy while generating water and carbon dioxide. Oxidative processes like fire do more than just release energy; they also release a variety of combustion byproducts, many of which are harmful to human health and the environment. This is particularly true for building materials that contain halogenated chemicals—fluorine, chlorine, or bromine—that when burned transform into a class of toxic chemicals known as dioxins.

⁴ <https://bcgc.berkeley.edu/sites/default/files/Semivolatile+Organic+Compounds.pdf>.

DEGRADATION. Chemical and physical processes can cause building materials to degrade, releasing substances or forming new compounds. For example, plastics are made up of long chains of molecules along with additives and colorants that can decompose, releasing their chemical constituents. This process can span a few years or a few decades, depending on the material. Degradation occurs through several mechanisms:

- Photodegradation is the rearrangement or breakup of molecules with exposure to sunlight. An example of this is the fading color of outdoor paint over time.
- Hydrolysis is the breakdown of the bonds between molecules in the presence of water. It is the main contributor to the softening and weakening of wood that comes in contact with water. In addition to changing physical properties, hydrolysis can also release a material's components into the surrounding environment.
- Abrasion is the mechanical scratching, scuffing, or rubbing away of a material's contents. For example, the fading and wear patterns seen on carpet in high-traffic areas are a result of abrasion. Some industrial processes, such as mining and machining, also involve abrasion. Any kind of friction applied to a surface can release particulates into the air, exposing workers and building occupants.

Whether through chemical reactions or physical processes, building material contents tend to migrate into air, dust, water, and the food supply, with the subsequent potential for human exposure.

HOW SUBSTANCES MOVE FROM BUILDING MATERIALS INTO HUMAN BODIES

Once substances have migrated out of building materials, people can come in contact with them through inhalation, ingestion, or dermal absorption (Figure 2-3). This contact is referred to as exposure.



Figure 2-3. Routes of exposure

INHALATION. Anything that can volatilize, aerosolize, or attach to particles in the air can be inhaled. Once in the lungs, substances can either have a direct irritant effect or, if they are small molecules, such as solvents, pass into the bloodstream and be distributed throughout the body.

INGESTION. Chemicals originating in building materials can be ingested directly through hand-to-mouth activity if someone touches a product or consumes contaminated dust. Although we don't commonly think of eating dust, it is estimated that adults inadvertently consume more than 30 mg of dust per day.⁵ Young children may consume as much as 60 mg of dust per day⁶ —significantly more than an adult on a body-weight basis—because they tend to spend more time on the floor and have more hand-to-mouth behavior. Less directly, substances that enter the environment in any part of a building product's life cycle can get into the food supply. This is particularly true of bioaccumulative and environmentally persistent chemicals, such as mercury, HFRs, and perfluorinated chemicals (PFCs).

DERMAL ABSORPTION. Human skin is a remarkable protective layer; however, many substances can pass through this barrier and enter the body via hair follicles or diffusion through or between skin cells. Although some chemicals can cause skin irritation or sensitization, such as methacrylates leaching from adhesives, more common is the systemic uptake of chemicals via the skin without any local effects. Organic solvents, pesticides, mercury, and isocyanates are among the chemicals in building materials with potential for significant dermal absorption.⁷

Exposures can occur during any stage of the materials life cycle. Workers in particular may be exposed during raw materials extraction or chemical synthesis, during product manufacturing, application or installation, and during demolition. Because a material's contents can continue to migrate into the surrounding environment over weeks or years, people who live near mining or manufacturing facilities, as well as building occupants, are at risk.

Biomonitoring data show that most people are routinely exposed to dozens if not hundreds of chemicals, but they can't tell us the origin of the exposure. Identifying those exposures that are particularly prevalent can provide clues to where we should look. For example, the presence of high concentrations of brominated flame retardants in people of all ages, including pregnant women, motivated a change in California's flame retardancy standards. As a result of targeted phaseouts, levels of several specific flame retardants have dropped dramatically in California women.⁸ In June 2014, Kaiser Permanente announced it would no longer purchase furniture treated with flame retardants.⁹

5 J. Bierkens, C. Cornelis, M. Van Holderbeke, and R. Torfs, Age specific estimates of hourly dust and soil ingestion rates in a residential area, http://www.2-fun.org/posters/children_exposure/poster_age_specific_estimates_of_hourly_dust_and_soil.ppt.

6 U.S. Environmental Protection Agency, <http://www.epa.gov/ncea/efh/pdfs/efh-chapter05.pdf>.

7 S. Semple, Dermal absorption to chemicals in the workplace, *Journal of Occupational and Environmental Medicine* 61 (2004): 376–82, <http://oem.bmj.com/content/61/4/376.full>.

8 A.R. Zota, L. Linderholm, J.S. Park, M. Petreas, T. Guo, M. Privalsky, R.T. Zoeller, and T.J. Woodruff, A temporal comparison of PBDEs, OH-PBDEs, PCBs, and OH-PCBs in the serum of second trimester pregnant women recruited from San Francisco General Hospital, California, *Environmental Science and Technology* 47 (2013): 11776–84.

9 Kaiser Permanente commits to purchasing furniture free from toxic flame retardant chemicals, June 3, 2014, <http://share.kaiserpermanente.org/article/kaiser-permanente-commits-to-purchasing-furniture-free-from-toxic-flame-retardant-chemicals/>.

BIOMONITORING DATA FOR U.S. RESIDENTS

Biomonitoring involves measuring the levels of chemicals in samples of human tissues (such as hair) and fluids (usually blood or urine). The levels of a compound found in a blood or urine sample reflect the amount of the chemical in the body. In some cases, a metabolite—a substance produced by the body after the original compound has been chemically altered—is measured instead.

Biomonitoring is used to identify chemicals to which people are exposed and in what quantities. The presence of a chemical does not provide information about its potential harm; a chemical's effects may or may not be harmful, depending on its toxicity (how hazardous it is) and its concentration, in addition to an individual person's susceptibility. The health risks of some chemicals, such as lead, are well understood, but many require additional research to understand their human and environmental health effects and the amounts at which they cause harm.

In the United States, major biomonitoring programs are conducted by the [Centers for Disease Control and Prevention \(CDC\)](#) and by the [California government](#). CDC publishes periodic biomonitoring reports, the most recent of which is the [Fourth National Report on Human Exposure to Environmental Chemicals](#). A representative sample of U.S. residents found more than 200 synthetic chemicals and pollutants, as listed in the table below.

NUMBER OF CHEMICALS AND POLLUTANTS FOUND IN U.S. RESIDENTS, 1999–2004

Category	
Tobacco smoke	2
Disinfection byproducts	4
Environmental phenols	4
Fungicides and metabolites	4
Herbicides and metabolites	19
Pesticides, insecticides, and metabolites	30
Metals and metalloids	27
Parabens	4
Perchlorate and other anions	3
Perfluorinated surfactants	12
Phthalates and phthalate alternatives metabolites	16
Phytoestrogens and metabolites	6
Polycyclic aromatic hydrocarbon metabolites	10
Volatile organic compounds and metabolites	57
Polybrominated diphenyl ethers	12
Polychlorinated and polybrominated dibenzofurans and dioxins	27
Polychlorinated biphenyls	42

CHEMICALS AND MATERIALS IN THE HUMAN BODY

Once a substance enters the body, the harm it can do is referred to as a hazard. Materials can have intrinsic hazardous properties. Understanding hazards posed by substances in building materials has led to some important public health improvements, such as the elimination of lead paint in the United States and some other countries, and the ban on some uses of asbestos. But many opportunities remain to optimize building materials in support of human health.



Figure 2-4. Toxicants versus toxins

Toxin refers to a poisonous substance produced by a living organism, such as a snake, bee, or fungus. **Toxicant** refers to a broader category of poisonous substances that include biological toxins and naturally occurring (e.g., arsenic) or synthetic (e.g., BPA) harmful substances. Generally, the correct term for harmful substances in building materials is **toxicants** or **toxics**.

Harmful substances are also known as toxicants, or toxics for short (Figure 2-4). Toxicants can affect human health and the environment in a range of ways, from causing acute effects like eye or skin irritation, to contributing to the development of chronic problems such as cancer, asthma, thyroid disease, infertility, or birth defects. These health effects, or endpoints of chemical exposure, are generally grouped into categories. Here we'll illustrate some of the more common health hazards associated with building materials. This isn't a comprehensive list of endpoints, but it highlights some that are amenable to improvement by materials selection.

ASTHMAGENS

DEFINITION AND HEALTH EFFECTS. Substances that cause new cases of asthma are known as asthmagens. Some substances act both as asthmagens and as asthma triggers in people who already have the disease.

EXAMPLES IN BUILDING MATERIALS. Many paints and coatings are based on epoxy resins, which are commonly made of bisphenol A diglycidyl ether ("BADGE"). This recognized asthmagen is associated with new cases of work-related asthma and can also exacerbate asthma in individuals who already have the disease.¹⁰ Similar concerns are associated with materials containing polyurethane, which consists of two primary components— isocyanates and polyester or polyether polyols. Isocyanates are one of the most common asthmagens in building materials, and workplace exposure to isocyanates is likely the most significant cause of occupational asthma.¹¹ The primary use of polyurethanes in construction is as thermal insulation, but they can also be found in flooring, fillings, binders, sealants, and varnishes.

CARCINOGENS

DEFINITION AND HEALTH EFFECTS. Substances with the potential to cause cancer are called carcinogens. Many common building materials contain and can release carcinogens.

¹⁰ Association of Occupational and Environmental Clinics Asthmagen Database, <http://www.aoecdata.org>.

¹¹ <http://www.environmentalhealthnews.org/ehs/newscience/greener-polyurethanes>.

EXAMPLES IN BUILDING MATERIALS. Wet-applied adhesives, such as those used to install carpet or resilient flooring, can contain high levels of the known carcinogen benzene. This chemical readily volatilizes, increasing the potential for exposure to building occupants and particularly construction workers.

Engineered woods, such as medium-density fiberboard (MDF) and laminates used in flooring, traditionally relied on urea-formaldehyde resin binders. Over their lifetime, these materials emit formaldehyde, a known human carcinogen. Not only is workplace exposure a concern in the manufacture of these materials, but testing has demonstrated that they continue to emit formaldehyde for months after installation.¹² Formaldehyde emissions increase if the materials are cut or left unsealed.

Often, it is not the core material but rather the surface treatments that cause the problem. Natural fiber furnishings and carpets do not present known health problems, but like their synthetic counterparts, they are often treated with stain-repellent coatings, which usually contain long-chain perfluorinated chemicals. Like other SVOCs, PFCs migrate into the surrounding environment, adhering to dust particles that people are exposed to through inhalation, ingestion, or dermal absorption. PFCs have been measured in people of all ages in breast milk and in umbilical cord blood.¹³ Some PFCs are designated by the Stockholm Convention (see Section 3.2) as persistent organic pollutants known to remain in the environment for decades and accumulate in human tissues. Although health effects of PFCs are mainly documented in animals, concern about some human cancers and developmental effects following prenatal exposure has led EPA to develop an action plan for this class of chemicals.¹⁴

Some particulates can also cause cancer when inhaled. Asbestos is a well-recognized example, but respirable particles of crystalline silica (quartz), produced by working with stone, masonry, concrete, plaster, and glass, are also known to cause lung cancer, as well as the often fatal lung diseases silicosis and emphysema.¹⁵ Silica is second only to asbestos as the leading cause of death from cancer acquired on the job. Construction workers, painters (using abrasive blasting), bricklayers, and workers involved in building demolition tend to be highly exposed, as do workers in the mines and quarries where those materials originate. Workplace safety practices such as wet dust suppression can dramatically reduce exposures, and regulators in the United States and European Union are working to reduce allowable exposure thresholds.¹⁶

12 S.K. Brown, Chamber assessment of formaldehyde and VOC emissions from wood-based panels, *Indoor Air—International Journal of Indoor Air Quality and Climate* 9 (1999): 209–15.

13 H. Fromme, S.A. Tittlemier, W. Volkel, M. Wilhelm, and D. Twardella, Perfluorinated compounds—Exposure assessment for the general population in western countries, *International Journal of Hygiene and Environmental Health* 212 (2009): 239–70.

14 U.S. Environmental Protection Agency, Long-chain perfluorinated chemicals (PFCs) action plan, December 30, 2009, http://www.epa.gov/oppt/existingchemicals/pubs/pfcs_action_plan1230_09.pdf.

15 International Agency for Research on Cancer, *A review of human carcinogens: Arsenic, metals, fibres, and dusts*, monograph, vol. 100C (Lyon: IARC, 2011), <http://monographs.iarc.fr/ENG/Monographs/vol100C/mono100C-14.pdf>.

16 *Hazards Magazine*, Sheffield, England, July 2014, <http://www.hazards.org/dust/silica.htm>.

Table 2-1. Health hazards associated with substances commonly found in building materials

NAME	USED IN	NOTABLE HEALTH HAZARDS
VOCs		
Benzene	Sealants, adhesives	Carcinogen, developmental toxicant, neurotoxicant
1,3-Butadiene	Synthetic rubber	Carcinogen
Ethyl acetate	Solvent	Irritant, acute toxicant
Formaldehyde	Adhesives, wood composites	Carcinogen, asthmagen
Isocyanates	Polyurethane, insulation	Asthmagen
Methylene chloride	Paint stripper, blowing agent	Carcinogen
Styrene	Insulation, resin, carpet backing	Probable carcinogen
Toluene	Solvent, polyurethane	Developmental toxicant
SVOCs		
Bisphenol A (BPA)	Paints, coatings	Endocrine disruptor
Halogenated flame retardants	Insulation, furnishings	Developmental toxicant
Perfluorinated compounds (PFCs)	Furnishings	Possible carcinogen, developmental toxicant
Phthalates	Plastics	Endocrine disruptor
INORGANICS		
Arsenic	Pressure-treated wood	Carcinogen, developmental toxicant
Crystalline silica	Processing masonry, concrete, glass	Carcinogen
Lead	Roofing, flashing	Reproductive toxicant, neurodevelopmental toxicant

ENDOCRINE DISRUPTORS

DEFINITION AND HEALTH EFFECTS. The endocrine system relies on hormones as chemical messengers that regulate the body's organ systems and that govern normal development, starting before birth. Endocrine disruptors interfere with these processes and can disrupt normal physiological functioning and development. Endocrine disruption is considered most problematic during fetal and childhood development, when interference in critical development sequences can produce lifelong effects.

EXAMPLES IN BUILDING MATERIALS. Endocrine disruptors can be found in a wide range of building materials. For example, epoxy resin-based paints and coatings are usually made from BPA, a chemical that has been shown to disrupt endocrine systems in ways that affect both neurological and reproductive development as well as priming some tissues—such as the breast and prostate—for later development of cancer.¹⁷

¹⁷ F.S. vom Saal et al., Chapel Hill bisphenol A expert panel consensus statement, *Reproductive Toxicology* 24(2) (2007): 131–38.

Another class of chemicals that include some known endocrine disruptors is ortho-phthalate plasticizers. Chemicals from this class are frequently added to polyvinyl chloride (PVC) to make this otherwise brittle polymer soft and malleable. Vinyl flooring, plastic molding, window treatments, and PVC carpet backing are all likely sources of ortho-phthalate exposure from building materials. Although a variety of chemicals can be categorized as ortho-phthalates, several have specifically been implicated as endocrine disruptors, causing reproductive tract abnormalities when exposure occurs during development.¹⁸

Several chemicals in the family of HFRs are also known endocrine disruptors with neurodevelopmental and reproductive health effects. These effects are discussed in more detail below.

NEUROTOXICANTS

DEFINITION AND HEALTH EFFECTS. Neurotoxicants are substances that damage the central nervous system or brain. They can have acute effects, such as dizziness and confusion, or they can cause chronic changes in behavior, motor control, or memory. When they affect children's cognitive development, they are referred to as neurodevelopmental toxicants.

EXAMPLES IN BUILDING MATERIALS. Lead is perhaps the most-studied neurotoxicant. For decades, it was added to oil-based paints to improve durability and color. Prenatal or early childhood exposures to lead can cause irreversible neurologic and behavioral changes, such as decreased IQ and hyperactivity. Children can be highly exposed by direct ingestion of chipped or peeling paint, by contact with lead-contaminated dust, by eating food grown in contaminated soil, or by playing in areas with contaminated soil. In adults, lead exposure can cause kidney failure, hypertension, immune dysfunction, and cardiovascular disease.¹⁹ The gradual elimination of lead from paint in the United States (voluntary phaseouts started in 1955, and lead paint was banned in 1978) and Europe (country-by-country phaseouts preceded a ban in 1989) has dramatically reduced this once-prevalent source of lead exposure for workers and for building occupants, particularly children.²⁰ But much of the world, including Russia, India, China, and Mexico, still uses lead-based paint and other lead-based materials. Even in areas that have banned lead paint, there remains a sizable reservoir in older buildings.²¹ Absent proper lead-abatement practices, the renovation or demolition of buildings containing lead paint and other materials exposes workers and residents to high levels of lead and contaminates surrounding soils. Lead is still added to some electrical cable insulation, and some materials used in roofing and flashing are lead based. Handling any of these can pose hazards to workers.

18 T. Colborn, F.S. vom Saal, and A.M., Developmental effects of endocrine-disrupting chemicals in wildlife and humans, *Environmental Health Perspectives* 101 (1993): 378–84.

19 World Health Organization, *Childhood lead poisoning* (Geneva: WHO, 2010), <http://www.who.int/ceh/publications/leadguidance.pdf?ua=1>.

20 Ibid.

21 R. Kessler, Lead-based decorative paints: Where are they still sold—and why? *Environmental Health Perspectives* 122(4) (April 2014), <http://ehp.niehs.nih.gov/wp-content/uploads/122/4/ehp.122-A96.pdf>.

REPRODUCTIVE AND DEVELOPMENTAL TOXICANTS

DEFINITION AND HEALTH EFFECTS. Reproductive and developmental toxicants adversely affect fertility, sexual function, and normal prenatal or early childhood development. Exposure to these substances can affect the reproductive capacity of both women and men and can cause birth defects, low birth weight, and developmental delays, such as impaired cognition.

EXAMPLES IN BUILDING MATERIALS. Some plastics contain chemical additives to enhance functional qualities, such as color and malleability. Ortho-phthalate plasticizers (described above) are classified as both developmental toxicants and endocrine disruptors. In wood and fiber composites, soy-based binders have emerged as attractive alternatives to formaldehyde-based glues, though their feedstocks include a resin manufactured from epichlorohydrin, which has been identified as a reproductive toxicant and probable human carcinogen.²²

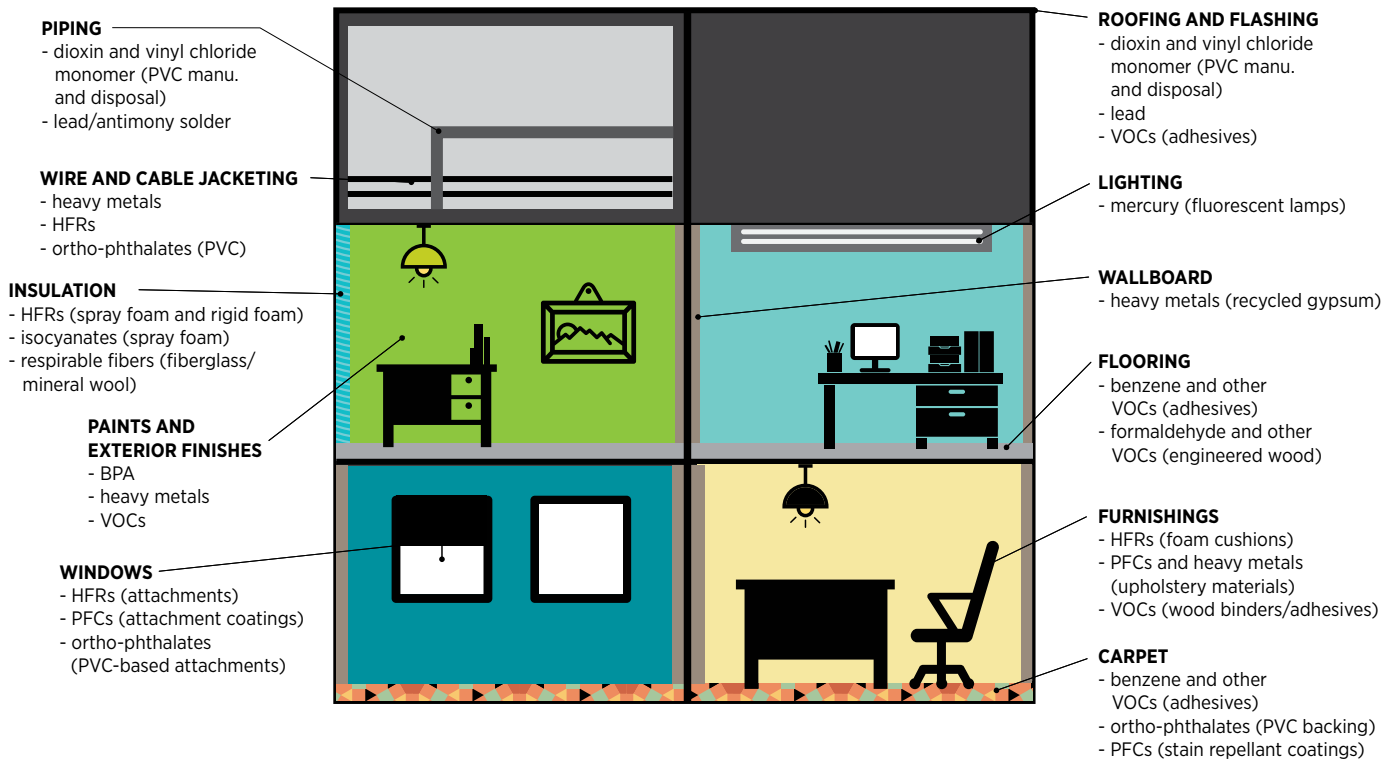


Figure 2-5. Examples of building material ingredients and byproducts that may be harmful during one or multiple stages of the materials life cycle. A typical structure can contain many substances that pose a hazard during the manufacturing phase, use phase, or other stage of the life cycle. Building professionals should be aware of these, and other examples, and evaluate trade-offs between alternative materials.

²² Healthy Building Network, Alternative resin binders for particleboard, medium density fiberboard (MDF), and wheatboard (May 2008), http://news.bio-based.eu/media/news-images/20090216-02/Alternative_Resin_Binders.pdf.

WHY FORM MATTERS

Substances can occur in many forms, shapes, and sizes, which influences their materials properties and their health effects. For example, the chromium used in stainless steel alloys is safe for food contact applications like knives, but the chromium dyes in oil-based paints are potentially very toxic. The chromium in the knife blade is different from the chromium in the dye in two important ways: (1) the chromium in the alloy is bound very tightly to the iron and carbon that make up the rest of the blade; and (2) the chromium found in the knife blade is in a safer form (Cr metal or Cr III), while the chromium in some dyes is (Cr VI), the toxic form made famous by the movie *Erin Brockovich*.

The health effects of ceramic particles, like titanium dioxide, can depend on their size and shape. Although larger particles may be safe, smaller particles (particularly those less than 10 μm , or approximately one-10th the diameter of a human hair) that can disperse in air and be inhaled readily are possible carcinogens. The very small, needlelike nature of ceramic mineral asbestos fibers is what allows them to be breathed in and causes them to remain lodged in our lungs, contributing to long-term toxic effects.

Because the hazards vary depending on the substance's form, it can be challenging to find relevant and reliable toxicity information. In these cases, a simple ingredient name without additional information does not provide enough information to determine human health hazards. Although it is a good idea to avoid highly toxic materials like lead and mercury whenever possible, it is important to consider how ingredients are being used and whether they are in a form that could be inhaled, ingested, or absorbed through the skin.

HEALTH CONSIDERATIONS ACROSS THE LIFE CYCLE

Since LEED's inception, Indoor Environmental Quality credits have emphasized reducing occupants' exposure to materials that release VOCs. Now, as information increasingly points to health effects of a wider variety of substances in building materials, there are opportunities to more specifically address potential health hazards by considering a full range of materials categories and their impacts on human health throughout their life cycle, from raw materials extraction or chemical synthesis through manufacture, installation, use, and end of life.

RAW MATERIALS EXTRACTION AND PROCESSING

Workers can be exposed to hazardous substances during extraction of the raw materials required to make building materials, even those designed to improve human health by reducing energy consumption to slow climate change. For example, compact fluorescent lightbulbs (CFLs), selected for their energy efficiency during use, require small amounts of mercury. When large economies such as the European Union switched to CFLs, those small amounts added up.

The surge in demand for these fixtures led to the reopening of long-shuttered mercury mines in eastern provinces of China, where the majority of CFLs are manufactured.²³ Operation of those mines has caused mercury poisoning among workers and polluted the surrounding environment.²⁴ Awareness of this issue can inform selection of safer alternatives, such as light-emitting diode (LED) bulbs, and help avoid shifting the risk from climate change to workers and communities exposed to heavy metals.

TRANSPORTATION

Materials are transported from one process site to another throughout the life cycle of the product. Although selecting lighter-weight materials can decrease the overall impact of the transportation phase of the materials life cycle, attention should be paid to transportation of hazardous feedstocks. Materials that depend on highly hazardous feedstocks perpetuate the potential for accidents that could jeopardize the health of large numbers of people near roads, railways, or ports.

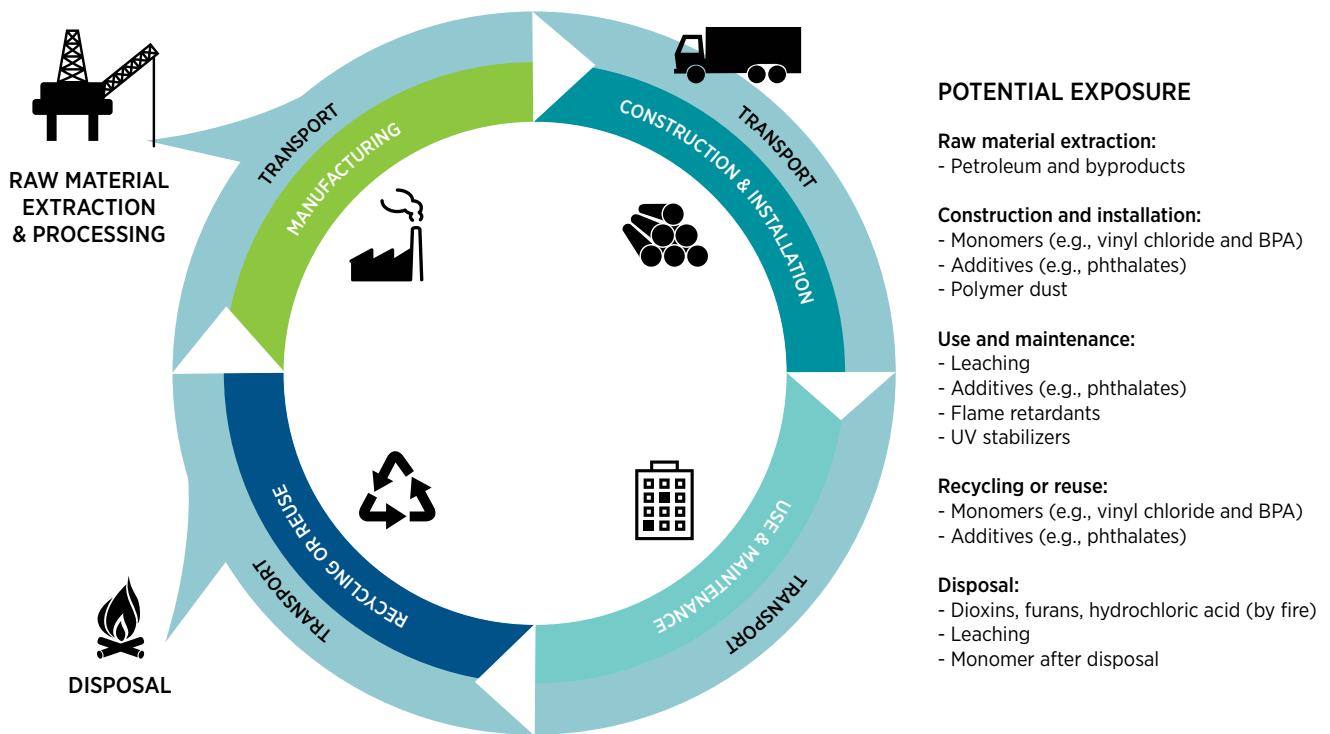


Figure 2-6. Life cycle of plastics

The materials that make a building can have complex life cycles that stretch far beyond the use phase. Plastics, for example, are built from petrochemical starting blocks, and undergo manufacturing and installation before we see them in buildings. At the end of their useful life, the materials are recycled or disposed of. Each phase of the life cycle could expose workers, building occupants, or surrounding communities to chemicals.

²³ <http://www.scmp.com/article/715102/toxic-mercury-mines-reopen-price-soars>.

²⁴ <http://www.theaustralian.com.au/news/world/deadly-cost-of-green-light-bulbs/story-e6frg6so-1225708008534>.

MANUFACTURING

For some materials, the largest opportunity for improvement occurs during processing or product manufacturing, when workers and surrounding communities can be exposed to hazardous substances. For example, styrene, used to make polystyrene insulation, carpet backing, and resins, is metabolized in the human body to form styrene-7,8-oxide, a chemical recognized as a probable human carcinogen.²⁵ A 1990 survey by the National Institute of Occupational Safety and Health found that more than 300,000 U.S. workers had been exposed to styrene.²⁶ Although occupational exposures have decreased with better protective practices, in 2005 styrene ranked fifth in the United States in fugitive air emissions, posing potential for exposure to surrounding communities as well.²⁷ Similarly, PVC production has historically released into the surrounding environment chlorine, cadmium, and mercury, as well as vinyl chloride monomer and dioxins, both of which are known human carcinogens.²⁸ A CDC study of residents and the environment near PVC plants in Mossville, Louisiana, found significantly elevated levels of dioxins in people ages 15–29 and over 45, as well as dangerously high dioxin levels in fish.²⁹

CONSTRUCTION AND INSTALLATION

In some cases, construction workers are the people most likely to encounter the hazardous portion of a product's life cycle. For example, spray polyurethane foam (SPF) systems, used for filling cracks and insulating roofs and exterior walls, can improve buildings' energy efficiency, but they typically rely on isocyanates. These chemicals are known sensitizers and irritants and are the leading attributable cause of asthma in the workplace.³⁰ Exposure occurs primarily during application of the SPF systems, when isocyanates are released from the uncured material. In fact, it is estimated that up to 15% of workers in the polyurethane industry suffer adverse effects from exposure to diisocyanates.³¹

USE AND MAINTENANCE

Increasing awareness of indoor environmental contamination from VOCs in building materials, finishes, and furnishings has informed several decades of prevention efforts, reducing the

25 International Agency for Research on Cancer, Monograph on evaluation of carcinogenic risks to humans, vol. 82 (Lyon: IARC, 2002), <http://monographs.iarc.fr/ENG/Monographs/vol82/mono82.pdf>.

26 National Toxicology Program, *Report on carcinogens* (Washington, D.C.: U.S. Department of Health and Human Services, 2011), p. 392, <http://ntp.niehs.nih.gov/ntp/roc/twelfth/roc12.pdf>.

27 International Agency for Research on Cancer, monograph update by P. Vineis and L. Zeise, <http://monographs.iarc.fr/ENG/Publications/techrep42/TR42-9.pdf>.

28 International Agency for Research on Cancer, Monograph on vinyl chloride, vol. 100F (Lyon: IARC, 2012), <http://monographs.iarc.fr/ENG/Monographs/vol100F/mono100F-31.pdf>; and K. Steenland et al., Dioxin revisited: Developments since the 1997 IARC classification of dioxin as a human carcinogen, *Environmental Health Perspectives* 112 (2004): 1265–68.

29 <http://www.atsdr.cdc.gov/HAC/pha/CalcasieuEstuary/CalcasieuEstuaryHCO31306.pdf>.

30 U.S. Environmental Protection Agency, Methylene diphenyl diisocyanate (MDI) and related compounds action plan (Washington, D.C.: U.S. EPA, 2011), <http://www.epa.gov/opptintr/existingchemicals/pubs/actionplans/mdi.pdf>; and idem, Toluene diisocyanate (TDI) and related compounds action plan (2011), <http://www.epa.gov/oppt/existingchemicals/pubs/actionplans/tdi.pdf>.

31 California Department of Toxic Substances Control's priority product profile, https://www.dtsc.ca.gov/SCP/upload/SPWP_RevisedSPF_9-14.pdf.

concentration of toxic solvents such as benzene and trichloroethylene in indoor air.³² New materials have been introduced, however, posing different kinds of challenges in the indoor environment.

For example, HFRs—a range of compounds containing bromine or chlorine added to insulation materials, furnishings, electronic equipment, and wires and cables—are SVOCs that readily migrate into the indoor environment, coating surfaces and attaching to dust particles. As a group, HFRs tend to bioaccumulate and persist in the environment, and they include compounds for which human or animal evidence points to reproductive toxicity, neurodevelopmental toxicity, endocrine disruption, and possible carcinogenicity. High levels of HFRs have been measured in the dust of homes, offices, and cars in the United States and Europe; the highest levels are in California, where until 2014 a stringent fire retardancy standard led to ubiquitous use of HFRs. People—and particularly young children—are exposed to HFRs through direct contact with products containing HFRs or ingestion of contaminated dust.³³

LEED SOCIAL EQUITY PILOT CREDITS

Health concerns often are linked to social equity and environmental justice when they affect people who are poor, work in dangerous and low-paying jobs, or live in communities exposed to hazards in the air, water, or soil. Three new LEED pilot credits begin to address issues of health and equity beyond the building's inhabitants:

- **Social Equity in the Project Team** encourages a project's team members to incorporate social equity by paying prevailing wages to construction workers, providing workforce development, or through corporate sustainability reports (CSRs).
- **Social Equity within the Community** encourages a project team to address identified needs and disparities in the community surrounding the project.
- **Social Equity within the Supply Chain** encourages social equity for those involved in the production of materials and products for our buildings, from raw materials extraction through final assembly through supplier assessments or codes of conduct that address basic human rights.

The Social Equity within the Supply Chain credit looks most directly at the impacts of materials. It goes beyond the environmental and health focus of the LEED v4 materials credits and addresses issues of human rights and fairness for all workers along the supply chain at all phases of the life cycle, including the use of child and slave labor.

See <http://www.usgbc.org/articles/usgbc-accelerates-social-equity-new-leed-credits> for more information.

32 C.J. Weschler, Changes in indoor pollutants since the 1950s, *Atmospheric Environment* 43: 153–69 (2009).

33 V. Babrauskas et al., Flame retardants in building insulation: A case for re-evaluating building codes, *Building Research and Information* 40: 738–55 (2012), <http://dx.doi.org/10.1080/09613218.2012.744533>.

END OF LIFE

Whether a building material's end of life occurs in a landfill, an accidental fire, or careful recovery, attending to potential hazardous exposures can ensure a safer built environment.

For example, wallboard represents about 15% of all construction and demolition debris, and in landfills bacteria can turn gypsum into hydrogen sulfide, a poisonous gas. Furthermore, water leaching through synthetic gypsum, as could be expected in a landfill, can have heavy metal levels more than 300 times the maximum allowable concentration in drinking water—despite relatively low levels of metals measured in the drywall itself.³⁴ Recovery and reuse of gypsum wallboard, or selection of safer substitutes, could help prevent these exposures.

In recent years, the use in concrete of additives such as fly ash has helped increase the recycled content, but it has also introduced potentially hazardous elements like heavy metals, which are present in fly ash in trace amounts and could leach from the concrete.³⁵ Many choices involved in green building pose similar inherent trade-offs, and designers are learning to weigh the value of recycled content against the potential for exposing workers to metals and other hazardous compounds that become airborne during demolition of fly ash-infused concrete.

The combustion of materials also can create carcinogenic byproducts, such as dioxins and furans from plastics and halogenated flame retardants, as well as other hazardous gases (e.g., NO_x, SO_x, and polycyclic aromatic hydrocarbons such as naphthalene) and particulates. Scrubber technologies may remove a significant portion of contaminants from incinerator output, but scrubber waste must then be disposed of in a way that is not vulnerable to leaks or spills. Furthermore, a large amount of construction material is disposed of in landfills where smoldering fires create an ideal environment for generation of these byproducts. A more sustainable destination for wood waste from mixed construction debris is as fuel in biomass combustion facilities.

In older buildings, recoverable materials are often mixed with hazardous materials, like asbestos. For certain vintages of buildings, for example, asbestos is a component of many materials, making recovery difficult and potentially hazardous to waste removal workers.

The array of hazardous substances to which people may be exposed across the life cycle of a building, as well as the complex considerations that go along with these exposures, can be daunting. As we understand more about the links between chemical exposures and prevalent health conditions, building professionals can take the lead in designing safe, high-performing buildings.

³⁴ <http://www2.buildinggreen.com/article/measuring-drywall-against-environmental-standards>.

³⁵ B. Walsh, Fly ash in building products: Proceed with caution, *Healthy Building News*, September 15, 2010. <http://www.healthybuilding.net/news/2010/09/15/fly-ash-in-building-products-proceed-with-precaution>.

WHY ARE WORKPLACE EXPOSURES SUCH A PROBLEM?

Because many manufacturing processes involve close contact with hazardous substances, workers are disproportionately affected by diseases linked to chemical exposure.¹ Although occupational diseases resulting from chemical exposures are ultimately avoidable, prevention hinges on awareness of the hazards posed by these substances. The standard regulatory mechanism for protecting workers from chemical exposure is the permissible exposure limit (PEL), the level considered safe for most workers, based on a 40-hour workweek. Yet the 450-some substances for which PELs have been set represent just 7% of the approximately 3,000 high-production-volume chemicals (those produced or imported at more than a million pounds per year). A 2007 analysis by California's Office of Environmental Health Hazard Assessment compared chemicals identified as carcinogens under the state's [Proposition 65](#) with the [federal PEL list](#) and issued these findings:

- PELs have not been set for 44 known carcinogens found in workplaces.
- The risk of cancer for six workplace carcinogens is estimated to be greater than one in 10 for workers exposed at the PEL.
- Of workplace chemicals suspected of causing cancer or reproductive harm, 60% are high-production-volume chemicals.²

In recognition of these issues, the U.S. Occupational Safety and Health Administration (OSHA) acknowledges on its website that “many of its permissible exposure limits (PELs) are outdated and inadequate for ensuring protection of worker health.”³ It recommends that “employers consider using ... alternative occupational exposure limits.” Some alternative guidelines include threshold limit values (TLVs) and workplace environmental exposure levels (WEELs) set by industrial hygiene associations.

1 J. LaDou, *Occupational and environmental medicine*, 2nd ed. (Stamford, Connecticut: Appleton and Lange, 1997).

2 California Environmental Protection Agency, *Occupational Health Hazard Risk Assessment Project for California: Identification of chemicals of concern, possible risk assessment methods, and examples of health protective occupational air concentrations* (Sacramento: Office of Environmental Health Hazard Assessment, December 2007), <http://www.cdph.ca.gov/programs/hesis/Documents/risksummary.pdf>.

3 U.S. Department of Labor, <https://www.osha.gov/dsg/annotated-pels/index.html>.

SUMMARY

- Building materials are increasingly recognized as a significant source of chemical exposures to building occupants, as well as to those who come in contact with these materials or their raw ingredients through manufacturing, construction, installation, and recycling, reuse, or disposal.
- The chemical contents of building materials are virtually all new in the past seven decades. Over this same time span, the incidence of some chronic diseases, such as asthma, diabetes, and some types of cancer, with hypothesized links to chemical exposures has risen sharply.
- Rather than being static or inert, building materials release their constituent chemicals into the indoor environment, and at other parts of their life cycle, into workplaces, ecosystems, water sources, and food chains.
- People are exposed to chemicals in building materials via air, food, water, and even dust and skin contact. This exposure is evidenced by biomonitoring, which has found dozens of synthetic chemicals and pollutants in a representative sample of the population.
- Although some health impacts of chemical exposure, like skin irritation, are short-lived, others, such as cancer or neurodevelopmental effects, have implications for a lifetime. The nature of the exposure itself may also be acute or chronic, depending on the substance's physical features (like vapor pressure or environmental persistence), as well as how people encounter it—whether they are exposed daily in a factory where the material is made, or briefly as an occasional visitor to a building.

TIPS FOR PRACTICE

START BIG. Begin with products you specify, purchase, or make in high volume. Research and compare the human health and environmental impacts of products at each phase of the life cycle. Focus on the big categories: source, transport, manufacturing process, ingredients, in-use performance, and end of life.

KNOW YOUR SUPPLY CHAIN. Manufacturers in particular should learn as much as possible about upstream suppliers and how their practices affect human health and the environment.

THE ABSENCE OF INFORMATION IS INFORMATION. As you learn more, note gaps and limitations in available information. These “blanks” represent sources of risk.

CONSIDER THE POTENTIAL FATE OF THE PRODUCTS YOU MAKE OR PURCHASE. Where will this product go after its primary use phase? Consider what you can do to influence the fate.

TALK TO EACH OTHER. Project teams should ask manufacturers about their human health and environmental practices and how much they know about the practices of their supply chain. Manufacturers should ask project teams how to improve products to meet their needs.

LEARN ABOUT TOOLS designed to analyze and distill environmental and human health information. These will be discussed in detail in Sections 3.4 and 3.5. Because new tools are emerging all the time, stay up to date with newsletters, webinars, and conferences.

CHAPTER 2. RESOURCES

ENVIRONMENTAL IMPACTS

- [Environmentally preferable building materials](#), U.S. EPA
- [Guidance on managing waste](#), U.S. EPA

CHEMICALS AND CHEMICAL CLASSES

- [Background on semivolatile organic compounds \(SVOCs\)](#) from University of California, Berkeley
- [Carcinogenic, mutagenic and reprotoxic substances](#), ANSES – French Agency for Food, Environmental and Occupational Health & Safety
- [OECD portal on perfluorinated chemicals](#)
- [Six Classes webinar series](#), Green Science Policy Institute
- [What are POPs?](#), Stockholm Convention on Persistent Organic Pollutants

REPORTS AND RESEARCH RELATED TO HUMAN HEALTH AND ENVIRONMENTAL IMPACTS OF MATERIALS

- [13th report on carcinogens](#), National Toxicology Program, National Institute of Environmental Health Sciences
- [Avoiding toxic chemicals in commercial building products](#), BuildingGreen
- [Fourth national report on exposure to environmental chemicals](#), Centers for Disease Control and Prevention
- Healthy Building Network [research and reports](#) (don't miss the archived reports link at bottom of the page!)
- [IARC monographs on the evaluation of carcinogenic risks to humans](#), International Agency for Research on Cancer (IARC)
- [Reducing environmental cancer risk](#), National Cancer Institute, President's Cancer Panel
- Silent Spring Institute [research and reports](#)

3.

CHAPTER 3. TOOLS FOR CHANGING THE BUILDING MATERIALS MARKET

3.1 Motivating change

- How has market failure contributed to the current state of building materials?
- How can green building interventions transform the market to improve building materials?

A HISTORY OF MARKET FAILURE

Just a few decades ago, the United States and most other countries had no national framework for controlling the human health and environmental impacts of materials and chemicals. The Cuyahoga River famously burned. The pesticide DDT turned the bald eagle into an endangered species. The Hooker Chemical Company dumped into Love Canal thousands of tons of toxic wastes, which sickened local residents after the waterway was filled to create a neighborhood with an elementary school. And in 1984 in Bhopal, India, a Union Carbide plant's accidental release of methyl isocyanate—a chemical involved in pesticide production—killed as many as 10,000 and injured hundreds of thousands of others. Such events prompted a U.S. community-based movement to address hazardous waste, raised public understanding that materials do not simply disappear at the end of their lives, and highlighted the fact that dangerous chemicals cannot always be safely managed.



Historical mismanagement of chemicals and resulting accidents prompted a U.S. community-based movement to address hazardous waste.

The underlying cause of those extreme events was a broad-based failure to anticipate and account for the human health and environmental costs of materials manufacturing, use, and disposal. In each case, market participants failed to recognize and internalize critical costs. Instead, decision-making systems relied on inadequate risk management and prioritized reactionary tactics over precaution and preventive measures to reduce or eliminate hazards before they caused harm. The risks and costs posed by particular practices—such as dumping untreated industrial wastewater into rivers, or contaminating the food chain with damaging pesticides—were typically externalized to society and individuals, reducing or eliminating incentives to understand and address problems.

ENVIRONMENTAL, HEALTH, AND SAFETY REGULATION

Beginning in 1970, changes in federal and state regulatory regimes sought to address those market failures and ensure that costs better reflected impacts. Notably, EPA was established to implement new laws generally intended to protect the environment and human health, and OSHA was established to set standards for worker safety, including human exposure to hazardous chemicals. The cooperative federalism model of several major environmental laws involved the states in pollution regulation as well. As Section 3.2 will show, these important steps and ensuing actions have helped control pollution sources, improve air and water quality, and reduce the health risks associated with exposure to hazardous substances. The core federal laws underlying these efforts, however, were based on the scientific and technical understanding of the era, and they were not designed to eliminate all risks to human health and the environment. These laws generally target single media (e.g., air, water), specific locations (e.g., workplace), and individual substances (e.g., asbestos). Such approaches can be effective; however, they contrast with current perspectives, which emphasize integrative design and interdisciplinary assessment.

In large part because of the success of those foundational policies, today's threats to the environment and human health are often less obvious than burning rivers or lethal chemical clouds. However, scientific and technical knowledge still lags far behind the development of new chemicals, commercial products, and real-world applications, and we have a fragmented and uneven understanding of the health and environmental impacts associated with building materials.

TRANSFORMING THE MARKET

Today, project teams often lack the information about human health and environmental attributes of materials (described in Chapter 2) they need to make informed product decisions. Consequently, reduced risk to human health and the environment does not and, as a practical matter, cannot be quantified and hence factored into decisions about the design and specification of building materials and buildings as a whole. This contributes to the misallocation of capital (e.g., purchasing inferior products when superior substitutes are available) and unanticipated exposure to hazards (e.g., DDT-impregnated wallpaper or mobile homes with toxic levels of formaldehyde). Without a change in these conditions, the consideration of human health and environmental attributes will be challenging at best.

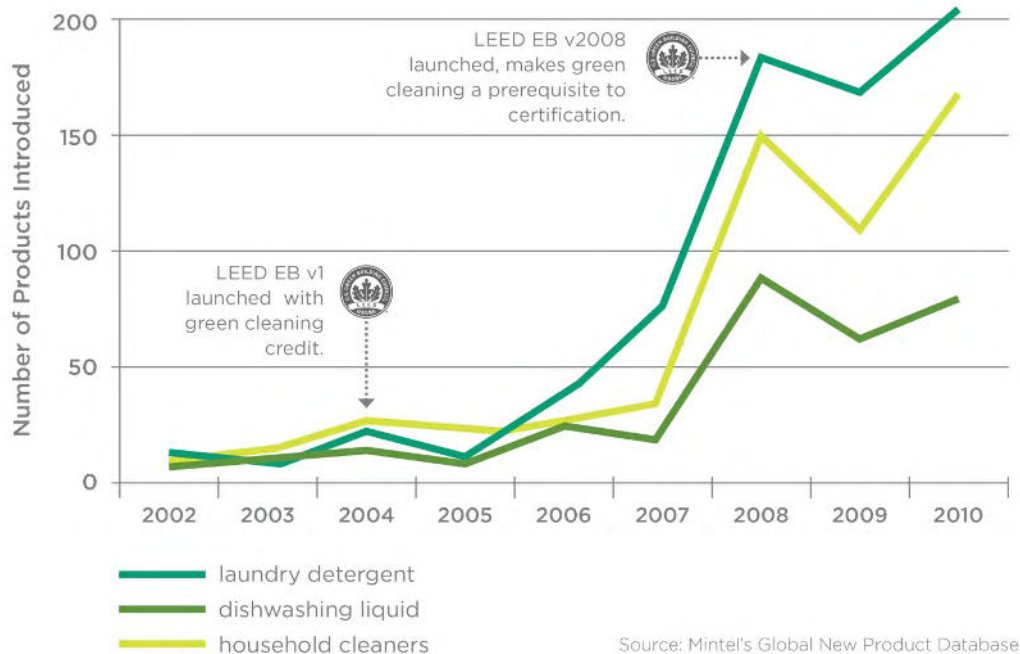


Figure 3-1. Product introductions with green claims, 2002–2010
 The availability of compliant cleaning products has increased since the introduction of LEED for Existing Buildings green cleaning requirements.
 Courtesy: U.S. Green Building Council

Experience has shown that market transformation can be a powerful force and drive permanent change. For example, a market transformation approach and interrelated factors, including awareness, education, and advocacy, accelerated the availability and use of green cleaning products across the country over a period of just five years (Figure 3-1). Similarly, consumer products have undergone a transformation in energy efficiency because of a mix of voluntary and regulatory approaches. Although some jurisdictions have gradually adopted more stringent legally binding energy codes, voluntary standards, such as the recognition of beyond-code levels of energy performance through rating systems like LEED, have accelerated change by helping market participants gain experience with higher levels of performance and by creating demand. In the case of energy efficiency, the energy crisis, fuel costs, regulatory codes, and voluntary standards have all played a role to push and pull the market toward higher performance. Similar opportunities are on the horizon for building materials.

The green building movement has always complemented and accelerated traditional policy mechanisms (Figure 3-2). This reflects its emphasis on market leadership through definition of best practices and, consequently, the creation of opportunities for competitive differentiation. This approach has particular relevance to markets for building materials, where regulatory and policy measures face persistent challenges and long-standing limitations. The green building movement thus has an important role in creating new sources of actionable information and helping decision makers recognize and address externalities.

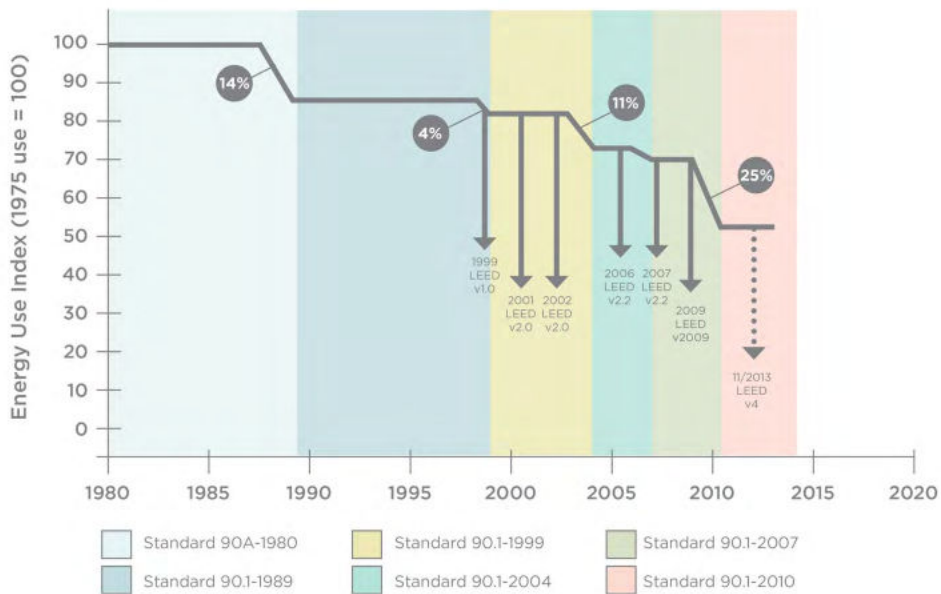


Figure 3-2. Relationship between ASHRAE Standard 90.1 and LEED requirements
 Design energy goals for new construction have become more stringent since 1970, as reflected in ASHRAE Standard 90.1 requirements. LEED requires projects to outperform this baseline, thereby accelerating market transformation.
 Courtesy: U.S. Green Building Council

For example, in the absence of clear federal standards for buildings that promote human health and environmental dimensions of materials, voluntary programs like LEED, the International Living Future Institute’s [Living Building Challenge](#), and Delos’s [WELL Building Standard](#) are creating new ways to identify buildings that provide superior conditions for occupants, reduce the use of potentially hazardous substances, and avoid environmental damage. These programs have new, ambitious, and clearly

articulated goals in these areas. Yet the ultimate success of these efforts relies on new sources of information and tools that are just beginning to become available to practitioners.

GREEN BUILDING INTERVENTIONS TO ACCELERATE CHANGE

The green building movement seeks to accelerate change in the status quo by defining a goal for superior performance, then implementing a series of targeted interventions that enable markets to function efficiently by systematically addressing information gaps and internalizing costs and impacts. These interventions include reporting, evaluation, preferential selection, and innovation (the market transformation cycle, introduced in Chapter 1) coupled with awareness, education, and advocacy (Figure 3-3). If successful, these interventions will contribute directly to a transformed market with products that are optimized to reduce human health and environmental impacts.

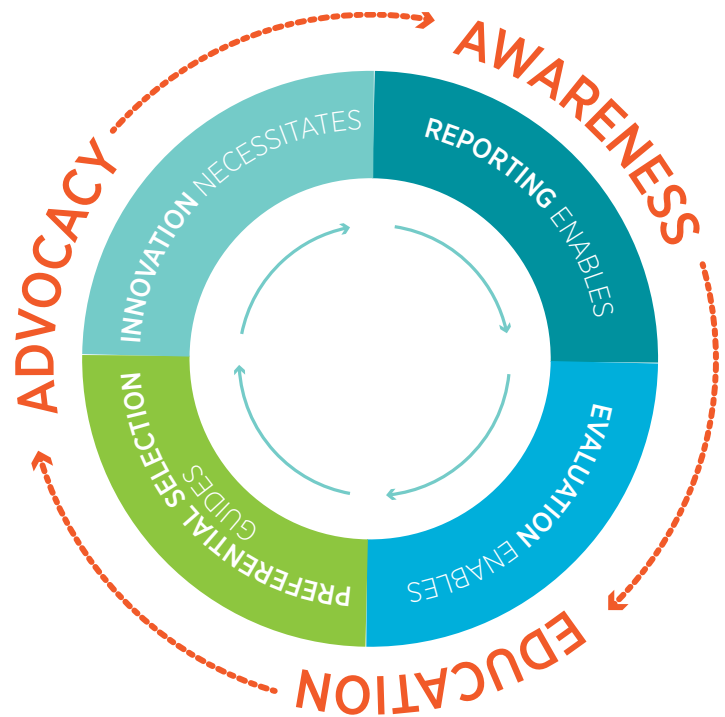


Figure 3-3. Market transformation mechanisms
 Targeted interventions, such as reporting, evaluation, preferential selection, and innovation, enable markets to function more efficiently. Awareness, education, and advocacy further assist and accelerate the market transformation cycle.

DEFINING A GOAL. Green building begins by providing a practical vision for a desired level of superior performance. For example, as a consensus-based “standard of standards,” LEED is a collection of specific references to best practices (e.g., green cleaning), third-party guidelines (e.g., Cradle to Cradle Certified), and performance levels (e.g., ventilation rates) that together define the essential elements of a high-performance green building. This bounds the concept of “green” and provides a common language for communication.

REPORTING. Information is the foundation for efficient markets. Consequently, efforts to encourage disclosure and create accessible, actionable information about building materials represent the foundation for market transformation. As will be described in more detail in Sections 3.4 and 3.5, schemes like environmental and health product declarations offer a standardized way to report this information, create systematic disclosure, and foster healthy, competitive markets.

EVALUATION. Once raw information about materials ingredients and processes is available, standardized methods for evaluating this information make it meaningful to decision makers. Put simply, we need to synthesize complex data and provide straightforward guidance on the attributes and performance that represent better choices.

PREFERENTIAL SELECTION. Once meaningful information is available, decision makers can act on it by choosing products that meet their design goals and purchasing criteria. As a wider range of data, such as human health and environmental attributes, is reported and distilled into actionable information, decision makers are able to expand their goals and criteria.

INNOVATION. As specifiers and purchasers expand their design goals and purchasing criteria, manufacturers are motivated to improve their products and processes, optimizing them to be fundamentally safer throughout their life cycle. The innovation process often involves navigating complex trade-offs between competing demands within a finite set of practical choices. For example, manufacturers must consider the consequences of alternative ingredients for human health and the environment as well as traditional considerations, such as function, durability, aesthetics, and cost. There are usually no single “right” answers to these challenging questions, and progress is achieved through a combination of technology, art, science, and stakeholder communication.

AWARENESS, EDUCATION, AND ADVOCACY. The market transformation cycle operates most efficiently when project teams and manufacturers are aware of and understand the information and have the expertise needed to apply it to building materials decisions across the life cycle of built environments. Consequently, effective market transformation must also transform the workforce such that professionals understand how and why to ask new questions about building materials and then use this information to guide specification, purchasing, use, and engagement with manufacturers and the supply chain. This workforce will need to develop the scientific and technical skills necessary to critically evaluate claims, understand the role of current and future tools, and ultimately help decision makers take actions that protect human health and the environment.

It is often tempting to focus on only one intervention, such as commercializing a new product or increasing ingredient disclosure. However, these mechanisms are part of a system. Effective and sustained market transformation engages the entire system to ensure a steady flow of new ideas and practical tools that support sustained improvements over time. Examples of such

sustained, long-term transformations include appliance energy efficiency¹ and energy output from photovoltaic panels,² both of which have markedly increased over the past several decades. Comparable patterns of investment will be needed to reduce the life cycle impacts of building materials. The growth of such investments and the success of resulting products will provide indicators of the success of the market transformation process.

SUMMARY

- Project teams often lack the information about human health and environmental attributes of materials they need to make informed product decisions. Consequently, human health and environmental attributes cannot be factored into decisions about materials. This contributes to the misallocation of capital (e.g., purchasing inferior products when superior substitutes are available) and unanticipated exposures to hazards.
- Experience has shown that market transformation can be a powerful force and drive permanent change. The green building movement has always complemented and accelerated traditional policy mechanisms and plays an important role in creating new sources of actionable information that help decision makers recognize and address externalities.
- The green building movement seeks to accelerate change in the status quo by defining a goal for superior performance then implementing a series of targeted interventions that enable markets to function efficiently by systematically addressing information gaps and internalizing costs and impacts. These interventions include reporting, evaluation, preferential selection, and innovation coupled with awareness, education, and advocacy. If successfully applied to building materials, these interventions will contribute directly to a transformed market with products that are optimized to reduce human health and environmental impacts.

¹ The American Council for an Energy-Efficient Economy's [website](#) provides information on the history and effectiveness of appliance standards.

² The National Renewable Energy Laboratory's [National Center for Photovoltaics](#) tracks investment and achievements in PV manufacturing.

3.2 Foundational public policies

- What do building professionals need to know about public policies related to building materials?
- What are the strengths and limitations of current public policies to protect human health and the environment?
- What are the most important federal, state, local, and foreign policies?
- What are the gaps between common expectations about materials management and actual policy?

Buildings and their materials contents are subject to an array of public laws, regulations, codes, and standards, which we refer to collectively as policies. Some policies are intended to help ensure that buildings are structurally sound, durable, fire resistant, and safe for construction workers and building occupants. Other requirements apply during production and disposal of building materials to, for example, control pollution, reduce the risk of accidental chemical release, and limit occupational exposures of workers.

These policies provide a foundation for managing human health and environmental risks associated with building materials' production, use, and disposal, but their patchwork nature has left various aspects of these processes under- or unregulated.

This chapter does not present an exhaustive review of policy instruments that affect building materials; instead, it provides examples of major laws and regulations intended to protect human health and the environment as well as some of the limitations in these policies. The discussion is divided into four parts: U.S. federal government policies, state and local policies, policies of other countries, and voluntary standards.

U.S. FEDERAL GOVERNMENT POLICIES

Federal policies that affect building materials include generally applicable environmental and safety regulations and a few federal laws that target specific products. In many cases these laws are implemented through regulations issued by a federal agency. In addition, executive orders impose requirements on executive agencies acting in their role as owners in purchasing building materials.¹ Some of the most important laws that affect building materials and their impacts on human health and the environment are presented in Table 3-1.

¹ For example, several executive orders have provided mandates for federal government procurement of environmentally preferable products in areas such as energy efficiency and reduced impacts on the environment and human health. These mandates advance the development and recognition of products with preferred attributes but do not impose generally applicable requirements on products and manufacturers.

Table 3-1. Selected U.S. laws related to environmental and health impacts of building materials

LAW*	SUMMARY
Environmental protection	
Clean Air Act	Requires EPA to set and enforce air quality regulations, including ambient standards, emission permits, and industry-specific contaminant emission standards
Clean Water Act	Requires EPA to set and enforce water quality regulations, including guidelines for water quality, discharge permits, and national industry-specific wastewater discharge standards
Resource Conservation and Recovery Act	Authorizes EPA to regulate generation, transportation, treatment, storage, and disposal of hazardous waste, and to set provisions for solid waste management, including materials recycling
Lacey Act	Prohibits importation of illegally harvested wood
Chemicals production and use	
Toxic Substances Control Act	Establishes conditional authorities for testing, reporting, regulating, or restricting certain chemicals
Federal Insecticide, Fungicide, and Rodenticide Act	Establishes system for registration and review of pesticides, including antimicrobials
Federal Hazardous Substances Act	Authorizes regulations and restrictions of certain household hazardous substances meeting criteria
Formaldehyde Standards for Composite Wood Act	Requires EPA to set standards for formaldehyde emissions from composite wood products
Emergency Planning and Community Right-to-Know Act	Requires covered companies to report certain information on hazardous and toxic chemicals at facility level, including releases to environment above thresholds; resulted in Toxics Release Inventory
Worker protection	
Occupational Safety and Health Act	Authorizes standards for workplace health and safety, including chemical exposure
Consumer products safety	
Consumer Product Safety Act	Authorizes safety standards for certain consumer products on commercial market
Flammable Fabrics Act	Restricts sale of highly flammable fabrics in furnishings, among other things

*References to laws are as amended

These federal laws and regulations directly or indirectly address certain aspects of the life cycle of building materials or their constituent ingredients. Each law focuses on specific media, concerns, pollutants, or industries. Some are more successful at achieving their intended purpose than others. It is useful for building professionals to have a basic understanding of this policy framework and the protections it does and does not provide. The following sections outline selected policies relevant to building materials and their impacts.

ENVIRONMENTAL PROTECTION

The major federal environmental protection laws were enacted in the early to mid-1970s to address growing concerns about pollution of air, water, and soil and the effects on the environment and human health. These laws have been amended over time to respond to new information and concerns.

The *Clean Air Act* requires EPA to establish ambient air quality standards for designated pollutants² at levels protective of public health and welfare. These ambient standards apply throughout the country. EPA also establishes regulations limiting emissions of those and other hazardous pollutants from specific industries. The Clean Air Act does not authorize EPA to regulate indoor air quality.

The *Clean Water Act* gives EPA the authority to regulate discharges of pollutants to U.S. waters and to set criteria by which states establish quality standards for surface waters. Regulated discharges include pipe discharges, such as from factories and wastewater treatment plants, as well as some sources of stormwater—notably, from city drains and industrial and construction sites. Some sources of stormwater, which may include runoff from roofs, driveways, or parking surfaces, are not regulated under the Clean Water Act.

The *Resource Conservation and Recovery Act* (RCRA) focuses on the management of hazardous materials at the end of their useful life, when they are treated or disposed of as waste. Under RCRA, EPA regulates landfilling, incineration, energy recovery, and recycling of hazardous wastes. Among other things, RCRA created a cradle-to-grave system to track hazardous wastes from generation—such as at a manufacturing facility—to ultimate disposal. RCRA also prohibits open dumping of nonhazardous solid wastes. EPA has issued technical guidelines, but states have the primary regulatory role over solid wastes.

Two other important federal environmental laws are the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA, also known as Superfund), which provides procedures for identifying and remediating contaminated sites, and the *Safe Drinking Water Act*, which sets standards to protect drinking water from natural and man-made contaminants.

Early environmental laws focused on treatment and disposal. In 1990 the U.S. Congress enacted the *Pollution Prevention Act* to promote the prevention of pollution at the source; the premise is that source reduction is “fundamentally different and more desirable than waste management and pollution control.” Rather than imposing requirements directly on manufacturers, this act charges EPA with developing and implementing a strategy to promote source reduction, including collaboration with industry.

Other areas of law relate to raw materials. In the United States, the extraction and harvesting of raw materials, such as minerals and wood, on federal land is generally subject to some regulation, although materials extraction or harvesting on private land is generally not subject to federal regulation. Even on federal lands, the regulations have limitations. For example, hardrock mining regulations lack specific environmental standards. Ancillary activities, such as discharging

² Referred to as “criteria” pollutants, these currently include ozone, particulate matter, carbon monoxide, nitrogen oxides, sulfur dioxide, and lead.

pollutants to streams, may or may not trigger regulations under broad environmental laws. For example, contaminants in stormwater from logging roads are not subject to federal permits and standards. Imports of raw materials may be subject to regulation. For example, the *Lacey Act* prohibits the importation of illegally harvested wood.

CHEMICAL PRODUCTION AND USE

The *Toxic Substances Control Act* (TSCA) is the primary federal law addressing the regulation of chemicals manufactured and used in industry and gives EPA the following authorities related to chemicals in commerce:

- **CHEMICAL NOTIFICATION.** TSCA requires chemical manufacturers and importers to inform EPA of new chemicals and, if required by EPA, new uses. More than 84,000 chemicals are listed in the TSCA inventory, but it is not known how many are in use today.
- **CHEMICAL TESTING.** TSCA does not require manufacturers to test substances for health or environmental effects, but they must submit results from tests voluntarily conducted for new chemicals.
- **TOXICITY AND EXPOSURE DATA.** If EPA can adequately demonstrate that an existing substance poses certain “unreasonable risks,” it may issue rules to require manufacturers to submit available data or conduct additional testing.

TSCA has well-documented limitations.³ For example, although TSCA states that manufacturers are responsible for testing chemicals, EPA’s authorities to require testing have proved exceedingly difficult to use. As a result, of the 84,000 chemicals in the TSCA inventory, fewer than 200 have been comprehensively tested under the TSCA requirements (Figure 3-4).



Figure 3-4. Chemical testing requirements and restrictions under TSCA

³ See, for example, Environmental Defense Fund, <http://www.edf.org/health/policy/chemicals-policy-reform> (accessed October 6, 2014); U.S. Government Accountability Office, Toxic substances: EPA has increased efforts to assess and control chemicals but could strengthen its approach, GAO-13-249 (Washington, D.C.: GAO, 2013).

Another often-cited issue is the law's approach to the 62,000 chemicals that were in use when TSCA was enacted in 1976. For these, EPA must be able to identify an "unreasonable risk" before it can require the testing necessary to prove an unreasonable risk, a requirement that some have termed a catch-22.

Developing evidence of risk to support EPA's use of its authorities under TSCA is costly and can take many years, and federal funds to support such research are limited. Moreover, TSCA can act as a disincentive for manufacturers to study health effects, since they do not have to report what they do not know. Finally, EPA has the burden to prove a chemical poses an unreasonable risk before the agency can restrict it—which EPA has done successfully fewer than 10 times.⁴ Although a broad array of legislators, organizations, and industry groups have called for amendments, TSCA remains in effect as the primary industrial chemical management law in the United States.

REGULATION OF ASBESTOS IN THE UNITED STATES

Although the dangers of asbestos have been recognized for more than a century and 55 countries have banned its use, the United States lacks a comprehensive federal law or regulation addressing asbestos. Instead, Clean Air Act regulations specify work practices for asbestos during demolitions and renovations, and the Occupational Safety and Health Act sets standards for worker exposures to asbestos. In 1989 EPA published final regulations under TSCA, banning the use of asbestos in most applications, but the Supreme Court vacated the rule. Today, asbestos is restricted from many commercial products but not from building materials such as pipe insulation, vinyl-asbestos flooring, roofing felt, mill board, and asbestos-cement pipe.

The *Federal Insecticide, Fungicide, and Rodenticide Act* (FIFRA) provides for review and registration of pesticides, including antimicrobials. Beyond their direct use on pests in a building (e.g., in sprays or traps), pesticides also are used in some building materials. Conventional pressure-treated wood, for example, contains the antimicrobial chromated copper arsenate, and house paints contain biocides like triclosan. Pesticides are also applied to many agricultural crops used for manufacturing biobased products.

Federal law generally does not specifically regulate building materials' chemical content or emissions, with a few notable exceptions. For example, the 2010 *Formaldehyde Standards for Composite Wood Products Act* sets national emissions standards for formaldehyde in plywood, particleboard, and MDF. The standards do not become effective until EPA issues implementing regulations, which EPA proposed in June 2013 but has not yet finalized. In 2007, however, California issued its own regulations (see below), and the market has responded. Several building material suppliers already offer wood products that contain no added formaldehyde.

⁴ The chemicals that EPA has regulated under TSCA include PCBs, fully halogenated chlorofluoroalkanes (related to protection of the ozone layer), dioxin, asbestos (significant portions of the regulations were remanded by a federal court and never went into effect), and hexavalent chromium. EPA also issued rules for four new chemicals used as metalworking fluids. Under targeted provisions of TSCA or other laws providing authority for specific chemicals, EPA has regulated renovation of houses with lead paint and chlorofluorocarbons and has proposed a regulation for formaldehyde. EPA has developed action plans for another 10 chemicals or classes of chemicals.

EPA has also issued regulations on VOC emissions from architectural coatings and certain consumer products, including cleaners, polishes, and adhesives. Notably, these regulations were issued not to address indoor air quality but under the Clean Air Act authority to limit VOCs as a precursor of ozone, which has significant health and environmental effects.

The *Emergency Planning and Community Right-to-Know Act* of 1986 (EPCRA) requires companies to report information on hazardous and toxic chemicals at their facilities to help communities plan for emergencies. Facilities that manufacture, process, or otherwise use more than the specified quantities of any of some 600 listed chemicals and chemical categories must report to the state and local fire department the quantities and locations of hazardous chemicals at the facility. In addition, facilities must report annually the amounts of these chemicals released to the air, water, or soil. EPA makes this information available to the public through the [Toxics Release Inventory \(TRI\) database](#). Although EPCRA does not regulate these chemicals or releases, its disclosure requirements have provided significant incentives for companies to reduce chemical releases.

WORKER PROTECTION

The federal *Occupational Safety and Health Act* authorizes OSHA to regulate hazardous substance exposures at worksites. This includes standards for materials handling, storage, and use; personal protective equipment; chemical information disclosure; worker education; and maximum permissible exposure limits for some hazardous substances.

OSHA's standard-setting authorities are limited, however. For example, although the Occupational Safety and Health Act provides authority to issue emergency temporary standards, OSHA used it only nine times between 1971 and 1983 and not at all since. A federal report noted that although OSHA has issued specific exposure limits for some hazardous substances, such as formaldehyde, the agency indicated it would be impossible to test and establish specific exposure limits for all chemicals present in the modern workplace.⁵

The [OSHA Hazard Communication Standard](#) sets criteria for chemical identification, product and container labeling, worksite postings, and worker training. Over the past decade, many of the workplace information graphics, terms, and practices have been standardized to align with the international [Globally Harmonized System for Hazard Classification and Labelling of Chemicals](#) (described in Section 3.5).

⁵ Government Accountability Office, *Workplace safety and health: Multiple challenges lengthen OSHA's standard setting*, GAO-12-330 (Washington, D.C.: GAO, 2012).

CONSUMER PRODUCTS SAFETY

The [Consumer Product Safety Commission](#) has responsibilities and authorities for the safety of certain consumer products under several laws. Under the *Consumer Products Safety Act*, the commission has authorities related to ensuring the safety of articles and components sold to consumers for use in and around a residence, school, or otherwise. The majority of products it regulates are children's products, but the commission has issued regulations regarding some furnishings (e.g., carpet and lead paint on furniture), fixtures (e.g., ceiling fans), architectural glass, some adhesives, and cellulose insulation. Under the *Flammable Fabrics Act*, the commission regulates highly flammable interior furnishings, including carpet. In another example, the *Federal Hazardous Substances Act* resulted in a ban on the sale of lead-containing paint for most consumer and residential uses. Congress sharply reduced the lead limit effective beginning in 2011. Generally, however, the commission's regulations related to building products, like water-repellent mixtures for masonry, roof coatings, and lacquers, are limited to requiring labels when certain components exceed the exempt thresholds and conditions.

STATE AND LOCAL POLICIES

Building materials may also be subject to regulatory systems of states and localities, depending on their place of manufacture, sale, and use. States can serve as laboratories for experimentation by creating new policies that may later influence federal programs (Figure 3-5). State regulations typically cannot be less restrictive than any corresponding federal regulations, but some can go beyond. For instance, several states prohibit the sale of urea-formaldehyde foam, and some states restrict sales of products containing chemicals such as certain brominated flame retardants and mercury. States such as California and New York represent such a substantial share of the national market that their more restrictive standards can become de facto standards for the entire country when a manufacturer makes a single version of a product for nationwide distribution.

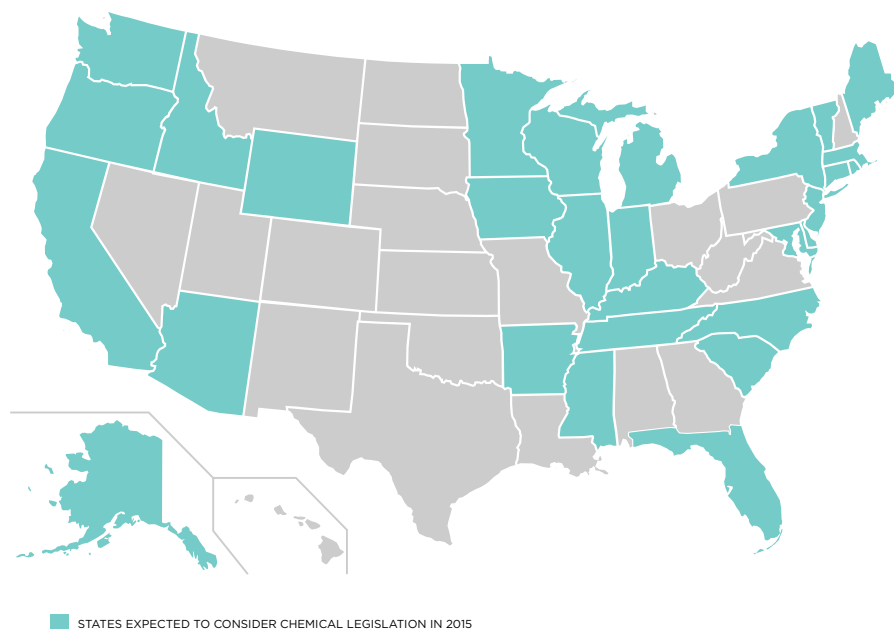


Figure 3-5. States expected to consider chemical legislation in 2015
Image created based on data from [saferstates.com](#)

California is a leading state in several areas. For example, CARB set rigorous emissions standards for formaldehyde in certain plywood and MDF materials in 2007. Three years later, Congress followed suit. Currently, California is implementing a new approach to reducing toxics in consumer products. Under a 2010 state law, the [Department of Toxic Substances Control](#) has issued regulations identifying candidate chemicals of concern and establishing a process by which manufacturers of priority products will be required to conduct an alternatives assessment to determine whether safer and more preferred chemicals or production methods could replace the chemicals of concern. In response, state regulators can take further action to support the safer substitutes, which could lead to safer choices in building materials. Thus far, the department has identified three priority products, including certain spray polyurethane foam products and paint and varnish strippers containing methylene chloride.

Another notable California initiative is the state's [Proposition 65](#), which voters approved in 1986. Proposition 65 requires the state to publish a list of chemicals known to cause cancer or birth defects or other reproductive harm. This list currently includes approximately 800 chemicals. Among other things, businesses must provide a clear and reasonable warning for products that contain above-threshold amounts of a listed chemical. Thus, for example, electrical wires and cords often have a Proposition 65 warning label associated with lead in their surface coverings. The cost and potential stigma of labeling to comply with this type of disclosure requirement can give manufacturers incentive to find safer alternative materials.

FLAME RETARDANTS AND FURNITURE

For decades, many furniture manufacturers added brominated flame retardants to their upholstery foam to meet a California requirement ([Technical Bulletin 117](#)) that the material be resistant to an “open flame” test. Using materials that could pass this test became a de facto standard across the country. Scientific evidence, however, demonstrated that these chemicals could pose serious health concerns, which led to studies of whether the flame-retardant foam truly increased fire safety. In 2013 California revised the regulation ([Technical Bulletin 117-2013](#)) to require a “smolder-only” test—a requirement deemed sufficient to ensure the fire safety of upholstered furniture. The new requirement can be met with barrier materials (like wool) and smolder-proof cover fabrics (which prevent furniture from igniting) rather than flame-retardant foam.

Local government requirements affect building materials through municipal building codes that set standards for building layout, siting, safety, sanitation, light, and ventilation. Most municipalities adopt their provisions from model building codes. Since the 1990s, the [International Building Code](#) (IBC) has become the standard model building code in the United States with most municipalities developing their provisions from it.

Beyond the IBC model codes, new models attempt to establish environmental requirements. The International Green Construction Code (IGCC) is the first model code intended to consider environmental sustainability for the entire construction project, from design to final occupancy. Thus far, the IGCC has been the basis for codes adopted by the District of Columbia and is

being considered by several other jurisdictions. [*CALGreen*](#) is a state building code, issued by the California Building Standards Commission in 2010 and subsequently updated, that sets mandatory green building requirements for residential and nonresidential construction in California.

POLICIES IN OTHER COUNTRIES

Governments of other countries also regulate aspects of building materials, significantly differing from U.S. regulations in some areas. These regulatory efforts may affect products sold or produced in the United States. Just as state regulations may become de facto standards for the entire United States, a manufacturer with global product distribution may choose to make a single product that meets the most restrictive requirements of the countries where the product will be sold. In addition, U.S. companies may adopt technologies and innovations developed abroad in response to other countries' regulations. In other instances, building products used in the United States may be made in another country where their manufacture may be subject to that nation's laws.

In chemical policy, the European Union is a leading influence worldwide. Regulations relevant to building materials include the following:

- [*Biocide Directive*](#). This regulation prohibits the use of 900 pesticides, some of which (e.g., triclosan) remain authorized for use in the United States.
- [*Restriction on Hazardous Substances Directive*](#). This directive restricts the use of lead, cadmium, mercury, hexavalent chromium, and two brominated flame retardants in electronic products, including electric refrigerators, ranges, dishwashers, and other appliances and devices. It is anticipated that additional substances will be restricted.

In 2007 the European Union overhauled its chemical management policies by instituting the [*Registration, Evaluation, Authorisation and Restriction of Chemicals*](#) (REACH) regulation. REACH requires manufacturers to disclose chemical and materials data, including environmental and human health effects. Manufacturers and importers of products manufactured or sold in EU countries may also have obligations under REACH, such as notifying the European Commission of products containing an above-threshold amount of an identified "substance of very high concern" (SVHC). REACH is discussed in more detail in Section 3.5.

A small but influential set of international treaties also addresses building materials, either within the signatory countries or globally if the treaty changes worldwide practices. Two such treaties are notable:

- [*Stockholm Convention on Persistent Organic Pollutants*](#). The parties agree to take actions to eliminate or reduce the manufacture and use of certain pesticides and other persistent bioaccumulative toxicants. Although the United States has not ratified the treaty, the treaty limits the use of restricted chemicals in products sold internationally.
- [*Montreal Protocol on Substances That Deplete the Ozone Layer*](#). The parties agree to reduce the manufacture and use of chlorofluorocarbons and other ozone-depleting chemicals. The Montreal Protocol has been adopted by all recognized nations.

VOLUNTARY STANDARDS

Standards developed by professional organizations and private entities also influence the content and life cycle impacts of building materials. Many of these standards have been adopted to address materials' strength, durability, or fire safety; they affect human health and the environment only indirectly. Some of these standards become requirements when adopted in government codes, and others remain voluntary.

Voluntary standards adopted by professional associations are typically developed by technical committees of experts and stakeholders and may also be referred to as model codes. These standards often focus on the safety and structural integrity of materials or on a specific topic, such as energy efficiency in [ASHRAE](#) standards. Most are not expressly intended to support green buildings or safe materials.

Recently, however, some associations have been “greening” voluntary standards for specific building products and processes. For example, the [Business and Institutional Furniture Manufacturers Association](#) (BIFMA) has several standards focused on sustainable furnishings, such as its standard for formaldehyde and VOC emissions and its furniture sustainability standard. The Carpet and Rug Institute has developed [Green Label Plus](#) for low-emissions carpet and the Resilient Floor Covering Institute has developed [FloorScore](#), a similar standard for resilient floor coverings.

CHALLENGES AND OPPORTUNITIES FOR THE U.S. POLICY FRAMEWORK

Even though the United States has federal policies aimed at protecting air, water, and land, as well as consumers' health and safety, these policies tend to be fragmented and poorly coordinated and do not provide a holistic and nuanced consideration of relative hazard, exposure, and risk. This piecemeal approach to policy makes our buildings and communities safer than they would otherwise be, but it also leaves significant gaps in protecting human health and the environment.

Even when government policies address building materials and their uses, the regulations and laws often lag behind advances in science. For example, the risk assessments conducted as a basis for setting human safety regulations have often failed to consider the unique vulnerabilities of children, even though researchers have long recognized that some chemical exposures in childhood may cause adverse health outcomes.

In some cases government policies can actually inhibit the selection of greener building materials. For instance, federal construction specifications often require that building materials be sourced from U.S. suppliers, and the typical government requirement that building material specifications list a minimum of three likely suppliers may limit the ability to select a new and potentially safer product.

In the area of chemicals used in building materials, it is important for building professionals to note that the United States has no fundamental federal requirement for manufacturers to prove the safety of their chemicals in advance of commercial use. Further, the existing federal

law may provide a disincentive for evaluation of health and environmental hazards, and EPA faces challenges in requiring such testing. Over the past 30 years, only a small number of commercially available chemicals have been rigorously evaluated, and few have been subject to significant restrictions.

Moreover, no federal requirement compels manufacturers to disclose the ingredients of most building products. Even when manufacturers voluntarily list ingredients on the packaging, the list may not be sufficient for building professionals or scientists to gauge the health or environmental impacts of the product and compare it with alternatives.

Building professionals need to recognize the limitations associated with current government policies so that they can turn to other mechanisms, such as voluntary standards, to guide leadership in designing and constructing buildings that are safe and protective of the environment. Policy gaps are natural places for leadership in improving the sustainability of buildings. Market interventions that promote disclosure, evaluation, education, and optimization can help bridge the gaps. The following sections explain the current state of efforts to encourage building product information disclosure and evaluation, and they consider how new approaches to optimization can set the stage for products that are better for human health and the environment.

SUMMARY

- Buildings materials are subject to an array of policies that provide a foundation for managing human health and environmental risks associated with building materials' production, use, and disposal, but their patchwork nature has left various aspects of these processes under- or unregulated.
- Federal policies that affect building materials include generally applicable environmental and safety regulations; only a few federal laws target specific building products. Each law focuses on specific issues, concerns, pollutants, or industries. Some are more successful at achieving their intended purpose than others.
- TSCA is the primary federal law addressing the regulation of chemicals used in industry; however, it does not require manufacturers to disclose the ingredients of most building products or compel chemical suppliers to prove the safety of their chemicals in advance of commercial use. Fewer than 200 of 84,000 chemicals in the TSCA inventory have been comprehensively tested for health and environmental effects.
- Building materials may also be subject to regulatory systems of states and localities. Populous states represent such a substantial share of the national market that their more restrictive standards can become de facto standards for the entire country when a manufacturer makes a single version of a product for nationwide distribution.
- Governments of other countries also regulate aspects of building materials, significantly differing from U.S. regulations in some areas. Just as state regulations may become de facto standards for the entire United States, a manufacturer with global product distribution may choose to make a single product that meets the most restrictive requirements of the countries where the product will be sold.

- Standards developed by professional organizations and private entities also cover building materials. Many of these standards address materials' strength, durability, or fire safety; they affect human health and the environment only indirectly. Some of these standards become requirements when adopted in government codes, and others remain voluntary.
- Even though the United States has federal policies aimed at protecting air, water, and land, as well as consumers' health and safety, these policies tend to be fragmented and poorly coordinated and do not provide a holistic and nuanced consideration of relative hazard, exposure, and risk. Policy gaps are natural places for leadership in improving the sustainability of buildings.

3.3 Disclosure and evaluation

- Why are disclosure and evaluation important for identifying and promoting preferable materials and products?
 - What are the different approaches to disclosure and evaluation?
 - What are their strengths and limitations?
 - What are the barriers to disclosure and evaluation?
-

Everyday experience and economic theory show that timely and relevant information on options and implications for product selection can improve decision making. Conversely, the absence of information—for instance, on the hazards associated with product ingredients or the potential environmental impacts of a manufacturing process—contributes to the failure of the market to promote preferable products and the need for public and private initiatives to intervene to actively promote disclosure.

Information disclosure is particularly important when materials attributes cannot be determined by simple observation. Color, texture, and approximate durability can be determined by examining and handling a product. The human health and environmental aspects of a product, on the other hand, cannot be determined unless the manufacturer discloses information about the constituents, including the chemical ingredients and their source, transport, and processing. For instance, if information disclosure had been more developed in the supply chain of gypsum board production, manufacturers might have better identified the contaminants in gypsum board imported from China in the mid-2000s.

Disclosure can provide even greater benefits when combined with an evaluation of the reported information that distills it into actionable recommendations or judgments, such as third-party labels or certifications.¹ The results of such evaluations allow decision makers to differentiate among products and select those matching their values and requirements. Evidence from some programs, such as food labeling, indicates that the provision of information can have immediate and long-lasting effects on product selection.² Ultimately, preferential selection of products matching a project team's values and requirements provides incentives for manufacturers to meet this demand by developing less hazardous and more environmentally preferable products.

The extent of disclosure and level of evaluation for products varies considerably today. It is important for project teams to understand this landscape, including strengths and limitations in the provision and interpretation of building product information.

¹ For more information on the outcomes of food product labeling, see *Front-of-package nutrition rating systems and symbols: Promoting healthier choices* (Washington, D.C.: National Academies Press, 2011) ([read online](#)).

² For one of many examples, see Sutherland et al., *Guiding stars: The effect of a nutrition navigation program on consumer purchases at the supermarket*, *American Journal of Clinical Nutrition* 91(4) (2010): 1090S–10945S ([download](#)).

APPROACHES TO DISCLOSURE AND EVALUATION

In the simplest sense, disclosure refers to revealing information. For the human health and environmental attributes of building materials, the most relevant information concerns life cycle environmental impacts, chemical contents, and their associated life cycle hazards. These are typically reported systematically through mechanisms like environmental product declarations and Health Product Declarations (described in more detail in Sections 3.4 and 3.5).

A basic level of evaluation can take the form of a market claim, product label, or certification. Market claims are widely available; however, they often have only marginal value for evaluation. For instance, some building materials manufacturers call their products “safe,” “green,” or “environmentally friendly” to make them more appealing to consumers. This information can be helpful in some cases; however, a lack of standardized definitions for these terms means these claims can be incomplete or potentially misleading. Whereas marketing claims for foods, drugs, and pesticides are reasonably well regulated, claims for building materials have not been subject to rigorous oversight. Some manufacturers have come under fire for making false or exaggerated claims or for “greenwashing” by using terms that are vague, misleading, and poorly documented. The Federal Trade Commission addresses greenwashing by offering nonregulatory [Green Guides](#) designed to help marketers ensure that the claims they make about the environmental attributes of their products are truthful and nondeceptive. Product labels and certifications are a more standardized way of communicating human health and environmental attributes, although the level of depth in which they evaluate a material or product varies greatly.

ISO CLASSIFICATION FOR ENVIRONMENTAL CLAIMS

The International Organization for Standardization (ISO) has established a [classification for environmental claims](#), with rules and guidelines for how the environmental aspects of a product can be represented legitimately on a label. There are three types:

- Type I, a voluntary, third-party program, based on multiple criteria, that awards a license that authorizes the use of environmental labels on products, indicating overall environmental preferability of a product within a particular product category based on life cycle considerations (“ecolabels”).
- Type II, informative environmental self-declaration claims.
- Type III, voluntary programs that provide quantified environmental data of a product, under preset categories of parameters set by a qualified third party and based on life cycle assessment, and verified by that or another qualified third party (“environmental product declarations”).

VARIATIONS IN EVALUATION

Assessments that evaluate a product's attributes come in many forms, reflecting differences in the breadth and depth of issues considered and information used:

- **SINGLE-ATTRIBUTE VERSUS MULTIATTRIBUTE EVALUATIONS.** Evaluations may examine one aspect (e.g., VOC emissions) or multiple dimensions (e.g., chemical hazards, energy consumption, and water use) of a product.
- **SINGLE-STAGE VERSUS LIFE CYCLE EVALUATIONS.** An evaluation may focus on a single stage of the life cycle (e.g., the operational use phase) or encompass the entire life cycle, from raw materials sourcing to end of life or reuse.
- **“FAST AND LIGHT” VERSUS “DEEP AND INTENSIVE” EVALUATIONS.** Some evaluations are meant to provide an initial assessment of crucial information, whereas other evaluations go into depth on the attributes they examine to provide more detailed information.
- **MANUFACTURER STUDY VERSUS THIRD-PARTY VERIFIED.** Manufacturers conduct evaluations of the types listed above; in some cases the manufacturer has the evaluation verified by an independent third party.

Each type of assessment has advantages and disadvantages. For example, a single-attribute assessment, such as a recycled content certification, may provide a robust evaluation of one important aspect of a product. Similarly, a fast-and-light check of a product's ingredients list against a hazardous substances list may immediately reveal the presence of an undesirable constituent.

A deeper, more rigorous evaluation of a product across multiple attributes and its entire life cycle provides a detailed picture of the product and the most information for decision makers. However, such research can be time consuming, expensive, and sometimes impossible, given available information. Consequently, project teams should explicitly consider variation in the depth and rigor of available information and select the level of detail that fits their goals and resources.

RESTRICTED SUBSTANCES LISTS

Some labels and certifications are based on restricted substances lists (RSLs), or “red lists,” which are lists of substances that a firm has deemed harmful enough to avoid. RSLs are used extensively by both manufacturers and materials specifiers. They provide a relatively simple approach to product evaluation; however, project teams should be aware of their limitations.

Building materials suppliers and design and construction firms often formulate their RSLs from lists of hazardous chemicals developed by governments or other authoritative bodies. Government hazardous chemical lists, such as the International Agency for Research on Carcinogens (IARC) [List of Carcinogens](#), the EPA [Toxic Release Inventory List of Persistent, Bioaccumulative and Toxic Substances](#), or California's [Proposition 65 list](#), contain hundreds of chemicals and have been used by some firms in developing their RSLs. Privately developed RSLs like those of [Perkins+Will](#) and the [Living Building Challenge](#) are typically shorter and prioritize the set of ingredients those

organizations believe should be avoided. An example of a very basic label based on an RSL is “BPA free,” commonly found on plastic bottles and containers. In this case, the label indicates the product has been screened for a single chemical, bisphenol A. The Living Building Challenge’s [Declare label](#), on the other hand, indicates that a product is verified not to contain any of 22 red-listed chemical classes.

PROP. 65 WARNING

This product contains one or more chemicals known to the State of California to cause cancer, birth defects, or other reproductive harm.

California Proposition 65 warning label

However, there are many limitations to using RSLs. A label indicating that a product has been screened against a firm’s RSL can be useful for prioritizing the avoidance of certain chemicals of high concern, but RSLs are not a substitute for an assessment of the full ingredients of a building product. As scientific research and advocacy efforts evolve, new substances are always being added to even the most exhaustive hazardous chemical lists.³ For example, when the plastics industry realized that bisphenol A was hazardous, in many instances manufacturers substituted its chemical cousin, bisphenol S. However, toxicological research on bisphenol S has suggested the chemical may be no less dangerous than BPA, meaning “BPA-free” plastics may still be hazardous.⁴ Therefore, a guarantee that a product does not contain a substance on a particular RSL should not be mistaken for verification that the product does not contain substances harmful to human health and the environment.

Further, alternatives to RSL ingredients may have serious life cycle health or environmental effects. For example, they might require much more energy for production or operation, depend on a rare metal that involves destructive mining practices, or contribute to various environmental or social justice problems. In many cases, the “best” choice may not be a chemical alternative but rather a change in design that avoids the need for a product or a broader search for a fundamentally different solution to the function requirement.

Perhaps counterintuitively, the widespread use of RSLs may indirectly and inadvertently slow innovation. If a manufacturer knows what substances are on the RSL of its primary customers, it may not have a strong incentive to look beyond these RSL-listed substances to more comprehensively improve the health and environmental attributes of its products. Multiattribute assessments aimed at continual optimization can better assist manufacturers in preventing regrettable substitutions.

³ For example, see Apple’s 31-page [Regulated substances specification](#).

⁴ [BPA-free plastic containers may be just as hazardous](#), *Scientific American* (August 2014).

FLAME RETARDANTS: A CASE OF REGRETTABLE SUBSTITUTION

For decades, polybrominated diphenyl ethers (PBDEs) were widely added to foam furniture and baby products to make them less flammable. Because of health concerns, some U.S. manufacturers phased them out in the early 2000s and substituted another flame-retardant chemical, tris(1,3-dichloro-2-propyl) phosphate (TDCPP), or “chlorinated tris.” Numerous scientific studies have linked TDCPP to cancer and neurological deficits—it had already been banned from use in children’s pajamas in 1977—yet a 2011 study showed that it was the most common flame retardant found in baby products with foam.¹ In 2011, California added TDCPP to its Proposition 65 list as a known carcinogen. This hazardous chemical, once intended as a simple substitute, is still prevalent today.

¹ H.M. Stapleton, S. Klosterhaus, A. Keller, P.L. Ferguson, S. van Bergen, E. Cooper, T.F. Webster, and A. Blum, Identification of flame retardants in polyurethane foam collected from baby products, *Environmental Science and Technology* 45(12) (2011): 5323–31.

VERIFYING INFORMATION

Health and environmental information cannot improve decision making unless it is accurate. The complexity of multitiered, global supply chains and the building industry’s relative inexperience with health and environmental data are reasons to be cautious when verifying information about building materials. Anecdotal stories of errors, omissions, and misrepresentations are common.

These circumstances create the opportunity for independent third parties to provide verification, as well as interpretation, with the aim of establishing a reliable basis for decision making. Typically, third-party verifiers (e.g., Cradle to Cradle Products Innovation Institute, Green Seal) evaluate information provided by manufacturers or other intermediaries and use their experience and expertise to identify errors, omissions, or inconsistencies. They also help digest and interpret complex data, often using assessment tools, such as the [GreenScreen for Safer Chemicals](#) (discussed more in Section 3.5).

Some manufacturers prefer not to work with third-party verifiers. These manufacturers may report information in their own formats or create their own labels or criteria to describe health and environmental attributes. The reliability or veracity of this information may be excellent, but the lack of an independent evaluation makes it difficult or impossible to know.

Moreover, one-time disclosure and evaluation are not sufficient. Global supply chains and products are dynamic. If a product’s ingredients change, then all associated documentation and evaluations need to be updated. Similarly, a change in the manufacturing process may require revisions to assessments of life cycle impacts. Project teams must therefore be aware of the vintage of the information they are using and actively pursue up-to-date, ideally third-party-verified data.

Consideration for the attributes of building materials does not end with specification but should continue through installation, use, and ultimately to end of life. Project teams often encounter

information gaps between the design, construction, and operations phases of the building process. For example, team members involved in planning and design may specify materials with certain health or environmental attributes. The construction team may not know the rationale behind these specifications and, as circumstances change, may substitute materials. These substitutes may have equivalent functional features but may not meet the health and environmental goals chosen during planning design. Addressing this issue requires good communication over the life cycle of the project, inclusion of health and environmental attributes in substitution processes, and procedures to monitor and document procurement and installation. For example, LEED for Healthcare creates incentives for such integrative project delivery with credits that encourage documentation from contractors to validate that installed materials meet health and environmental criteria.

BARRIERS TO DISCLOSURE AND EVALUATION

Complete ingredients lists are rare for building products, for several reasons:

- the absence of policies and regulatory requirements;
- liability concerns;
- intellectual property concerns, and;
- the lack of necessary information.

Section 3.2 addressed policy and regulation. The following paragraphs address the remaining three issues.

LIABILITY CONCERNS

As explained in Section 3.2, the vast majority of products on the market have never been tested or studied to determine their human health and environmental impacts. In addition, chemical mixtures may present concerns or hazards that differ from those associated with individual chemical ingredients. Such tests and assessments are not generally legally required, and a manufacturer may be reluctant to voluntarily disclose some or all of the ingredients in its products if it believes customers might choose not to buy them, particularly if the manufacturer believes the ingredients are safe as used in its products. Moreover, manufacturers' concerns are not limited to present circumstances. Even if manufacturers use only ingredients that today are considered safe, they may be concerned that future scientific study will reveal that an ingredient or process makes their product unsafe. Concerns about disclosure are balanced by the recognition that product liability claims often result from a manufacturer's failure to adequately warn of risks associated with its products. Manufacturers may be able to manage their potential liability by publicly disclosing product ingredients and associated risks. This disclosure helps the manufacturer demonstrate that it exercised a reasonable level of care.

LIABILITY CONSIDERATIONS FOR ARCHITECTS AND CONTRACTORS

Disclosure is a new topic, so building professionals rightfully wonder whether it will affect their liability. The primary way professionals incur liability is by breaching the contract with their client. Those claims most often arise when the contracting parties had differing expectations regarding the professional's scope of work. If a project calls for manufacturers to provide HPDs or other disclosures, each professional's client contract should describe his or her role and limitations.

Typically, the architect's role is to request disclosures, and the contractor's role is to gather and provide them to the architect as a submittal. The best practice is to provide copies of all disclosures to clients, who then cannot say they were not informed. The professional's contract should indicate that his or her responsibility for disclosure is limited to providing manufacturers' information.

If manufacturers' disclosures will inform which product is selected and the professional plays a role in the selection process, the contract should describe the selection criteria that will be used.

Most architects and contractors are not qualified to evaluate whether a specific product's ingredients pose a health risk. To avoid any dispute regarding the professional's scope and purported expertise, client contracts should disclose that he or she is not qualified to make such determinations and recommend that the client hire a qualified expert if such information is desired.

INTELLECTUAL PROPERTY CONCERNS

Many manufacturers closely guard the recipes of their formulations and processing conditions as confidential business information (CBI). In theory, CBI represents valuable intellectual property created with significant investment and inspiration. Manufacturers worry that competitors could unfairly gain insight into product formulations and ultimately create competitive products. Respect for CBI is an important part of intellectual property protection, essential for free markets. However, CBI can also be used to obstruct efforts to gain access to relevant health and environmental information. It is often difficult or impossible to deduce the true motivations underlying a specific circumstance; there is voluminous legal and regulatory guidance on navigating CBI, trade secrets, and related concerns.⁵

⁵ [ABA SEER TSCA trade secret and confidential business information, Briefing paper](#), American Bar Association Section of Environment, Energy, and Resources (2014).

INCOMPLETE KNOWLEDGE

Beyond liability and competitive concerns, the lack of disclosure may reflect the absence of information and understanding. Within the linear flow of constituent materials along an increasingly complex string of custody—a supply chain (Figure 3-6)—raw materials suppliers are “upstream” and product manufacturers are “downstream.” The flow of information along a supply chain depends on the willingness and ability of upstream suppliers to disclose information to downstream stakeholders. The issues listed above—liability, intellectual property, and incomplete information—can apply to suppliers throughout the supply chain, compounding the difficulty of obtaining complete information. Furthermore, the exact formulations of some constituent materials or the specific suppliers of raw or intermediate materials can vary over time in response to many factors, some under their control, many not. A manufacturer might have several potential suppliers for constituent materials and use a variety of business and engineering tactics to select a specific vendor at a given time.

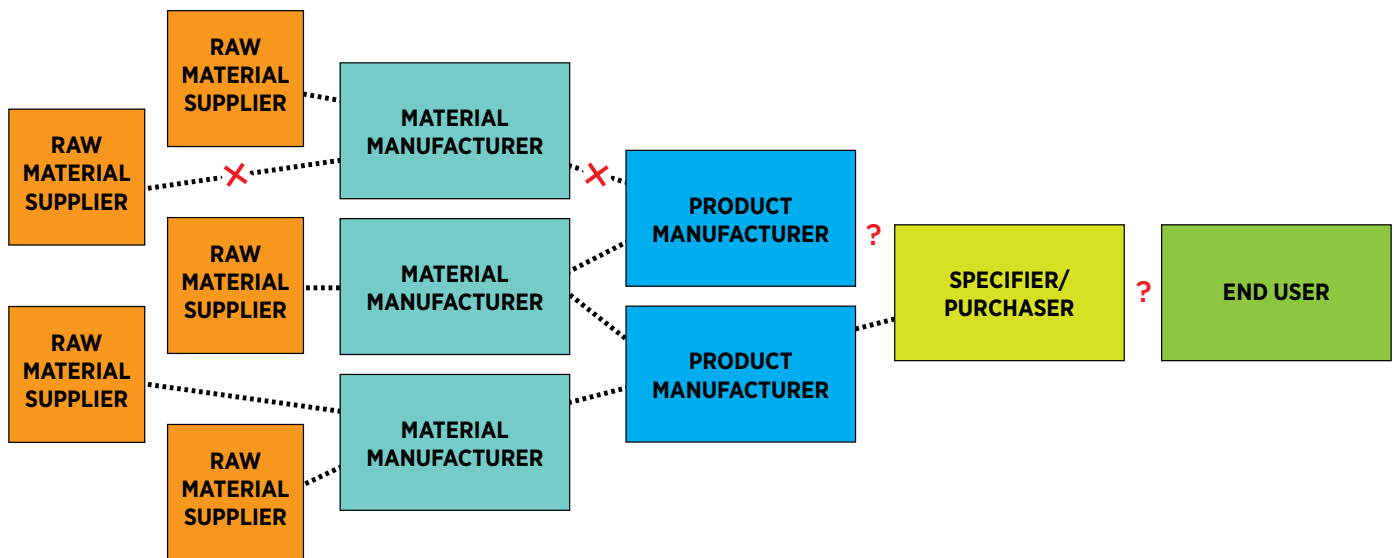


Figure 3-6. Materials supply chain

To reach the end user, materials information must traverse the entire supply chain, from all raw materials suppliers, through materials manufacturers, product manufacturers, and specifiers or purchasers. Any break in the chain of information upstream means that downstream information will be incomplete.

Global supply chains often make it particularly difficult to track product ingredients across many suppliers operating in multiple countries. Moreover, very few manufacturers have complete, end-to-end control over their products. Complex materials, such as paints, adhesives, flooring, or siding, and product assemblies, like windows, furniture, or prefabricated wall panels, have long, multitiered supply chains composed of many manufacturers and suppliers. These range from chemical manufacturers and raw materials suppliers to processors, formulators, and compounders, through to component manufacturers and eventually product manufacturers.

These complexities and barriers are not confined to the building products industry. Pressure from stakeholders has introduced these issues to nearly every manufacturing sector. Familiar companies in the textile and footwear industry, such as Nike, Adidas, Reebok, Levi-Strauss, Burberry, and

Timberland, have spent years developing information disclosure systems that traverse their entire supply chains.⁶ These tools allow them to carefully monitor the raw materials and contents of their final products and choose preferable ingredients.

DEFINING THE “COMPLETE” INGREDIENTS LIST

Think of a desk chair. The cushion, armrests, legs, wheels, and pneumatic height adjustment mechanism may all come from different suppliers. The cushion’s foam padding, base material, and covering fabric may each come from a different supplier. And the fabric manufacturer may source its dyes from any one of several suppliers, depending on price and stock availability at any given time, and the cotton, wool, or synthetic fiber from others. To list every ingredient in the chair, therefore, the chair manufacturer would need to trace the steps through multiple tiers of the supply chain, each with multiple manufacturers. The complete ingredients list would consist of lists from tens to even hundreds of suppliers.

In many cases, corporate disclosure is a response to consumer or advocacy pressure. Large firms with significant market shares have more clout for gathering information on products than smaller firms. The biggest consumer product brand owners may procure such a large volume of materials that they may be able to encourage or force suppliers to reveal information. Likewise, large retailers like Wal-Mart, Target, Home Depot, and Staples have enough purchasing power to require ingredients disclosure from the manufacturers of products they sell.

However, even in these cases, the ingredients are often disclosed to only a specific company or retailer, which agrees not to disclose the information more broadly. Other times, a manufacturer agrees to disclose ingredients only to a third party, which checks the ingredients list against a company’s RSL and then verifies that the product contains no unwanted ingredients.

Experiences with manufacturers and retailers are instructive. However, they may be only partially relevant to the building materials market, which is less consumer oriented, less concentrated, and less sensitive to pressure from traditional environmental advocates. Moreover, the sector has fewer large, publicly traded corporations that may respond to shareholder pressure. Consequently, it may be more difficult to promote greater access to information on building materials’ ingredients. At the very least, such efforts in the building sector will require new or complementary tactics.

Knowledge may also be incomplete if the scientific information needed to conduct an evaluation is missing. For instance, if chemical hazard information is not available in a trusted database, an assessor may need to delve into peer-reviewed scientific literature and grapple with studies that make conflicting conclusions about a substance’s toxicity. Information may be difficult to obtain if the scientific journals are proprietary,⁷ indexing services are expensive, or access to

⁶ Sustainable Apparel Coalition.

⁷ L. McKenna, [Locked in the ivory tower: Why JSTOR imprisons academic research](#), Atlantic (January 2012).

databases is limited.⁸ These create significant barriers to information, particularly for nonacademic stakeholders, including the public, industry, and nongovernmental organizations.⁹

FULL MATERIALS DISCLOSURE AT SEAGATE

Seagate Technologies is a market leader in the production of computer hard drives. As a provider of a complex electronic product, Seagate has long, multitier supply chains, many of which have components manufactured in Asia. Early on, Seagate began to demand health and environmental information disclosure from its suppliers. With a credible threat to close out contracts on noncooperating firms, Seagate has been able to build a large database of all the chemicals and materials that go into its hard drive assemblies. This database has proven particularly valuable as concerns arise about newly identified hazardous chemicals. Instead of going back to its myriad suppliers in such cases, Seagate searches its own database of ingredients to determine whether a questionable chemical is in its finished products.

Regardless of access to research, in many cases, a substance's toxicity may not have been studied thoroughly or at all. An additional challenge for assessors is obtaining and evaluating relevant metadata, or data about the data. For instance, an ingredients list may include "titanium dioxide" and may provide its [Chemical Abstracts Service](#) (CAS) registry number, but it's unlikely to include particle size and shape, both of which affect its toxicity.

Although the disclosure and evaluation landscape of today is varied, several tools are recognized as established or emerging industry leaders. Section 3.4 addresses leading tools for assessing and reporting environmental materials information, and Section 3.5 discusses tools that evaluate and distill materials information affecting human health.

SUMMARY

- Timely and relevant information on materials options and implications can improve decision making. Disclosure can provide even greater benefits when combined with an evaluation.
- A basic level of evaluation can take the form of a market claim, product label, or certification. Market claims are widely available; however, they are often unverified and therefore of limited value for evaluation. Product labels and certifications are a more standardized way of communicating human health and environmental attributes, although the level of depth in which they evaluate a material or product varies greatly.

⁸ See [The Cost of Knowledge](#).

⁹ Learn more about barriers to access to scientific research from [RighttoResearch.org](#), [How to hasten open access](#), and a [Brief History of the Open Access Movement](#).

- A deeper, more rigorous evaluation of a product across multiple attributes and its entire life cycle provides a detailed picture of the product and more information for decision makers.
- Restricted substances lists, or red lists, are widely used and can be helpful for prioritizing the avoidance of certain chemicals of high concern. However, RSLs are not a substitute for an assessment of the full ingredients of a building product.
- Verification of disclosed information is important. Third-party verification can identify errors, omissions, or inconsistencies.
- Complete ingredients lists are rare for building products for several reasons, including the absence of regulatory requirements, liability concerns, intellectual property, and the lack of necessary information.
- A manufacturer may be reluctant to voluntarily disclose some or all of the ingredients in its products if it believes customers might choose not to buy them. Manufacturers may also be concerned that competitors could unfairly gain insight into product formulations and ultimately create competitive products.
- A lack of disclosure may also reflect the absence of information and understanding when manufacturers and distributors have difficulty tracking product ingredients across multitiered global supply chains. Knowledge may also be incomplete if the scientific information needed to conduct an evaluation is missing.

TIPS FOR PRACTICE

ASK FOR INFORMATION. The extent of disclosure and rigor of evaluations for products varies considerably, and project teams should understand strengths and limitations of different types of information. Requesting better information sends a signal to manufacturers that disclosure and evaluation are priorities and can lead to better products.

START WITH RESTRICTED SUBSTANCES LISTS. Some substances are well-known health and environmental hazards, based on decades of scientific evidence. Many of these substances populate restricted substances lists. It is prudent to consult these lists and avoid the listed substances.

RELIANCE ON RED LISTS ALONE CAN HAVE UNINTENDED CONSEQUENCES. It is easy to find many instances of “regrettable substitutions,” where materials selected to avoid one hazard are found to have others. Look for inherently safer products and materials.

DISCLOSE TO REDUCE LIABILITY. Many manufacturers believe that disclosure is always a risk. However, in many instances prompt, proactive disclosure has prevented surprises and reduced liability.

SPECIFY BETTER PRODUCTS TO ACCELERATE MARKET TRANSFORMATION. The preferential selection of building materials with fewer potentially hazardous ingredients and lower life cycle environmental impacts is the foundation for market transformation.

3.4 Tools for evaluating environmental impacts

- What tools are currently available to help project teams and manufacturers understand the environmental impacts of materials?
- What is the scientific and technical basis for these tools?
- What are their strengths and limitations?

Chapter 2 introduced the complex and multifaceted nature of human health and environmental attributes of building materials. Navigating such issues is challenging for specialists in these fields, let alone typical building industry professionals. Yet managing potential health hazards and reducing environmental impacts requires practitioners to understand, interpret, and act on essential product attributes and performance. A practical toolkit is emerging to serve this purpose.

Health and environmental issues are intimately connected; however, they rely on different bodies of knowledge and communities of experts and thus have separate toolkits. This section introduces the features and functions of some of the most important tools available to help manufacturers and project teams understand and act on environmental impacts. A complementary treatment of health-related tools follows, in Section 3.5.

Life cycle thinking (described in Chapter 1) provides the conceptual foundation for understanding the environmental attributes of building materials. It is based on a holistic approach that includes multiple attributes and environmental impacts and covers the entire life cycle of a product, from extraction of raw materials through to final disposal or recycling. As reviewed in Section 2.2, the scope and breadth of environmental impacts across the life cycle of typical building materials can be daunting. Two important tools help in this process: life cycle assessment estimates these impacts and identifies areas of concern, and the environmental product declaration presents the LCA's key findings in a consistent and credible manner.

LIFE CYCLE ASSESSMENT

LCA is a method used to identify and quantify potential impacts that occur throughout a product's life cycle, and it provides the foundational data for EPDs. It collects, organizes, and characterizes data from raw materials extraction and processing, transportation, manufacture, installation, and use through disposal, recycling, or reuse of a product. It then identifies the processes that occur at each stage of the life cycle and their associated inputs (e.g., energy, water, materials) and outputs (e.g., solid, liquid, and airborne wastes, greenhouse gases, and co-products¹) (Figure 3-7).

¹ Co-products, substances created in addition to the one being assessed, are typically desirable, intentional results from synthesis, as opposed to waste.

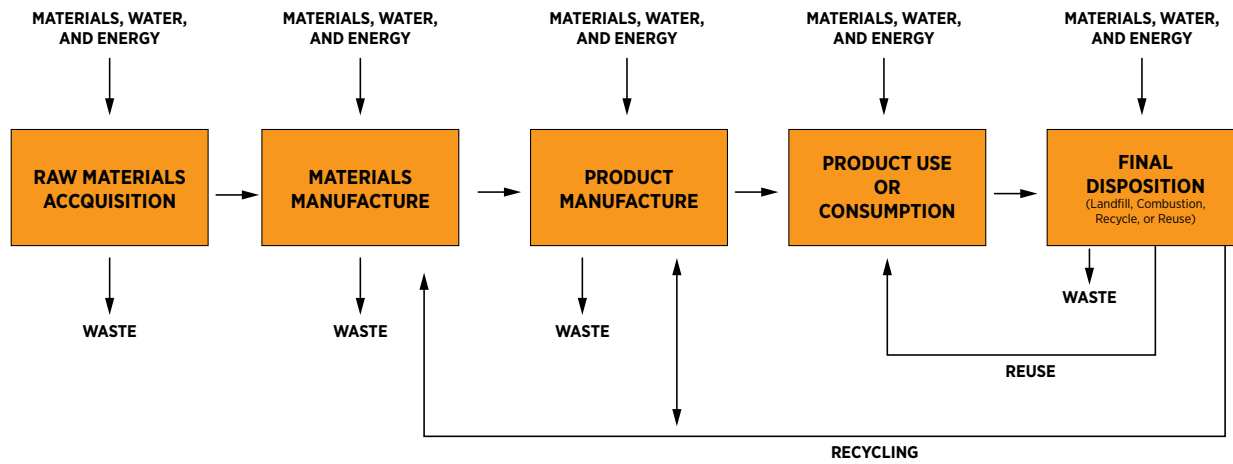


Figure 3-7. Information considered in life cycle assessments

LCA quantifies these inputs and outputs and identifies their potential impacts or burdens on the environment. Since environmental impacts, such as air or water pollution, are often linked to health, LCA results can help identify potential human health concerns. Tools specifically designed to examine health effects are best suited to explore these impacts in detail (see Section 3.5).

Building industry professionals can use LCA to compare and select products or processes that have preferable environmental and health attributes throughout their life cycles, or to compare and evaluate alternative strategies for whole buildings. Manufacturers can use it to study and optimize processes within a manufacturing plant, to evaluate constituents of their products, or to make a comparative assertion in the market, such as “our product uses 20% less energy.” No tool or method provides all information needed for a complete picture, but LCA is more comprehensive than single-attribute considerations such as recycled content or embodied energy.

LCA is a tool for education as much as a tool to assist in decision making. The more manufacturers and project teams understand the potential environmental (and human health) impacts of the products they make and use, the more likely it is that these products will undergo continuous improvement as manufacturers innovate to meet the demand for better products. LCA helps focus this demand and innovation on real improvements, not just shifting environmental burdens from one place to another.

Most building project team members do not need to know how to perform an LCA. However, familiarity with the language and underpinning methodology can help determine whether an LCA is credible and how to evaluate it to select products or make overall project decisions. LCA is central to implementing systems-based approaches to materials selection and integrative methods of project design, construction, and operations.

HOW DOES LCA WORK?

LCA methodology and language have been developed through consensus processes over more than 30 years, primarily through efforts of the [Society of Environmental Toxicology and Chemistry](#), ISO, and the sustained efforts of researchers in private industry and academia. There is now

international agreement on terminology and methodology as well as communication of results, as codified in standards promulgated by ISO. The objective of the ISO standards is to ensure consistent methodology for LCA studies and permit apples-to-apples comparisons through the use of common units, metrics, and processes. In addition to the ISO standards, there are standards specific to whole-building LCA from other organizations. See the Resources section at the end of the chapter for more information on standards.

The ISO standards define four phases for LCA studies:

- **GOAL AND SCOPE DEFINITION:** describes the study parameters and methodology, including the material or process to be analyzed, the boundaries of the analysis, any assumptions or limitations, and impact categories to be included. In some industries, these parameters have been agreed upon and codified in product category rules (PCRs).
- **INVENTORY ANALYSIS:** identifies and quantifies the inputs (raw materials, water, energy) and outputs (air emissions, waterborne effluents, solid waste, other environmental releases, and co-products).
- **IMPACT ASSESSMENT:** translates inventory data into potential environmental impacts, such as global warming potential, ozone depletion potential, and other indicators.
- **INTERPRETATION:** reports conclusions, limitations, and recommendations, if any.

LCA practitioners have defined categories of potential impact that are used in LCA studies and often used in EPDs as well. Not all impact categories are included in all studies. Commonly used impact categories include the following:

- **GLOBAL WARMING POTENTIAL:** a measure of emissions of carbon dioxide and other greenhouse gases that can contribute to climate change.
- **STRATOSPHERIC OZONE DEPLETION POTENTIAL:** a measure of emissions, like chlorofluorocarbons and halons, that can degrade the ozone layer.
- **GROUND-LEVEL OZONE FORMATION POTENTIAL:** a measure of “smog,” or ground-level ozone, created by chemical reactions between air pollutants and sunlight.
- **ACIDIFICATION POTENTIAL:** a measure of acidifying compounds, such as sulfur oxides and nitrogen oxides, emitted to air that can fall to earth through rain, fog, snow, or dry deposition, contributing to the acidification of lakes, streams, rivers, oceans, and soil, where the effects can harm plants and animals.
- **EUTROPHICATION POTENTIAL:** a measure of emissions of nitrogen and phosphorus into soil or water, which ultimately can deplete oxygen that fish and other organisms need to survive.
- **ECOTOXICITY POTENTIAL:** a measure of how chemicals affect the environment, including its organisms. This indicator in LCA is evolving. Ecotoxicological data for many chemicals are currently limited but are continually being developed.

LCAs typically report total quantities for resource consumption and waste creation, although they do not convert them into indicators of potential impact. Examples include raw resources

use, including materials, fossil fuel, and water use, and cumulative energy demand, including nonrenewable fossil, nuclear, renewable biomass, wind, solar, geothermal, and water energy. LCA addresses some human health impacts but not occupational exposures, accidental releases to communities, and building occupant exposures; other tools are better suited for assessing these impacts, particularly for the use stage, in which building occupants' exposures are most important.

LCA IN THE BUILDING SECTOR

LCA methods have evolved since their early applications in consumer products, which informed debates like cloth versus disposable diapers and paper versus plastic grocery bags. Advances in databases and tools now enable the building sector to use LCA to inform decisions on individual materials and products, assemblies, and whole buildings. Manufacturers and project teams use LCA in different ways, but both typically with the goal of reducing the environmental impacts of their work.

Some manufacturers in all sectors have used LCA to measure and mitigate the environmental consequences of their materials and products. Since LCA is an effective analytical technique for finding potential environmental “hot spots” in the product life cycle, it can inform decisions about improvements to existing products or new product development. This work requires special expertise and the use of professional LCA tools like [GaBi](#) and [SimaPro](#), as well as supply chain data specific to a particular product and its life cycle. Some manufacturers have this skill in-house, while others engage outside consultants. LCA data may be kept confidential within the organization or it may be made publicly available, either in the form of a full LCA report or summarized in an EPD. When shared with project teams, particularly in the form of an EPD, LCA information can guide material and product selection. Figure 3-8 illustrates use of LCA to compare two alternatives for a specific application.

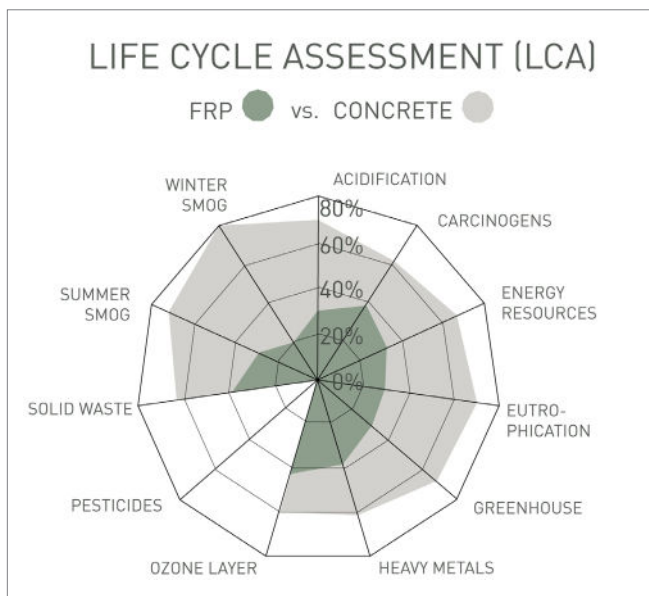


Figure 3-8. LCA comparison of two materials
Kreysler and Associates worked with Prof. Michael Lepech and his students at Stanford University to compare two materials for an installation at the Monterey Bay Aquarium: a tank with fiber-reinforced polymer (FRP) walls on a base of reinforced concrete, and a tank constructed entirely of reinforced concrete. Read the full report [here](#). Courtesy: Kreysler and Associates

Project teams can also perform LCA to evaluate the impacts and trade-offs between alternative designs for one particular assembly in a building or to assess the environmental footprint of the whole building. In addition, LCA is useful for examining the relative environmental impact of new construction versus rehabilitating an existing building. In North America, two software tools are now widely recognized for whole-building evaluation: the [Athena Impact Estimator for Buildings](#) is a free, stand-alone desktop software tool, and [Tally](#) is a commercial cloud-based Revit plug-in. Project teams can use these tools, which have the complex LCA methods and background data built in, to get LCA results without engaging outside consultants. The tools allow teams to more readily evaluate impacts and trade-offs in design decisions for materials, structural systems, building envelopes, and so forth.

Performing LCA on building products is often more challenging than conducting LCA on consumer products such as diapers and grocery bags: buildings and their materials may undergo multiple modifications and renovations as use patterns, users, and aesthetics change over time, building products have a long use phase yet are often replaced before their technical end of life, and building materials can have a complex end-of-life phase. Because of challenges associated with analyzing the end-of-life phase, such as difficulties separating recyclable components from nonrecyclable ones and predicting waste management infrastructure decades in the future, LCAs of building products are often “cradle to gate,” addressing only the upstream stages of the life cycle, before the construction and use phases begin (Figure 3-9).²

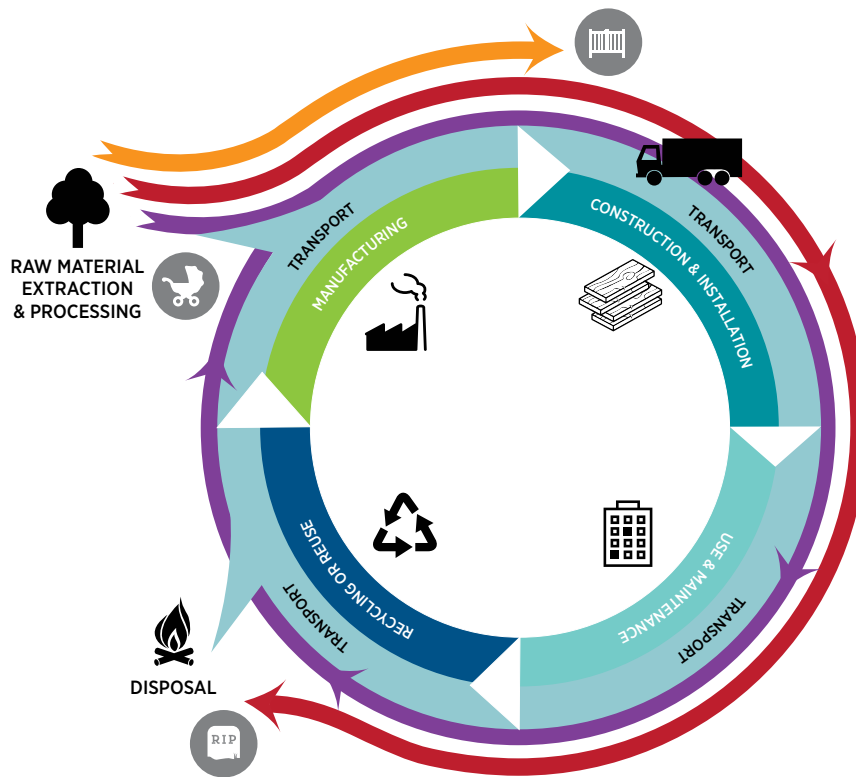


Figure 3-9. Comparison of LCA scopes

Life cycle assessments can be “cradle to grave,” addressing all phases of the life cycle, or “cradle to gate,” addressing only the upstream stages, before the construction and use phases begin. “Cradle-to-cradle” assessments are a particular kind of cradle-to-grave assessment, where the end-of-life step is a recycling or reuse process.

² Cradle-to-gate analysis contrasts with other approaches that may consider impacts from extraction through end of life or reuse. Results from analyses of different life cycle phases are not directly comparable.

PRODUCT LCA VERSUS WHOLE-BUILDING LCA

Manufacturers perform LCA on their individual products to quantify environmental impacts, identify where in the product supply chain or life cycle they might find improvements, and explore modifications for a lighter footprint. They might use LCA to improve an existing product or develop a new product. A manufacturer may report the key findings of an LCA study in an EPD, which project teams can use to select products that have preferable environmental profiles.

Cradle-to-grave whole-building LCA enables building professionals to understand the cumulative energy use and other environmental consequences resulting from all phases of the building's life. A comprehensive, quantitative analysis helps determine which materials best fit the project's needs throughout the building's lifetime. Employed as a design tool, LCA may reduce the amount of materials used ("dematerialization"), which can in turn reduce environmental harms and save money. Whole-building LCA also allows the design team to understand the trade-offs between materials selection and energy performance and find an appropriate balance between the two. For example, high thermal mass can reduce a building's peak energy demands; an LCA can quantify the environmental damage associated with the materials used so that the team can compare those effects with the benefits for energy performance and then make more informed design decisions. Looking at how materials interact within the whole structure and enclosure rather than merely individually makes it possible to gain a larger perspective and reduce overall environmental effects over the long term.

Teams can analyze and compare options for structural systems or optimize the bay size and slab depth of a specific system, compare envelope assemblies and select assemblies with lower impacts, or revise the design to minimize the use of high-impact materials. Whole-building LCA can be an important component of integrative design because the architect must work closely with the structural engineer to identify opportunities for reducing impact while also ensuring that decisions about materials do not diminish the operational performance of the building. Project teams should perform whole-building LCA in conjunction with energy modeling and other analytical tools to optimize design.

Product and whole-building LCA can be used together to improve the selection of materials and the performance over the entire life of the building.

ENVIRONMENTAL PRODUCT DECLARATIONS

A report from a typical LCA can run more than 100 pages full of technical detail and minutiae. Most decision makers need a digested and condensed version of this information. EPDs address this need by providing a standardized and typically more concise presentation of the LCA results. EPDs can be created for a specific product from a particular manufacturer or can be industry-wide declarations generic to a product type, such as concrete.

Note that EPDs are neither product endorsements nor green labels; having an EPD does not guarantee a product is environmentally preferable. An EPD simply organizes the results of the LCA—good or bad—into a standardized and digestible format. Unlike a food nutrition label, an EPD does not provide a “recommended daily value” or a threshold under which impacts are deemed “acceptable” since the goal should be that all impacts are minimized to the extent possible. The primary intent of EPDs is to facilitate informed decisions by describing environmental attributes in a consistent way so that purchasers can compare Product A with Product B. This consistency is one of the goals of product category rules.

A PCR is a standardized set of rules describing which characteristics should be disclosed for a particular product type—for example, whether it will be just environmental issues or also health issues.³ PCRs narrow the parameters for conducting the LCA to increase consistency from one study to the next, and they also define the “functional unit” to ensure comparability between products within the category. A functional unit is the quantity of product needed to serve an intended purpose, including any auxiliary products that may be required for a complete system. For example, a functional unit for carpet might be one square meter of installed flooring system including carpet, adhesive, and underlay. In the case of builders’ hardware, the functional unit may be one unit, such as one hinge, within a defined reference unit, with typical usage defined as three hinges per standard door leaf. Like LCA, EPDs can encompass the entire life cycle, from cradle to grave, or they can address only the upstream portion of the life cycle—that is, cradle to gate—omitting use and end-of-life data if the PCR allows it.

THE PROCESS OF DEVELOPING EPDs AND PCRs

The EPD development process is specified in ISO guidelines. An independent agency, called the program operator, oversees the full EPD process, including development of PCRs by interested parties, assurance that the EPD is developed according to ISO standards, and verification of the final report.

The process begins with the organization that will pay for and own the EPD—typically a manufacturing company that desires the EPD for a specific, brand-name product. The EPD owner chooses a program operator, who then determines whether a relevant PCR exists. If it does not, representatives of groups that care about that product type—manufacturers, environmental advocates, government officials, specifiers, contractors, and suppliers—set rules for a new PCR. Next, the organization commissioning the EPD performs an LCA study of the product in a manner consistent with the PCR—or adapts existing LCA data to the PCR if needed—and documents the results in a report. Then the EPD is written using summary information from the LCA report. The LCA and the EPD are submitted to the program operator for verification, and the program operator officially registers the EPD and enters it into a public repository.

Among the program operators servicing the growing EPD market in the United States are [UL Environment](#), [ICC Evaluation Service](#), [NSF International](#), [ASTM International](#), and [SCS Global Services](#). Ultimately, the role of the program operator is to establish and manage a program

³ Examples of PCRs include http://site.ul.com/global/documents/offerings/businesses/environment/PCRs/UL_Environment_PCR_for_Building_Envelope_Thermal_Insulation_v1.2.pdf and <http://site.ul.com/global/documents/offerings/businesses/environment/PCRs/IMPandMetalCladding.pdf>.

that facilitates the creation of PCRs and EPDs and to give a credible stamp of approval so that a manufacturer's EPD has legitimacy.

The PCR provides the basis for developing EPDs that are consistent within a product category. Project teams and specifiers may request EPDs directly from suppliers. Alternatively, program operators maintain searchable repositories of registered EPDs.

EPDs typically include the following sections in some form:

- **COVER PAGE:** an image and general description of the product and the manufacturing company.
- **GENERAL INFORMATION:** a table with the PCR identification, date of publication, period of validity, and authorized signatures attesting to verification.
- **MATERIAL CONTENT:** a list of Tier 1 ingredients in the product and where they come from. Tier 1 suppliers have a direct relationship to the final manufacturer (which sells to the consumer) and can supply components or parts of components.
- **PRODUCT MANUFACTURING:** diagrams and flow charts showing how the product is put together.
- **DELIVERY AND INSTALLATION:** how the product is meant to be installed.
- **USE STAGE:** information about environmental impacts from maintenance, and sometimes about indoor emissions.
- **SINGULAR EFFECTS:** how fire, water, and other potential damage functions may affect durability and service life.
- **END OF LIFE:** how the product is typically disposed of.
- **LIFE CYCLE ASSESSMENT RESULTS:** how the LCA was conducted and what the results were. This section contains the deepest information.
- **ADDITIONAL INFORMATION:** any results of the manufacturer's internal research not included in the LCA. Because human health impacts are not typically included in an LCA, indoor emissions are often addressed here in the form of product ecolabels.
- **REFERENCES:** relevant standards, laws, literature, and databases used in creating the EPD.

To distill information even further, some EPDs have an accompanying summary document, sometimes called a transparency summary, that contains essential EPD information in just a couple of pages; it may feature a table that summarizes the environmental impacts by life cycle impact category. Figure 3-10 shows EPD transparency summaries for two kinds of carpet.



EPD Transparency Summary

COMPANY NAME Interface

PRODUCT TYPE Modular Carpet Tile

PRODUCT NAME Modular Carpet Tile with GlasBac®RE Backing & Solution Dyed Type 6 Nylon

PRODUCT DEFINITION Modular carpet with recycled solution dyed Nylon 6 yarn face cloth combined with GlasBac®RE backing. Manufactured by Interface in Georgia, USA.

PRODUCT CATEGORY RULE (PCR) PCR - Floorcoverings
Harmonised Rules for Textile, Laminate and Resilient Floor Coverings

CERTIFICATION PERIOD September 19, 2011-September 19, 2016

DECLARATION NUMBER 110919.11CA29311.103.1



LIFECYCLE IMPACT CATEGORIES

The environmental impacts listed below were assessed throughout the product's lifecycle – including raw material extraction, transportation, manufacturing, packaging, use, and disposal at end of life.

	ATMOSPHERE			WATER		EARTH	
	Global Warming Potential refers to long-term changes in global weather patterns – including temperature and precipitation – that are caused by increased concentrations of greenhouse gases in the atmosphere.	Ozone Depletion Potential is the destruction of the stratospheric ozone layer, which shields the earth from ultraviolet radiation that's harmful to life, caused by human-made air pollution.	Photochemical Ozone Creation Potential happens when sunlight reacts with hydrocarbons, nitrogen oxides, and volatile organic compounds, to produce a type of air pollution known as smog.	Acidification Potential is the result of human-made emissions and refers to the decrease in pH and increase in acidity of oceans, lakes, rivers, and streams – a phenomenon that pollutes groundwater and harms aquatic life.	Eutrophication Potential occurs when excessive nutrients cause increased algae growth in lakes, blocking the underwater penetration of sunlight needed to produce oxygen and resulting in the loss of aquatic life.	Depletion of Abiotic Resources (Elements) refers to the reduction of available non-renewable resources, such as metals and gases, that are found on the periodic table of elements, due to human activity.	Depletion of Abiotic Resources (Fossil Fuels) refers to the decreasing availability of non-renewable carbon-based compounds, such as oil and coal, due to human activity.
TRACI	6.28 kg CO2-Equiv.	1.09E-06 kg CFC 11-Equiv.	0.36 kg O3-Equiv.	0.033 kg SO2-Equiv.	0.001 kg N-Equiv.		
CMIL	6.31 kg CO2-Equiv.	9.07E-07 kg R11-Equiv.	0.0034 kg Ethene-Equiv.	0.036 kg SO2-Equiv.	0.0024 kg Phosphate-Equiv.	4.19E-06 kg Sb-Equiv.	

FUNCTIONAL UNIT One square meter of carpet medium face weight (712 grams/square meter, 21 ounces/square yard). The use stage is considered for one year of service life. The reference flow is one square meter of carpet.



Environment



EPD Transparency Summary

COMPANY NAME Interface

PRODUCT TYPE Modular Carpet Tile

PRODUCT NAME Modular Carpet Tile with NexStep® Backing & Solution Dyed Type 6,6 Nylon

PRODUCT DEFINITION Modular carpet with solution dyed Nylon 6,6 yarn on NexStep® backing manufactured by Interface in LaGrange, Georgia USA.

PRODUCT CATEGORY RULE (PCR) PCR - Floorcoverings
Harmonised Rules for Textile, Laminate and Resilient Floor Coverings

CERTIFICATION PERIOD October 10, 2012 - October 10, 2017

DECLARATION NUMBER 110919.11CA29311.129.1



LIFECYCLE IMPACT CATEGORIES

The environmental impacts listed below were assessed throughout the product's lifecycle – including raw material extraction, transportation, manufacturing, packaging, use, and disposal at end of life.

	ATMOSPHERE			WATER		EARTH	
	Global Warming Potential refers to long-term changes in global weather patterns – including temperature and precipitation – that are caused by increased concentrations of greenhouse gases in the atmosphere.	Ozone Depletion Potential is the destruction of the stratospheric ozone layer, which shields the earth from ultraviolet radiation that's harmful to life, caused by human-made air pollution.	Photochemical Ozone Creation Potential happens when sunlight reacts with hydrocarbons, nitrogen oxides, and volatile organic compounds, to produce a type of air pollution known as smog.	Acidification Potential is the result of human-made emissions and refers to the decrease in pH and increase in acidity of oceans, lakes, rivers, and streams – a phenomenon that pollutes groundwater and harms aquatic life.	Eutrophication Potential occurs when excessive nutrients cause increased algae growth in lakes, blocking the underwater penetration of sunlight needed to produce oxygen and resulting in the loss of aquatic life.	Depletion of Abiotic Resources (Elements) refers to the reduction of available non-renewable resources, such as metals and gases, that are found on the periodic table of elements, due to human activity.	Depletion of Abiotic Resources (Fossil Fuels) refers to the decreasing availability of non-renewable carbon-based compounds, such as oil and coal, due to human activity.
TRACI	15.1 kgCO2-Equiv.	1.24E-06 kg CFC 11- Equiv.	0.65 kg O3-Equiv.	0.057 kg SO2-Equiv.	0.0121 kg N-Equiv.		
CM1	15.2 kgCO2-Equiv.	1.04E-06 kg R11-Equiv.	0.0061 kg Ethene-Equiv.	0.06 kg SO2- Equiv.	0.0102 kg Phosphate-Equiv	1.50E-05 kg Sb-Equiv.	

FUNCTIONAL UNIT One square meter of carpet medium face weight (712 grams/square meter, 21 ounces/ square yard). The use stage is considered for one year of service life. The reference flow is one square meter of modular carpet.



Environment

Figure 3-10. Example EPD transparency summaries
Courtesy: InterfaceFLOR LLC dba Interface Americas

STRENGTHS AND LIMITATIONS OF LCA AND EPDs

STRENGTHS

Compared with older, single-attribute approaches, LCA provides a more holistic picture of the potential environmental impacts associated with a product, material, or process. Since an EPD distills the complex results from an LCA, EPDs feature the same strengths as LCA. Ideally, EPDs allow project teams to examine a range of environmental impacts in a consistent and standardized format.

LCA reveals “hot spots” of potential environmental impact in the life cycle. At the product level, it helps manufacturers understand how to reduce the environmental consequences across the life cycle of their products. When the LCA is performed according to a relevant PCR and the results are made available through EPDs, it also helps project teams select products that meet their environmental goals. At the whole-building level, LCA allows project teams to evaluate the implications of design alternatives. It can even prompt the essential question of whether a structure, assembly, or product is really needed, given its environmental impacts. Eliminating or reducing the need for a high-impact process, material, or structure is almost always the first choice. When this is not possible, LCA helps manufacturers (at the product level) and project teams (typically at the whole-building level) explore options to offset high-impact processes or components with impact reductions elsewhere.

Questions asked during the LCA process can challenge manufacturers and materials suppliers. Product supply chains can be complex, involving large numbers of suppliers. Manufacturers often have difficulty tracking all the materials, processes, and potential impacts that are involved as they trace the many links in their supply chains toward raw materials extraction. Ideally, LCA requires information from each link in the chain. In turn, LCA provides insights into previously unknown attributes of materials and, in some cases, gives manufacturers incentives to pursue changes in their materials sourcing or supply chain. And LCA’s integrative approach provides information on multiple impact categories simultaneously. These multicriteria data help specifiers and manufacturers better understand potential trade-offs and avoid substituting one negative impact for another when considering an alternative product, raw material, or process.

Because they summarize environmental characteristics in an accessible and consistent way, EPDs enable comparisons of products in the same category, and particularly among products from the same manufacturer. Both LCAs and EPDs are governed by ISO guidelines, which ensure their objectivity. In addition, ISO guidelines require EPDs to be verified by an independent third party. The PCRs that guide EPD development help ensure that the reported data are comparable from Product A to Product B. In addition, the PCRs take into account any auxiliary products (e.g., adhesive or hardware) needed for a complete system.

The outcome of using EPDs may not always be selection of the product with the lowest environmental impact. It could be deeper engagement with suppliers if, for example, the EPD prompts the specifier to say, “I see that your biggest impacts are related to energy consumption; what are you doing to address this?” Such conversations, combined with the information manufacturers learn through the process of performing an LCA, will incentivize manufacturers

to go beyond product disclosure toward optimization, and ultimately drive improved environmental outcomes.

LIMITATIONS

LCA is not a silver bullet; it often does not reveal a clear “best” decision. And simply conducting an LCA does not necessarily ensure a good outcome from a decision-making process.⁴ Instead, LCA provides systematic and objective information on the relative levels of potential impact so that a project team or manufacturer can compare alternatives.

Although an LCA provides an inventory of the inputs and potential outputs of a system, it cannot predict when, where, or whether the outputs will occur—only what the highest total output could be. LCA also does not generally indicate the conditions or context that would affect the nature of actual impacts, such as the pollutant levels already present in the air or water and the proximity of surrounding residential communities. Most importantly, LCA cannot weigh the relative importance or value of different types of impacts. It is up to project teams to take the information provided by LCAs and weigh it against their own goals and circumstances.

LCA is best at reporting the potential impacts calculated from quantifiable inputs of identifiable feedstock materials, energy, and water as well as outputs of wastes and co-products. It is less successful at reporting the potential impacts of raw materials extraction, such as land degradation, habitat destruction, and reduction in biodiversity or effects on species. These effects tend to be place specific and are better explored through other environmental assessment methods, such as environmental impact assessment, ecological risk assessment, and site-specific scientific studies of mining, deforestation, land-use conversion, or other activities.

LCA also has limitations in exploring human health impacts of product life cycles, particularly during the use stage. Although emissions of toxic chemicals or other potential human health impacts may be identified, LCA generally does not address the exposure of populations, since most databases do not attribute data to specific locations and times. For example, LCA may reveal the emission of a particular toxic substance but cannot determine whether workers are given proper safety equipment or whether specific factories are located in low-income communities facing other risks. However, the results related to potential environmental impacts can point to potential human health concerns that are caused by those environmental conditions.

Recognizing the limitations of LCA, LEED v4 uses it where it is strongest, by focusing it on environmental aspects of materials. One MR credit seeks to motivate manufacturers to produce EPDs, which summarize the results of LCAs, and another creates an incentive for project teams to perform whole-building LCA during design. (Other credits in LEED v4 address the environmental impacts of raw materials extraction, and additional credits and tools address human health concerns; see Chapter 1 and Section 3.5.)

Since EPDs summarize information from LCA, the same limitations that apply to LCA filter down to the EPD. In addition to these limitations, there are some other things project teams should

⁴ For more on this long-standing issue, see <http://www.usgbc.org/Docs/Archive/General/Docs2241.pdf> and <http://www.usgbc.org/articles/life-cycle-leed-out-now-edcs-january-issue>.

keep in mind when using EPDs to make decisions. First, even though ISO guidelines govern EPD development, they do not strictly specify formatting and layout. EPDs from different manufacturers or program operators may therefore present information in different ways, complicating the comparison of products from different manufacturers. Second, because LCAs can be performed with different tools and use different data sets to map input flows, somewhat different impact values for similar scenarios may result, and the corresponding EPDs may not be directly comparable. Third, although EPDs summarize LCA results, those findings are still technical, so familiarity with LCA principles will help in interpretation. And finally, EPDs have a limited scope of validity, so project teams should always check that the EPDs they are referencing are up to date.

EPDs are more common in markets outside the United States, particularly in Europe and parts of Asia, but they're becoming more prevalent. Despite their limitations, their value has led to increasing use and growing awareness of their importance, prompting a dialogue among industry leaders about a more standardized and harmonized approach to considering environmental impacts. As project teams become more familiar with EPDs and demand them more, these tools will increasingly help purchasers make better-informed decisions.

SUMMARY

- Life cycle assessment at the product and whole-building levels and environmental product declarations help project teams and manufacturers understand the environmental impacts of their materials choices. Product-level LCA is more commonly performed by manufacturers, while whole-building LCA is performed by project teams or consultants. EPDs are created by manufacturers and verified by program operators to summarize the results of a product-level LCA.
- Product-level LCA is used to identify and quantify potential impacts that occur throughout a product's life cycle. Whole-building LCA tools enable project teams to explore interactions among building systems and to develop optimal combinations of materials and assemblies, as well as to compare entire building designs and the impacts of a new building with renovation of an existing building.
- LCA quantifies the inputs and outputs from raw materials extraction and processing, transportation, manufacture, installation, use, and end of life and identifies their potential impacts or burdens on the environment and, to a limited extent, on human health. It provides a more complete assessment than single-attribute, snapshot-in-time assessments.
- EPDs distill the findings from the LCA and, by describing environmental characteristics in a consistent way, help project teams make informed decisions.
- LCA is not a silver bullet; it often does not reveal a clear "best" decision. And simply conducting an LCA does not necessarily ensure a good outcome from a decision-making process. It cannot predict when, where, or whether the outputs will occur—only what the highest total output could be. LCA also has limitations in exploring human health impacts of product life cycles, particularly during the use stage. Since EPDs summarize information from LCA, the same limitations that apply to LCA filter down to the EPD.

TIPS FOR PRACTICE

ASK FOR EPDs. Whether a supplier has EPDs is an indicator of the degree to which it has considered environmental issues. Notice whether the EPD follows ISO guidelines or represents a house brand. Let product representatives know that you study and care about this information. Engage them to better understand problem areas and what the supplier is doing to improve.

USE WHOLE-BUILDING LCA TO HELP ACHIEVE GREENHOUSE GAS REDUCTIONS. Many architecture firms have commitments to reduce the carbon impact of buildings, like the Architecture 2030 challenge. Whole-building LCA and the specification of products with low global warming potential can contribute to emissions reductions.

USE CAUTION WHEN COMPARING LCAs OR EPDs PRODUCED BY DIFFERENT ORGANIZATIONS. LCAs can be performed with a variety of tools and use different data sets. Practitioners should determine the assessments' assumptions before using the resulting EPDs to compare products from different manufacturers.

LOOK FOR INDUSTRY-WIDE EPDs. During specification writing, investigate whether industry-wide EPDs are available for specific product types. If so, compare product-specific EPDs against the industry-wide benchmarks, or include performance thresholds in the specification.

ASK ABOUT LIFE CYCLE IMPACTS. Most EPDs are cradle to gate; a true comparison requires information on the entire life cycle. Can the product be recycled or reused? Ask manufacturers about take-back programs for end-of-life products, and if programs exist, use them.

MONITOR PURCHASING. Work across the decision-making chain to make sure that each person understands the rationale for prioritizing specific health and environmental performance attributes. Then track purchases through construction to ensure the products purchased meet the same criteria as those originally specified.

3.5 Tools for evaluating human health attributes

- What tools are currently available to help building professionals and manufacturers understand the human health attributes of materials?
 - What is the scientific and technical basis for these tools?
 - What are their strengths and limitations?
-

Increased demand for information about the human health attributes of building materials has created the need for more robust and standardized methods for assessing, distilling, and reporting health information. In recent years, several tools and programs have emerged to meet this need.

This section explains the assessment protocols and classification systems that form the basis for considering health attributes and then focuses on tools and programs that are referenced in the LEED v4 rating systems: GreenScreen for Safer Chemicals, Cradle to Cradle Certified, the Health Product Declaration Open Standard, and REACH.

CHEMICAL HAZARD AND RISK ASSESSMENT

Chemical hazard and risk assessments are scientific methodologies that underlie many materials evaluation tools and programs. A chemical hazard assessment focuses on identifying substances of potential harm to human health. A risk assessment incorporates consideration of the amount of the substance that causes harm and the likelihood of being exposed to that amount. It is not typically necessary for building professionals to know the details of these methodologies, but knowing about these approaches is useful for understanding commonly reported materials health information.

A chemical hazard assessment examines the potential harm that a particular substance may cause. It assesses the type of effect, or endpoint, that exposure to the substance could cause (e.g., irritation, carcinogenicity, endocrine activity), the intensity of the effect (potency), and whether the effect is acute (immediate and short-lived) or chronic (prolonged). Chemical hazard information may come from toxicological experiments that expose human or animal cells or live animals to the substance, or more rarely, it may derive from live human studies or epidemiological evidence that links human health effects to chemical exposure. Toxicological data exist for only a small fraction of the tens of thousands of chemicals on the market. In some cases, scientists may use computer simulations to model a substance's effects, employing existing data on a similar substance. Such surrogate measures can help fill data gaps but may introduce additional sources of uncertainty.

Toxicological studies also assess the degree to which a substance can cause harm, or its toxicity, which varies with the dose (amount) of the substance to which an organism is exposed and takes in. A chemical's toxicity depends on factors such as the pathway of exposure (inhalation, ingestion, or dermal absorption), the frequency and duration of exposure, the species that is exposed, and the age, sex, or particular vulnerability of the individual exposed. One commonly reported but very coarse measure of toxicity is the median lethal dose, or LD_{50} —the amount of a substance required to kill half the animals in the study population after a defined duration.

Exposure is typically estimated by assessing several factors, including the amount of a substance in environmental media (e.g., air, water, soil) and in the food supply, exposure pathways (e.g., dust ingestion or inhalation in the workplace), and an approximation of the likely number and duration of exposures. Risk assessment combines information about the dose-dependent response (toxicity) with the likelihood of exposure to quantify the probability that an adverse effect will result. Risk assessment further incorporates safety factors to account for uncertainty in these estimates. The final step in risk assessment—risk characterization—summarizes the overall risk and identifies any uncertainties and assumptions in the calculation.

HAZARD, TOXICITY, EXPOSURE, AND RISK

The terms used when discussing hazard and risk assessments are interrelated but distinct. Hazards are things with the potential to cause harm. The type of harm they may cause—their toxicity—is included in a hazard assessment. When risk assessments are performed for regulatory purposes, they include a hazard assessment as well as an evaluation of the dose-response—the variation in toxicity (i.e., response) over a range of doses. A risk assessment further includes an exposure assessment, which either measures or estimates the quantity of a substance a population or ecosystem is exposed to. Interpreting the results of an exposure assessment in the context of a dose-response assessment can provide a sense of whether common exposures are likely to produce toxic effects. The risk calculated by the risk assessment is the likelihood that toxicity will occur at typical exposure levels. To be valid, risk assessments must also account for the particular vulnerabilities of some populations or ecosystems. These vulnerabilities can stem from age-specific factors, genetic variation, preexisting disease, or the cumulative effects of multiple stressors.

HAZARD	EXPOSURE	DOSE	RISK	ADDITIONAL CONSIDERATIONS
Ice on sidewalk (which may cause pedestrian to slip and fall)	How much ice is on sidewalk?	How much ice does person walk on in daily activities?	What is overall likelihood that person will slip and fall on ice on sidewalk?	At what speed is person walking? What type of shoes is person wearing? Is person elderly, or does person have poor balance?
Asbestos insulation (which may cause cancer)	What amount of asbestos is handled by worker?	How much asbestos does worker breathe in over duration of job duties?	What is overall likelihood that person exposed to asbestos will develop cancer?	How effective is any protective gear being worn? Is insulation friable or encased in ceiling tile? Does exposed person smoke?

Hazard assessment, exposure determination, and risk assessment are well-defined practices; however, they are subject to significant and typically irreducible uncertainties. For instance, although a substance's LD₅₀ is a relatively easily measured assessment of acute toxicity, some endpoints, such as the ability of a chemical to disrupt hormone systems or to cause cancer, can be significantly more complex to measure.

Risk-based studies face additional challenges. It is difficult for exposure models to take into account all exposure scenarios or the interactions among multiple substances, and the scientific and technical literature routinely provides examples of the discovery of new, previously unanticipated modes of exposure or differential sensitivity among groups of people. These factors make it especially challenging to set science-based bounds for risks to specific populations in real-world circumstances, as three examples show:

- **VULNERABLE POPULATIONS AND ECOSYSTEMS.** Some substances, such as lead, are significantly more toxic to the developing brain of a child than to an adult. An individual who is already sick or a woman who is pregnant may also be more vulnerable.
- **SYNERGISTIC EFFECTS.** Exposure to multiple substances may cause interactions that are difficult to predict or that magnify the impact of individual exposures. For instance, smokers who are exposed to asbestos are more likely to develop mesothelioma than nonsmokers exposed to the same amount of asbestos.
- **AGGREGATE EXPOSURES.** Exposure to a single substance may come from multiple sources. For example, a person may be exposed to plasticizers from many different building materials as well as from food processing and packing and other plastic products. Exposure from any one of these sources may be below the “safe” threshold, but the sum of aggregate exposures may be harmful.

Exposure models may also fail to consider unexpected exposures during the use or misuse of a substance. And they may not adequately estimate how a chemical degrades in the environment or our bodies: many of the chemicals found in surface waters and in human fluids, such as breast milk, were not expected to end up there. Because of the uncertainties involved in calculating risk, a precautionary approach based primarily on hazard (described in Chapter 4) is best able to ensure human and ecosystem safety. The precautionary principle has been adopted by the USGBC board of directors as a guiding principle in [USGBC's 2013-2015 Strategic Plan](#) and is incorporated into the LEED rating systems.

CHEMICAL HAZARD CLASSIFICATION

Chemical hazard classification systems are responsible for communicating categories of hazards. In the case of human health, these categories are often focused around hazard endpoints, such as carcinogenicity, mutagenicity, and reproductive toxicity. Although the systems tend to be similar in content and approach, they are not uniform. Different regulatory bodies and certification organizations sometimes vary in the nomenclature, labeling, and even definition of similar hazards.

In 1992 the United Nations began developing the [Globally Harmonized System \(GHS\) of Classification and Labelling of Chemicals](#) in response to increasing international chemical

commerce and the need for consistency in communicating hazards across international borders to help ensure human and environmental safety. GHS uses standardized criteria to classify chemicals according to their health, physical, and environmental hazards, with a common set of graphics and hazard statements for each hazard category. Over the past few years, countries around the world have begun implementing GHS. Most large economies will have adopted the standard by the end of 2015.

GHS will be mandated by the governments of many countries, but private organizations have more flexibility to use their own variations of GHS for hazard classification. Two programs referenced in LEED v4—Cradle to Cradle Certified and GreenScreen for Safer Chemicals—use variations of the GHS categories (Table 3-2). Some hazard endpoints screened by these programs (e.g., neurotoxicity and persistence) are not included in GHS.

Table 3-2. Comparison of endpoints used by GHS, GreenScreen, and Cradle to Cradle Certified

GHS	GreenScreen	Cradle to Cradle		
Carcinogenicity	Carcinogenicity	Carcinogenicity		
Germ cell mutagenicity/ reproductive toxicity	Mutagenicity/ genotoxicity	Mutagenicity		
	Neurotoxicity	Neurotoxicity		
	Endocrine activity	Endocrine disruption		
	Persistence	Persistence		
	Bioaccumulation potential	Bioaccumulation		
Acute aquatic toxicity (fish, daphnia, algae)	Acute aquatic toxicity (fish, daphnia, algae)	Acute fish toxicity		
		Acute daphnia toxicity		
		Acute algae toxicity		
Chronic aquatic toxicity* (fish, daphnia, algae)	Chronic aquatic toxicity (fish, daphnia, algae)	Chronic fish toxicity		
		Chronic daphnia toxicity		
		Chronic algae toxicity		
Reproductive toxicity (repro+dev)	Reproductive toxicity	Reproductive toxicity (repro+dev)		
	Developmental toxicity			
Skin and respiratory sensitization	Skin sensitization	Skin and respiratory sensitization		
	Respiratory sensitization			
Skin corrosion/irritation	Skin irritation	Skin, eye, and respiratory corrosion/irritation		
Eye irritation	Eye irritation			
Acute toxicity (oral, dermal, inhalation)	Acute toxicity (oral, dermal, inhalation)	Oral toxicity	Dermal toxicity	Inhalative toxicity
Target organ single exposure	Systemic toxicity/ organ effects			
Target organ repeated exposure				
Flammability	Flammability	Other (human health)		
Reactivity	Reactivity			
	Other (terrestrial, avian, bee toxicity; physical properties, including nano properties)	Other (environmental)		
		Terrestrial toxicity		
Ozone depletion potential		Climatic relevance		
		Organohalogenes		
		Toxic metals		

*Includes bioaccumulation in the determination of chronic aquatic toxicity categories

TOOLS FOR ASSESSING CHEMICALS AND MATERIALS

LEED MR Credit [Building Product Disclosure and Optimization—Material Ingredients](#) references four tools and programs that assist in chemicals and materials assessment. Building professionals will be most interested in the ultimate information, result, or score a chemical, material, or product receives from one of these assessments; nevertheless, it will be helpful to understand the methodologies that underlie these programs.

All the programs require a detailed content inventory and a screening step that cross-references the ingredients with restricted substances lists and/or authoritative hazard lists.¹ GreenScreen and Cradle to Cradle Certified go a step further and require full hazard assessments of individual ingredients to provide more information about health hazards than the screening lists alone provide; the ultimate intent is to guide product optimization. The European REACH regulation plays a complementary role as part of its larger set of requirements addressing chemical registration, restriction, and substitution. The Health Product Declaration Open Standard is a standardized format that summarizes ingredient and hazard assessment information.

GREENSCREEN FOR SAFER CHEMICALS

The [GreenScreen® for Safer Chemicals](#) hazard assessment method, developed in 2007 and managed by [Clean Production Action](#), evaluates the hazards of individual ingredients and more complex mixtures. The tool can help manufacturers prioritize chemicals of concern that may need to be phased out and identify safer alternatives, and it can assist in procurement and risk management. It has been used by a diverse range of sectors, from electronics to cleaning products to building materials.

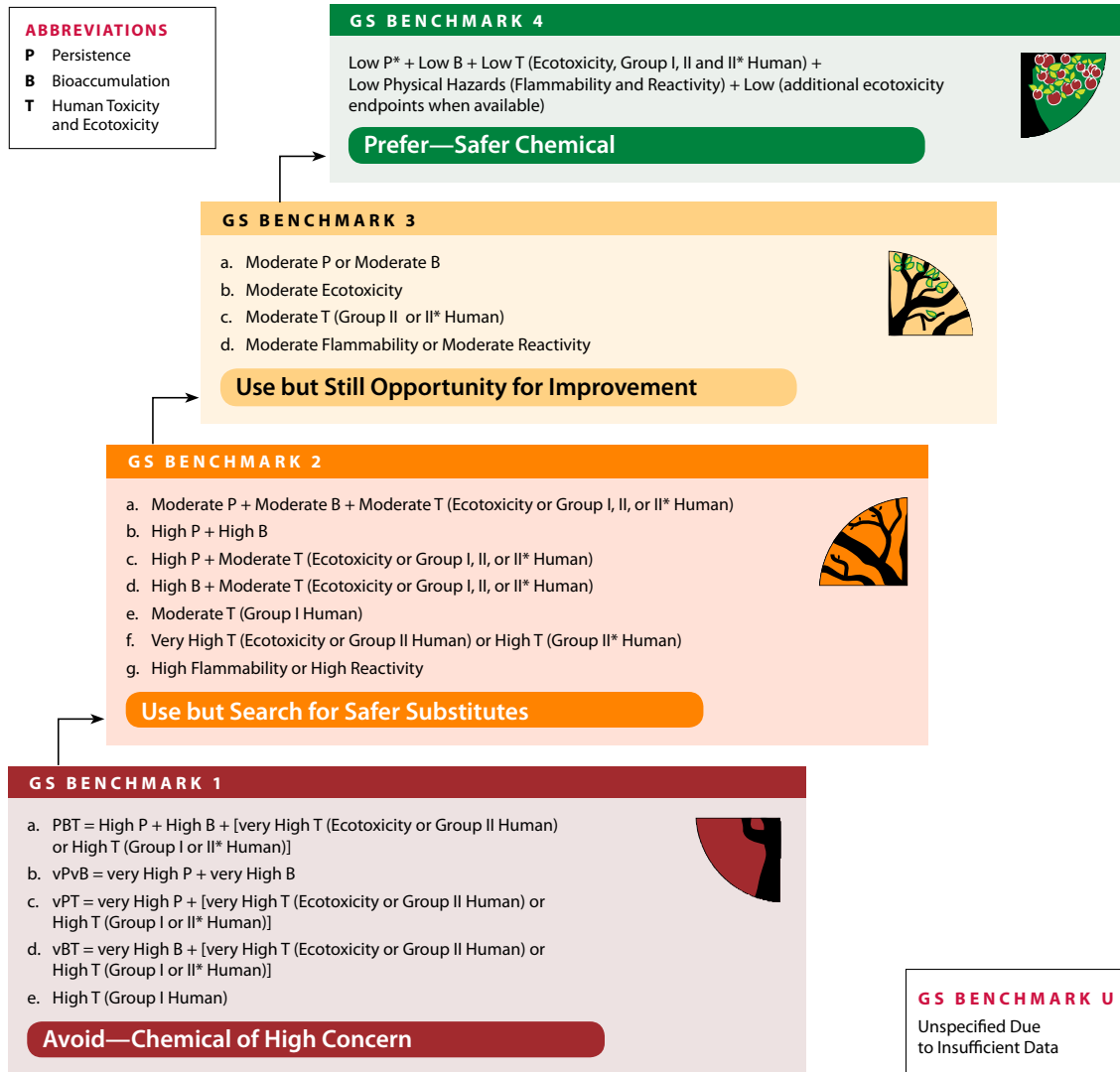
GreenScreen assessments begin with research and data collection on 18 human and environmental health endpoints associated with the substance being studied. An expert toxicologist then assigns a hazard level (ranging from Very High to Very Low) for each endpoint. Based on the hazard levels, an overall benchmark score is assigned to the chemical (Figure 3-11). The system uses a scale of 1 to 4, where Benchmark 1 chemicals are of most concern and should generally be avoided. They may be classified as Benchmark 1 because they have high human toxicity or because they have combinations of high persistence, bioaccumulation potential, and toxicity. Benchmark 4 chemicals are safest and have low hazard across all endpoints. In some instances, not enough research has been done on a particular chemical, resulting in a Benchmark U, for “unspecified.”

In addition to the benchmark score, GreenScreens include a hazard summary table with specific information on each relevant hazard endpoint (Figure 3-12). This information is supported by an in-depth summary of the data and justification for the classification levels. GreenScreens can be obtained from a variety of online sources, such as the [Interstate Chemicals Clearinghouse](#), [Chemical Hazard Assessment Database](#), the [GreenScreen Store](#), the [Pharos Project Chemical and Material Library](#), and the [Techstreet Store](#). Licensed GreenScreen profilers can be contracted to perform GreenScreens.

¹ For a detailed comparison of these programs, see Material Health Harmonization Task Group, Material health evaluation programs harmonization opportunities report ([download](#)).

NOVEMBER 2014

GreenScreen® for Safer Chemicals v 1.2 GreenScreen Benchmarks™



See Guidance (GreenScreen for Safer Chemicals Hazard Assessment Procedure) at www.greenscreenchemicals.org for instructions.

Group I Human includes Carcinogenicity, Mutagenicity/Genotoxicity, Reproductive Toxicity, Developmental Toxicity (incl. Developmental Neurotoxicity), and Endocrine Activity. **Group II Human** includes Acute Mammalian Toxicity, Systemic Toxicity/Organ Effects-Single Exposure, Neurotoxicity-Single Exposure, Eye Irritation and Skin Irritation. **Group II* Human** includes Systemic Toxicity/Organ Effects-Repeated Exposure, Neurotoxicity-Repeated Exposure, Respiratory Sensitization, and Skin Sensitization. Immune System Effects are included in Systemic Toxicity/Organ Effects. **Ecotoxicity** includes Acute Aquatic Toxicity and Chronic Aquatic Toxicity.

* For inorganic chemicals persistence alone will not be deemed problematic. See Guidance.

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Figure 3-11. GreenScreen for Safer Chemicals version 1.2 benchmarks

Courtesy: Clean Production Action

Rate of exposure	Group I Human					Group II and II*Human						Ecotox		Fate		Physical			
	C	M	R	D	E	AT	ST			SnS*	SnR*	IrS	IrE	AA	CA	P	B	Rx	F
							single	repeated*	single	repeated*									
Inhalation	M		<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>M</i>	<i>M</i>	<i>L</i>	<i>L</i>									
Oral	L	L	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	vH	<i>L</i>	<i>L</i>	<i>L</i>
Dermal	<i>L</i>		<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>									

Figure 3-12. GreenScreen hazard ratings for pigment-grade titanium dioxide

Note: Hazard levels (Very High (vH), High (H), Moderate (M), Low (L), Very Low (vL)) in italics reflect estimated (modeled) values, authoritative B lists, screening lists, weak analogues, and lower confidence. Hazard levels in bold font are used with good quality data, authoritative A lists, or strong analogues. Group II Human Health endpoints differ from Group II* Human Health endpoints in that they have four hazard scores (i.e., vH, H, M, and L) instead of three (i.e., H, M, and L), and are based on single exposures instead of repeated exposures.

Courtesy: ToxServices LLC

The [GreenScreen List Translator](#) is an abbreviated version of the full GreenScreen; it is a quick way to identify some hazardous ingredients. The List Translator maps authoritative and screening hazard lists to specific hazard endpoints (e.g., carcinogenicity, endocrine activity) and hazard classification levels (e.g., High, Medium, or Low). It provides an initial screening assessment to determine whether a chemical is a Likely Benchmark 1, Possible Benchmark 1, or Unknown and can help identify those chemicals that are best suited for a full GreenScreen assessment. The [GreenScreen List Translator](#) can be accessed via the [Pharos Project's Chemical and Material Library](#) or using the [GreenWERCS](#) formulation profiling tool.

CRADLE TO CRADLE CERTIFIED

Cradle to Cradle Certified™ is a multiattribute standard run by the [Cradle to Cradle Products Innovation Institute](#). It promotes continuous improvement in a product through five levels of certification, from Basic to Platinum. Cradle to Cradle evaluates products in five categories, one of which is material health. The material health assessment methodology is based on chemical hazard identification and qualitative exposure considerations during a product's final manufacture, intended (and highly likely unintended) use, and end of use. Material health assessments are conducted by accredited assessors who are trained and audited by the Cradle to Cradle Products Innovation Institute. Certification is valid for two years, and manufacturers are required to make a good-faith effort toward optimization in all five attributes for recertification. In addition to the full certification, Cradle to Cradle also offers Material Health Certificates, which allow manufacturers to complete just the material health portion of the Cradle to Cradle assessment.

The material health assessment begins at the Basic level by defining the generic materials in the product and ensuring that no banned chemicals are present; there is no chemical assessment at the Basic level. Each higher level of certification requires that a larger percentage of those substances be identified (up to 100 parts per million) and assessed for hazards across 24 human and environmental endpoints. If problematic chemicals are identified, strategies must be developed to phase them out. When all problematic substances are removed, the product achieves the Gold level, and when all problematic process chemicals are removed, the product achieves Platinum.

Although individual, chemical-level hazard and exposure endpoint ratings are not usually published as a part of Cradle to Cradle Certification, the inherent hazard of all chemical constituents subject to review is evaluated and summarized (Table 3-3).

Table 3-3. Summary criteria for Cradle to Cradle chemical constituent evaluation
 Courtesy: Cradle to Cradle Products Innovation Institute

	BRONZE	SILVER	GOLD	PLATINUM
MINIMUM PERCENTAGE ASSESSED	75%	95%	100%	100%
OPTIMIZATION	No banned-list chemicals	No exposure to carcinogens, mutagens, or reproductive toxicants	Fully optimized, safe for humans and environment	Process chemicals also fully optimized

Manufacturers may report their Cradle to Cradle assessment results through two formats—the overall certification label or the scorecard. The Cradle to Cradle product label shows the overall certification level and logo, based on the lowest level of achievement in any one of the five certification attributes. When viewing the label, purchasers should keep in mind that the product may have attained higher levels of achievement in some categories. Companies that wish to display more information about their certification may use the product scorecard to show the achievement level of each attribute (Figure 3-13). The Cradle to Cradle Products Innovation Institute maintains a [registry](#) of certified products.



Figure 3-13. Cradle to Cradle Certified product label and scorecard
 Cradle to Cradle Certified products may choose to display assessment details through the product scorecard or label, as shown in the upper left-hand corner.
 Courtesy: Cradle to Cradle Products Innovation Institute

REGISTRATION, EVALUATION, AUTHORISATION AND RESTRICTION OF CHEMICALS



The European Union's REACH regulation, which went into effect in 2007, requires all chemicals produced or imported into the European Union in quantities of at least one metric ton per year to be registered in a central database and prioritized for evaluation and possible avoidance based on their hazard profile. The European Commission or an EU member state may propose chemicals for inclusion on a public list of "substances of very high concern." These substances "may have serious and often irreversible effects on human health and the environment"—for instance, if they are carcinogenic, mutagenic, toxic for reproduction, or persistent, bioaccumulative, and toxic, and are being considered for regulation that would require authorization for some or all uses.

The European Chemicals Agency, which manages REACH, maintains several lists of hazardous chemicals. One is the [Candidate List](#) of SVHCs for authorization. The identification of a substance as an SVHC and its inclusion in the Candidate List is the first step of the authorization procedure. Suppliers of articles that contain listed substances in a concentration above 0.1% (weight/weight) are required to provide their customers sufficient information to allow safe use of the article. As of June 2015, this list contained 163 substances. The [Authorisation List](#) contains SVHCs from the Candidate List that have been identified as priorities. These chemicals can be used only with special authorization and when a manufacturer provides a plan to replace the SVHC with a safer alternative. The European Chemicals Agency also maintains a [List of Restrictions](#) for chemicals that it foresees strictly regulating or even banning. This list contained 105 substances as of June 2015 and included benzene, vinyl chloride, asbestos fibers, and several heavy metals. The SVHC lists have inspired manufacturers to be proactive: a wide range of companies across many industries track SVHCs in their supply chains and are already making changes in their formulations in anticipation of regulation and planning for phaseout.

HEALTH PRODUCT DECLARATION

The Health Product Declaration® Open Standard is a standardized format for reporting building product contents and their known associated hazard data. It was developed as a health-focused analogue to the EPD by a consortium of firms convened by the Healthy Building Network and BuildingGreen. It is a user-driven initiative, now managed by the [Health Product Declaration Collaborative](#). After a joint development process with manufacturers and other industry stakeholders, HPD version 1.0 was released in 2012. Version 2.0 will be released in mid-2015.

Like EPDs, HPDs are designed to distill information on product contents, but they also contain detailed information about health. Stakeholders may use HPDs at different points along the product supply chain. Suppliers can inform an HPD by completing a material content inventory, which contributes to the content section of the HPD. Manufacturers use the HPD to report product contents, emissions, and hazard endpoints using their own data or data from an independent lab. Designers, specifiers, builders, and other stakeholders request HPDs to help catalyze increased awareness and transparency throughout the building industry and then use the reported information to inform product selection.

The Collaborative has developed a free online platform to facilitate consistent preparation and timely publication of HPDs. Manufacturers are expected to post compliant, published HPDs on their websites and to distribute them to customers and other interested parties. Manufacturers may choose to keep HPDs private when they are in draft form; once an HPD is published, it is distributed to select building product libraries to encourage circulation. The Collaborative's website lists participating libraries.

INFORMATION INCLUDED IN HPDs. Information included in an HPD is reported by manufacturers in a standard format with six sections (Figure 3-14):

- **SUMMARY** gives basic product information, product description, and summary information of the inventory, hazards, and VOC content.
- **CONTENT** consists of a full ingredients list, in order of decreasing content, along with associated hazards.
- **CERTIFICATIONS AND COMPLIANCE** provide VOC emission information for interior finish materials and VOC content information for wet-applied materials.
- **ACCESSORY MATERIALS** are additional products required by warranty or recommended by the manufacturer for installation or for maintenance, cleaning, or operations.
- **NOTES** provide any additional explanations not covered by section-specific notes, including information about exposure and risk.
- **REFERENCES** include manufacturer contact information and explanations of abbreviations.

In the content section, materials and their chemical substances (i.e., inputs and reaction products that are added to the product by the manufacturer or a supplier and exist in the product as delivered) are listed in order of decreasing content with the following information for each substance: name, CAS registry number, percentage weight, associated hazards and warnings, GreenScreen benchmark, whether the ingredient contains recycled content, whether the ingredient is a nanomaterial, its role in the product, and relevant notes. Any known trace substances remaining from manufacturing steps or contaminants should be listed if known. Content names and CAS numbers can remain “unknown” or “undisclosed” if the manufacturer or supply chain has intellectual property concerns. However, the manufacturer should still identify the hazards of the ingredient and its role in the product, explain the reasons for nondisclosure, and provide a timeline for disclosure. Health hazard information is referenced from data published in a prescribed set of authoritative chemical hazard lists or an automated hazard compilation list, like the [Pharos Project Chemical and Material Library](#).

INFORMATION NOT INCLUDED IN HPDs. An HPD is not a full product risk assessment, although it does provide a place for manufacturers to explain any exposure or risk assessment they have done. Furthermore, an HPD does not provide a full assessment of the life cycle impacts of the product, meaning that it does not report health impacts of the process chemicals in manufacturing, combined exposures, or combustion, degradation, or other potential end-of-life reaction products. It does, however, request disclosure of byproducts or residuals from production that may end up in the final product. Some things cannot yet be fully characterized in an HPD, including process chemistry or recycled content, because of variability in the feedstock.

HPDs VERSUS MSDSs. HPDs are an improvement over the current approach to researching emissions and ingredients: requesting MSDSs from the product manufacturer and checking disclosed contents against RSLs. Although an MSDS can provide some basic ingredient information, its target is manufacturing workers' and installers' safety. MSDSs were developed to mitigate occupational risks from individual chemicals and to provide a base-level assessment of associated hazards, rather than to serve as a materials specification tool for teams considering the health attributes of products.

Moreover, ambiguities in reporting requirements mean many MSDSs lack full disclosure and have inconsistent hazard assignments and disclosure levels, such that MSDSs are not comparable. To address some of these inconsistencies, in 2015 OSHA will require U.S. chemical manufacturers, distributors, or importers to report information in a standardized safety data sheet (SDS) format following GHS guidelines. GHS includes hazard screening, and the GHS criteria are included in both the GreenScreen List Translator and HPD priority hazard lists. GHS SDSs are provided by manufacturers and are not third party verified. The threshold content for reporting is more stringent than the previous 1%, with many contaminants requiring reporting down to 0.1%.

FUTURE OUTLOOK FOR DATA AND TOOLS

Different databases, formats, and publications focus on different pieces of the puzzle. Even “comprehensive” databases consist of information gleaned from a variety of sources—manufacturers' representations, academic research, third-party analysis—each of which carries a different set of uncertainties and caveats that may compromise the data's validity and currency.

Such fragmentation and uncertainty pose a challenge for green building practitioners. Over time, practitioners can expect these tools to improve, consolidate, and gradually become more coordinated and aligned. However, this will take continued focus and investment. For now, LEED references the best, most practical tools to inform practitioners' decisions and incentivize manufacturers to improve products.

SUMMARY

- Increased demand for information about the health attributes of building materials has created the need for new methods for assessing and reporting health information, such as GreenScreen for Safer Chemicals, Cradle to Cradle Certified, HPD, and REACH.
- Chemical hazard and risk assessments underlie many materials evaluation tools. A chemical hazard assessment focuses on identifying substances of potential harm to human health, whereas a risk assessment incorporates consideration of the amount of the substance that causes harm and the likelihood of being exposed to that amount.
- Hazard assessment, exposure determination, and risk assessment are well-defined practices; however, they are subject to significant and typically irreducible uncertainties.
- The GreenScreen for Safer Chemicals, a hazard assessment method for individual ingredients and more complex mixtures, helps manufacturers prioritize chemicals of concern and plan for phaseout or find alternatives.
- Cradle to Cradle Certified is a multiattribute standard that promotes continuous improvement in a product through five levels of certification.
- REACH is a European Union regulation that addresses substances of very high concern that are being considered for regulation requiring authorization for some or all uses.
- The HPD is a standardized format for reporting building product contents and their known associated hazard data.
- Although each of these tools and programs provides some information about some products, none can be considered a complete resource. Over time, practitioners can expect these tools to improve and become more coordinated and aligned.

TIPS FOR PRACTICE

- **ASK FOR HPDs.** Prioritize products that disclose information, even if it's bad information, over those that do not. Look for third-party verification of bills of materials to ensure the information is complete. Let product representatives know that you study and care about this information. Engage them to better understand problem areas and what the supplier is doing to improve.
- **FUTURE-PROOF.** Protect human health and the environment by specifying and purchasing intrinsically safer materials.
- **DEFINE THE HEALTH GOALS OF YOUR PROJECT.** Articulate the goals for human health. Many organizations have vested interest in the health of their occupants. Health care organizations may have larger goals for preventive care at the community scale. Other projects may want to prioritize upstream impacts of product manufacturing.
- **ALIGN PRODUCT SPECIFICATION WITH PROJECT GOALS.** Use project goals to guide and prioritize product assessment and trade-offs among materials attributes.
- **UNDERSTAND THE RISK.** Just because a product has an ingredient with a hazard flag doesn't necessarily mean it will cause immediate harm to you or others in the supply chain. Ask the manufacturer to explain the context of that ingredient in its product.
- **MONITOR PURCHASING.** Work across the decision-making chain to make sure that each person understands the rationale for prioritizing specific health performance attributes. Then track purchases through construction to ensure the products purchased meet the same criteria as those originally specified.

CHAPTER 3. RESOURCES

POLICIES

U.S. FEDERAL GOVERNMENT POLICIES

- [U.S. laws and executive orders for protecting the environment and public health](#), U.S. EPA
- [EDF Health blog on chemicals and nanotechnology](#), Environmental Defense Fund

STATE AND LOCAL POLICIES

- www.saferstates.com
- [Better buildings, better policy: A compilation of green building policy adoptions in the United States, 2011-2014](#), USGBC
- [EDF Health blog on chemicals and nanotechnology](#), Environmental Defense Fund

FOREIGN AND INTERNATIONAL POLICIES

- [International Code Council](#)
- [Montreal Protocol, United Nations Environment Programme](#)
- [Stockholm Convention, United Nations Industrial Development Organization](#)
- [Understanding REACH, European Chemicals Agency](#)

AUTHORITATIVE HAZARD AND RESTRICTED SUBSTANCES LISTS

- [Index of priority hazard lists, Health Product Declaration Collaborative](#)
- [Living Building Challenge Red List](#)
- [Perkins+Will Precautionary List](#)

ENVIRONMENTAL CLAIMS AND CERTIFICATIONS

- [Behind the logos: Understanding green product certifications](#), Environmental Building News
- [Environmental labels and declarations: How ISO standards help](#), ISO
- [“Green Guides” for the use of environmental marketing claims](#), Federal Trade Commission. Read a [summary](#).

CHEMICAL HAZARD AND RISK ASSESSMENT

- [Assessment of chemicals, Organisation for Economic Co-operation and Development](#)
- [Globally Harmonized System \(GHS\) of Classification and Labelling of Chemicals](#).
Read a [summary](#).
- [Material health evaluation programs harmonization opportunities report](#), Material Health Harmonization Task Group
- [Risk assessment](#) at the U.S. EPA
- [Videos from USGBC's materials and health event series](#)

ENVIRONMENTAL AND HUMAN HEALTH TOOLS

- [AIA guide to building life cycle assessment in practice](#), AIA
- [Athena guide to whole-building LCA in green building programs](#), Athena Sustainable Materials Institute
- [Demystifying EPDs](#), USGBC
- [Health Product Declaration Collaborative](#)
- [LCA in construction: Status, impact, and limitations](#), Athena Sustainable Materials Institute and thinkstep
- [The product transparency movement: Peeking behind the corporate veil](#), Environmental Building News
- [Videos from USGBC's materials and health event series](#)
- [Whole-building life-cycle assessment](#): Taking the measure of green building, Environmental Building News

TOOLS FOR ASSESSING ENVIRONMENTAL AND HEALTH IMPACTS

Assessment type	Tool	Organization	Description
Environmental*	Athena Impact Estimator for Buildings	Athena Sustainable Materials Institute	Whole-building LCA
	Environmental product declaration	Governed by ISO standards	Reporting format. Data based on LCA.
	GaBi	thinkstep	LCA
	SimaPro	PRé Consultants	LCA
	Tally	KT Innovations, thinkstep, and Autodesk	Whole-building LCA
Health	Cradle to Cradle Certified (Material Health Assessment)	Cradle to Cradle Products Innovation Institute	Multiattribute assessment method for products. Material Health Assessment can be completed separately.
	Declare	International Living Future Institute	Chemical hazard assessment label for building products
	GHS safety data sheets	United Nations	Reporting format for substances and mixtures. Includes hazard information.
	GreenScreen for Safer Chemicals	Clean Production Action	Hazard assessment method for chemicals
	GreenScreen List Translator	Clean Production Action	Initial screening assessment for hazardous ingredients
	Health Product Declaration	Health Product Declaration Collaborative	Reporting format for products. Data include product contents and health hazards.
	REACH <ul style="list-style-type: none"> • Candidate List • Authorisation List • List of Restrictions 	European Chemicals Agency	EU regulation for chemical risk management

*Additional LCA tools are listed in [Whole-building life-cycle assessment: Taking the measure of green building](#), Environmental Building News

DATABASES OF CHEMICAL INGREDIENT, BUILDING MATERIAL, AND PRODUCT INFORMATION

Database	Organization	Type of info	Description	Related products and programs
ACToR (Aggregated Computational Toxicology Resource)	U.S. EPA	chemicals	All publicly available chemical toxicity data	
AOEC Exposure Code List	Association of Occupational and Environmental Clinics	chemicals	Substances that have been reported as asthmagens by experts in occupational asthma	
BASTA	IVL Swedish Environmental Research Institute and Swedish Construction Federation	building products	Building products that only include ingredients meeting criteria for hazardous properties based on the EU's REACH legislation	
BEES (Building for Environmental and Economic Sustainability)	National Institute of Standards and Technology (NIST)	building products	Product analysis based on environmental and economic performance measures	
Carbon Trust Green Business Directory	Carbon Trust	suppliers and installers	Suppliers and installers in the UK and Ireland accredited by the Carbon Trust	
ChemHAT (Chemical Hazard and Alternatives Toolbox)	BlueGreen Alliance	chemicals	Chemical hazard, exposure, and safer alternatives information. Includes authoritative lists and case studies for chemical substitutions.	SUBS PORT
C&L Inventory (ECHA classification and labeling database)	European Chemicals Agency	chemicals	Classification and labeling information on notified and registered substances received from manufacturers and importers. Part of the CLP Regulation .	eChemPortal, REACH registered substances
CleanGredients	GreenBlue	chemicals	Chemicals used primarily to formulate cleaning products that have been pre-approved to meet the U.S. EPA's Safer Choice Standard	
Cleaner Solutions	Toxics Use Reduction Institute	cleaning products	Performance evaluations and environmental assessments of cleaning products	
Cradle to Cradle Certified Products Registry	Cradle to Cradle Products Innovation Institute	products	Products with Cradle to Cradle certification	
Declare product database	International Living Future Institute	building products	Building products with Declare label	Living Building Challenge

Designer Pages	Designer Pages	building products	Building products and their associated information for architecture and interior design	
eChemPortal	OECD	chemicals	Chemical properties, ecotoxicity, environmental fate and behavior, and toxicity information	
GIGA	GIGA	building products	Building products and their associated information, including HPDs, EPDs, Declare label, C2C certification, as well as single-attribute characteristics and certifications such as FSC and FloorScore	
GreenSpec	BuildingGreen	building products	Building products selected by BuildingGreen as “greenest-of-the-green.” Includes contribution toward LEED credits and other green attributes.	
GreenScreen Store	Clean Production Action	chemicals	Chemicals with GreenScreen assessments	
GreenWizard	GreenWizard	building products	Environmental, health, and performance information. Includes HPDs, EPDs, LCA information, Declare label, C2C certified products as well as single-attribute characteristics and certification such as FSC and bio-based.	Also includes letters to manufacturers
IC2 Chemical Hazard Assessment Database	Interstate Chemicals Clearinghouse (IC2)	chemicals	Chemicals with GreenScreen and/or Quick Chemical Assessment Tool assessments	GreenScreen, Quick Chemical Assessment Tool (QCAT)
ICE database	Circular Ecology	building products	Embodied energy and carbon data for materials	
RISCTOX	ISTAS	chemicals	Database of hazardous substances. Includes health risks, environmental risks, and environmental and health-related regulations.	
Pharos Building Product Library	Healthy Building Network	building products	Product’s material contents and associated health hazards and product score based on VOCs, toxic content, manufacturing toxics, renewable materials, renewable energy, and reflectance.	Pharos Framework, Pharos Chemical and Material Library

Pharos Chemical and Material Library	Healthy Building Network	chemicals and materials	Substances screened against authoritative hazard and warning lists. Assigns hazard and priority levels. Includes HPD hazards and GreenScreen scores.	Pharos Building Product Library
REACH registered substance database	European Chemicals Agency	chemicals and products	Chemical data from REACH registration dossiers submitted to the European Chemicals Agency	eChemPortal C&L Inventory
Substances in Preparations in Nordic Countries (SPIN)	Nordic Product Registers	chemicals and products	Use of substances in products in Nordic countries	
TOXNET	U.S. National Library of Medicine, National Institutes of Health	chemicals	Group of databases covering chemicals and drugs, diseases and the environment, environmental health, occupational safety and health, poisoning, risk assessment and regulations, and toxicology	
U.S. Life Cycle Inventory Database	National Renewable Energy Laboratory	life cycle inventory data	Critically reviewed LCI data, including gate-to-gate, cradle-to-gate, and cradle-to-grave	

4.

CHAPTER 4. MATERIALS OPTIMIZATION AND INNOVATION

4.1 Goals and principles for materials selection and optimization

- What are the goals of materials selection and optimization?
- What principles should guide the design and specification of preferable materials and products?
- What are the roles of risk- and hazard-based approaches in designing and specifying preferable materials and products?

Both manufacturers and project teams play important roles in improving the status quo. As the ones designing and making products, manufacturers have a clear responsibility to optimize their processes and ingredients for human health and environmental protection. At the same time, practitioners, as the consumers of these products, drive manufacturer optimization and innovation by demanding more robust product disclosure and evaluation and by preferentially selecting products designed with improved human health and environmental attributes in mind.

LEED v4 aims to accelerate this process by helping to reorient materials design and selection from a reactive approach that addresses problems as they arise to a proactive approach that encourages inherently safer life cycle design and product specification. This convergence of interests around preferable materials provides an opportunity to bring together the expertise of manufacturers, project teams, and scientists around common goals of healthful, environmentally preferable, high-performing, and cost-effective materials.

Manufacturers do not set out to make products that are bad for human health and the environment, and practitioners do not intentionally specify their use in buildings. However, a tradition of narrowly focusing on attributes like product function, aesthetics, and price has contributed to inadequate information and value placed on human health and environmental dimensions. The result is that many products on the market today and in buildings include hazardous substances that may be associated with significant health and environmental impacts. This happens for various reasons. A summary of some of the most notable challenges, along with accompanying opportunities for action, is shown in Table 4-1.

Table 4-1. Challenges and opportunities for improving building materials

CHALLENGES	OPPORTUNITIES
Absence or inadequacy of information on health and environmental attributes of many building materials	New protocols for systematically documenting and communicating health and environmental attributes
Absence or inadequacy of information linking specific substances and their attributes to health and environmental outcomes	Ongoing research and data collection to predict potential health and ecosystem harms associated with materials' life cycles and identify preferable alternatives
Absence or inadequacy of resources and tools that communicate to practitioners scientific findings and technical information on potential health and ecosystem concerns or benefits of materials	Hazard and alternatives assessment tools (e.g., from Clean Production Action, Cradle to Cradle Certified) and training in identifying and developing preferable materials
Limitations of current public policy and regulations to provide comprehensive protection for human health and environment	Broad-based recognition of limitations and advocacy for federal and state policy reform
Relatively low priority given to health and environmental attributes of materials in materials design and specification	Increasing recognition of impacts and implications of building materials and increasing market incentives for preferable materials

Sections 3.4 and 3.5 focused on specific tools that aid both specifiers and manufacturers in making decisions that improve buildings and products. This section will examine the principles that underlie those tools and the materials optimization process as a whole. Familiarity with these technical concepts can help facilitate dialogue among manufacturers, designers, specifiers, and others, ultimately contributing to more informed decision making.

GOALS OF MATERIALS OPTIMIZATION

The path to better materials and products starts with minimizing or eliminating life cycle hazards early in the material or product design phase. Human health and environmental harms should be viewed as a design flaw, much like any other material or product deficiency. Knowledge about natural systems, environmental health, and engineering makes it possible to integrate considerations of human health and the environment into materials design to minimize these undesirable effects.

The materials optimization process has three basic goals:

- **TO INTEGRATE HUMAN HEALTH AND ENVIRONMENTAL CONSIDERATIONS INTO DECISION MAKING.** Human health and environmental attributes of materials should be considered critical design criteria, on equal footing with other factors like cost, performance, and aesthetics.
- **TO DESIGN AND SPECIFY MATERIALS TO REDUCE NEGATIVE HUMAN HEALTH AND ENVIRONMENTAL IMPACTS THROUGHOUT THEIR ENTIRE LIFE CYCLES.** As noted throughout this guide, materials have human health and environmental implications from raw materials extraction through end of life or reuse.
- **TO IMPROVE PRODUCTS TO BE INTRINSICALLY PREFERABLE RATHER THAN INCREMENTALLY LESS HAZARDOUS AND PROMOTE THEIR SPECIFICATION.** To date, significant effort has focused on incrementally reducing hazards and damages associated with building materials and products. Alternative approaches avoid potential hazards and can even benefit the environment (e.g., carbon-sequestering concrete).

PRINCIPLES FOR PREFERABLE MATERIALS AND PRODUCTS

Principles are broad, overarching statements that guide particular actions or activities and provide a reference point to understand whether actions align with desired goals. Three principles that guide materials optimization toward preferable materials and products are right to know, precaution, and prevention.

RIGHT TO KNOW

Right to know is the legal principle that individuals should have access to information about potential chemical hazards, uses, and environmental releases in their communities and the workplace. For example, the federal [Toxics Release Inventory](#), authorized by the 1986 Emergency Planning and Community Right-to-Know Act, creates an obligation for some manufacturers to publicly disclose the release of certain pollutants and to report on waste generation. TRI has dramatically increased the availability of information on the generation and fate of a wide variety of industrial pollutants. Over time, this has contributed to a reduction in environmental releases and greater accountability for certain pollutants.¹

This legal principle is complemented by efforts for more comprehensive disclosure, beyond what is required by right-to-know regulations. As explained in Section 3.1, product information transparency is necessary to transform the building materials market. It is impossible to make informed choices about preferable products without access to reliable, relevant, and actionable information that flows systematically through materials supply chains to companies, governments, and the general public.

PRECAUTION

The concept of precaution as applied to materials and products is rooted in scientific principles and human experience. From a scientific perspective, we recognize that the current understanding of the health and environmental impacts of materials is incomplete, uneven, and ambiguous. There is no indication that this situation will fundamentally change in the near future. From an experiential perspective, we have repeated evidence that people are very poor at risk assessment, with many examples of long lag times between academic recognition of hazards and effective market or policy action. The combination of science and experience motivates the use of a precautionary approach to materials design and selection.

One of the first and most commonly cited definitions of the precautionary principle comes from the 1992 Rio Declaration of the United Nations Conference on Environment and Development: “Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental

¹ U.S. Environmental Protection Agency, *The toxics release inventory in action: Media, government, business, community, and academic uses of TRI data* (Washington, D.C.: EPA, 2013), http://www2.epa.gov/sites/production/files/documents/tri_in_action_final_report_july_2013.pdf.

degradation.” In line with this recommendation, the precautionary principle is a guiding principle of the U.S. Green Building Council.²

Although definitions for the precautionary principle vary, they have similar elements: if there is uncertain yet credible scientific evidence or concern of threats to human health or the environment, precautionary measures should be taken. Early warnings should prompt preventive action even if the nature and magnitude of the risk are not fully understood.

Implementing the precautionary principle in the context of green building requires new approaches to product design and decision making:

Shift the questions asked.

- **CONVENTIONAL FRAMING:** “What level of risk is acceptable? How much contamination can the environment or a human assimilate?”
- **PRECAUTIONARY FRAMING:** “What are the alternatives or opportunities for avoiding hazards while still achieving our goals? Is this ingredient, process, or functionality needed in the first place?”

Shift presumptions.

- **CONVENTIONAL FRAMING:** “Materials should be presumed safe until proven harmful.”
- **PRECAUTIONARY FRAMING:** “Materials have the potential to harm people and the environment. If the hazards are uncertain, proceed with caution.”

Make decisions transparent and inclusive.

- **CONVENTIONAL FRAMING:** “Information on material ingredients and life cycle impacts should not be disclosed to consumers.”
- **PRECAUTIONARY FRAMING:** “Information on material ingredients and life cycle impacts should be disclosed to support health and environmental claims.”

Start with goals rather than inevitabilities.

- **CONVENTIONAL FRAMING:** “Negative impacts are an inevitable consequence of manufacturing and applying building materials.”
- **PRECAUTIONARY FRAMING:** “Negative impacts are design flaws. We can set goals for the future and set a course toward those goals.”

² One of the guiding principles of the 2013–2015 USGBC Strategic Plan states, “USGBC will be guided by the precautionary principle in utilizing technical and scientific data” (<http://www.usgbc.org/sites/default/files/usgbc-strategic-plan-2013-2015.pdf>, 4).

PREVENTION

Prevention, in its simplest sense, is the avoidance of harm. In the public health arena, prevention is divided into multiple categories. Primary prevention aims to prevent disease from occurring in the first place by addressing risk factors and reducing or eliminating exposure to harmful substances. Secondary and tertiary prevention, on the other hand, focus on treating diseases early and preventing diseases from causing other problems. A counterpart for the environment is preventing waste and pollution rather than capturing and treating it.

The industrial hygiene field has established a hierarchy of prevention that states that hazards should be controlled in the following order:

1. **SUBSTITUTION** of harmful chemicals, processes, and activities with safer ones.
2. **ENGINEERING CONTROLS** that manage the hazard at its source, such as redesigning a facility or process to remove the hazard and erecting barriers to enclose the hazard to prevent or reduce exposure in normal operations.
3. **ADMINISTRATIVE CONTROLS** that change the way workers do their jobs to reduce their exposure to hazards.
4. **PERSONAL PROTECTIVE EQUIPMENT** (PPE), such as respirators, hardhats, face and eye protection, hearing protection, gloves, and protective clothing and footwear, to mitigate exposure to hazards that cannot be completely engineered out of normal operations.

AN EXAMPLE OF PREVENTIVE ACTION

Flammable floor finishes in the United States have caused several fires and explosions that have killed mainly immigrant workers. The workers may have been provided instructions on how to use the chemicals safely and use personal protective equipment. However, language barriers and working conditions may have limited the effectiveness of these measures (e.g., warm indoor temperatures may make protective gear uncomfortable to wear, limiting compliance). Substituting high-performing floor finishes that were nonflammable and less toxic would have reduced risks for these workers and also reduced harms in both production and disposal.

Although approaches that use all levels of the hierarchy of prevention are important in protecting workers, substitution is the only way to completely eliminate a hazard and is the preferred approach. Engineering controls provide an important mechanism to limit exposure to potentially harmful substances (e.g., venting emissions from a factory into a scrubber and the outside air), but they can be expensive and shift hazards from the workers to the environment. Administrative controls can effectively reduce hazards but require continuous monitoring and communication and may not prevent exposure altogether. Finally, PPE may allow workers to handle potentially dangerous substances, but it can be burdensome and thus discourage compliance (e.g., a worker may find it challenging to wear a respirator all day), it may require extensive training to use, it can be expensive to purchase and maintain, and it may fail.

Exposure controls present limitations at additional phases of the life cycle. For instance, they are difficult to implement in the use phase if a substance is not bound to the material (e.g., flame retardants in furniture foam) and may leach out at an unpredictable rate. Similarly, chemicals that easily disperse, such as solvents in adhesives or cleaning formulations, are hard to control and often end up in dust or wastewater treatment systems. Exposure controls may also be difficult to implement at end of life if a material is disposed of in a landfill or, as in the case of many electrical and electronic materials, disassembled in developing countries where protections are limited.

In the field of environmental protection, a paradigm shift occurred in 1990 with the passage of the Pollution Prevention Act. Previously, most environmental protection efforts focused on either treating pollution once it entered the environment—in landfills or waste treatment facilities—or controlling emissions through expensive technologies, such as scrubbers and filters, that tended to shift pollutants from one medium to another (e.g., air to water) or from the workplace to the community. The Pollution Prevention Act, on the other hand, states that “... pollution should be prevented or reduced at the source whenever feasible ... disposal or other release into the environment should be employed only as a last resort ...”

In the area of materials selection and product design, there are different levels of prevention, each requiring more complex changes and stakeholder involvement but offering potentially greater benefits:

- **PROCESS LEVEL.** A manufacturer replaces a hazardous chemical with a safer alternative.
- **PRODUCT LEVEL.** A product designer eliminates the need for a material containing a hazardous ingredient by redesigning the product or designing new products with inherently safer attributes.
- **SELECTION LEVEL.** A specifier chooses products with inherently safer life cycle attributes, or a designer finds a different way to provide the function of a particular chemical, material, or product (e.g., designing open plenum spaces with more sprinkler systems may reduce the need for flame-retardant chemicals in building materials).

LIONS VERSUS LAMBS

The precautionary principle and prevention prioritize hazard reduction over mitigating risk through exposure control. This approach reduces the need to consider the implications of potential failures in exposure controls or safety systems. Trevor Kletz, an industrial engineer who created the field of inherent safety (i.e., the design of chemical processes that eliminate catastrophic accident hazards), used an analogy to describe this wisdom.

If the meat of lions were good to eat or their skins made very good clothes, our farmers would be asked to farm lions, and they could do so. They would need cages in the field instead of fences, but by good design and operations they could make the chance of an escape very small. ... But why keep lions when lambs will do instead?

—Trevor Kletz, *Process Plants: A Handbook for Inherently Safer Design*, 12–13

SCIENCE UNDERPINNING BETTER MATERIALS DECISIONS

As explained in Section 3.5, hazard is an intrinsic property of a substance that refers to its potential to harm humans and the environment. Scientists and policy makers like to be fairly certain before making a determination that a substance is dangerous. For example, epidemiological findings are rarely accepted unless there is at least a 95% certainty that the results were not by chance alone. Exposure refers to how and how much the environment or a person is subjected to a substance, including the duration, frequency, and magnitude. Risk is then a measure of the probability and magnitude of an impact's occurrence, given the substance's intrinsic hazards and predicted exposures.

Risk assessment has become a central element of U.S. government human health and environmental decision making (e.g., to determine whether a substance poses enough of a threat to warrant action) and is used by many companies to determine whether a particular material is safe to use. Assessment often starts from an assumption that the substance in question may be toxic but that exposure might be deemed "safe" under certain circumstances.

"Safe," also known as acceptable risk, is not a scientific determination but rather a policy one. For example, EPA defines safe as an excess risk of 1 in 100,000 or 1 in 1,000,000 illnesses or deaths over a lifetime exposure to a substance, whereas OSHA defines safe as a 1 in 1,000 excess risk of illness. Risk assessments on the same substance conducted by different analysts can have very different results, and years may be spent conducting a single risk assessment as scientists attempt to fill in knowledge gaps and come to consensus on how a particular chemical causes harm or how much exposure to that chemical an individual might experience over a lifetime. Precautionary, preventive approaches, on the other hand,

- are proactive rather than reactive, enabling action to be taken sooner based on accumulating knowledge;
- do not depend on the proper functioning of exposure controls but may incorporate them;
- do not depend on the accuracy of a risk assessment; and
- focus attention on innovative solutions, like substitution and redesign.

There is no risk-free material from a life cycle perspective: there will always be a need to consider exposure and evaluate risk. But the starting point should be to identify materials that are inherently less hazardous, reducing risk throughout the life cycle.

ASSESSING THE RISK OF TRICHLOROETHYLENE

The case of trichloroethylene (TCE) demonstrates the limitations of risk-based approaches for certain chemicals and uses. TCE is a widely used solvent in degreasing operations, adhesives, textiles, and paints, among other applications. It works exceptionally well but is a probable human carcinogen and reproductive and neuro toxicant, and it is one of the most common chemicals found in hazardous waste cleanup sites. EPA spent more than 20 years (and millions of dollars) conducting a detailed risk assessment for TCE, which was finally published in 2014.

Much of the debate in assessing TCE's risk focused not on its toxicity, which has been well known for almost half a century, but rather on determining the exact biological mechanism by which it causes cancer in humans. Even though significant epidemiologic and toxicological data had demonstrated TCE's hazards, EPA's "Is it safe?" approach required detailed evidence of why it wasn't safe, including a quantitative estimate of risk.

In contrast, the Massachusetts Toxics Use Reduction Act requires manufacturing firms to take a more precautionary approach to hazardous chemicals, asking, "Is it necessary? Are there safer alternatives?" These questions have forced companies to consider whether TCE was actually needed in their processes, whether other chemicals or processes could fulfill TCE's function, or whether the function could be eliminated altogether. With support from the Massachusetts Toxics Use Reduction Institute to test alternative methods, Massachusetts manufacturers were able to reduce TCE use by 95% and save money by reducing the costs of permitting, disposal, and handling, without ever doing a quantitative risk assessment.

A more detailed understanding of materials hazards and exposures is important and can help identify and prevent problems in the future. But delaying preventive action while awaiting a more detailed understanding of a chemical's risks can have significant costs for society, both economically and in terms of human health and the environment. As the European Union's [*Late Lessons from Early Warnings*](#) report showed, early concerns about potential harm are more often than not correct, and we often learn, as with lead and mercury, that substances may be much more dangerous than originally predicted. The best available science must therefore be combined with innovation, and we should err on the side of caution.

SUMMARY

- Materials selection and optimization seek to integrate human health and environmental considerations into decision making; to design and specify materials that have minimal negative human health and environmental impacts throughout their entire life cycles; to improve products to be intrinsically preferable rather than incrementally less hazardous; and to promote the specification of these preferable materials and products.

- The path to better materials and products starts by minimizing or eliminating life cycle hazards early in the material or product design phase. Three principles that guide materials optimization toward preferable materials and products are right to know, precaution, and prevention.
- Right to know is the legal principle that individuals should have access to information about potential chemical hazards, uses, and environmental releases in their communities and the workplace.
- Precautionary approaches encourage action to avoid potential harm even if the nature and magnitude of the risk are not fully understood.
- Preventive approaches work hand-in-hand with precautionary approaches by prioritizing harm avoidance over mitigation. Although exposure controls can reduce harm, substitution is the only way to completely eliminate a hazard and is the preferred approach.
- A more detailed understanding of materials hazards and exposures is important and can help identify and prevent problems in the future. But delaying preventive action in the meantime can have significant costs for society, both economically and in terms of human health and the environment.

TIPS FOR PRACTICE

DEFINE GOALS FIRST. Start with the assumption that negative human health and environmental impacts are design flaws that can be avoided and set goals for materials optimization and specification accordingly.

USE PRECAUTION. Recognize that materials have the potential to harm people and the environment. If the hazards are uncertain, proceed with caution. This means asking questions and, when possible, selecting safer alternatives.

PRIORITIZE INHERENTLY PREFERABLE MATERIALS. Seek opportunities to make changes at the process, product, and selection levels that ensure materials are inherently preferable, eliminating the need for substances of concern.

4.2 Strategies for materials optimization and innovation

- What are some of the more common practical approaches to improving the health and environmental attributes of materials?
- How can a comprehensive framework like alternatives assessment guide optimization?
- What are the different strategies for approaching innovation? What are their relative strengths and limitations?
- What tools can accelerate materials optimization and innovation?

Several scientific and technological strategies support improving the health and environmental attributes of materials. In general these strategies take one of two forms: design after natural systems and design that considers the life cycle impacts of materials. The principles and concepts outlined in Section 4.1 can guide manufacturers and project teams in identifying opportunities and solutions that significantly reduce the health and environmental impacts of materials throughout their life cycles. Although the concepts and strategies outlined below relate primarily to product designers and manufacturers, familiarity with these concepts can help building professionals more effectively interact with manufacturers by better understanding common constraints and opportunities.

PRACTICAL APPROACHES TO IMPROVING MATERIALS

Some of the concepts that support materials optimization and innovation are outlined in this section. Despite their differences, they all focus on modifying processes and product design to reduce impacts. Some of these concepts apply to improving existing designs, while others integrate sustainability considerations into new materials and products. All rely on continuous improvement in impact reduction. The concept of cleaner production, an implementation of the principle of prevention, underlies all of these strategies.

Cleaner production typically involves the continuous application of an integrated process to identify opportunities to prevent impacts to humans and the environment at all stages of a product's life cycle (Figure 4-1). Cleaner production relies on the continuous optimization of materials and processes and is aided by access to information and feedback from materials users. Cleaner production design strategies fall into two main categories:

- **DETOXIFICATION** aims to reduce the use of toxic substances throughout a product's life cycle, through development and use of safer chemical and design substitutes.
- **DEMATERIALIZATION** aims to reduce the amount of materials used or discarded in a product or process—that is, to reduce the materials “intensity.” Strategies for dematerialization include closing the loop on materials flows by recycling or reusing waste, using less material, increasing product life, substituting services for materials, selecting materials that can be recycled or composted, and designing for repair, reuse, upgrade, and adaptation.

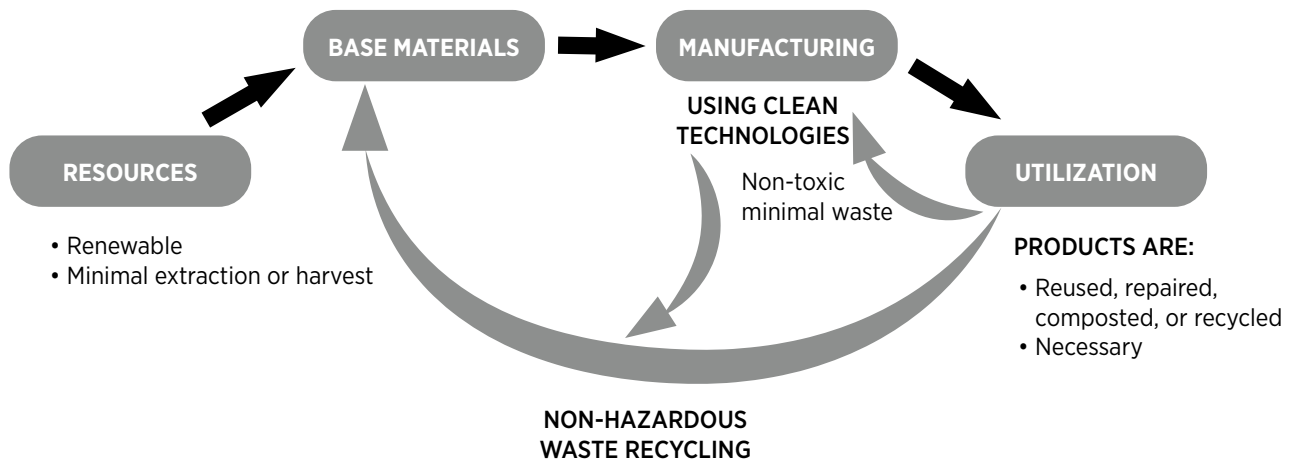


Figure 4-1. Cleaner production process

The following sections highlight selected approaches to achieving cleaner production.

EXTENDED PRODUCER RESPONSIBILITY

Extended producer responsibility requires product manufacturers or specifiers to assume responsibility for the impacts of their products throughout their full life cycles, including reclaiming and reusing them at the end of their operational life. This strategy provides an incentive to make and use products that are longer lasting, upgradable, reusable, and recyclable, and to minimize the use of toxic materials (since those who made the product will be responsible for managing these wastes at the end of its life cycle).¹

Common examples of extended producer responsibility include computer take-back requirements (e.g., that manufacturers take back end-of-life electronics for safe recycling) and packaging return policies. Such programs are relatively rare for building products.

BIOMIMICRY

Biomimicry uses inspiration from natural systems to inform the design of materials and products. Biomimetic approaches attempt to emulate nature's efficient solutions and apply them to many technological challenges, such as harnessing energy, making strong and lightweight materials, and creating better adhesives.

Advocates for biomimetic approaches note that natural processes often involve very long periods of intense competitive selection that results in exceptionally efficient and often elegant functional solutions. For example, consider the amazing process used by many organisms to create hard

¹ Find more information about extended producer responsibility [here](#).

shells from seawater at ambient temperature and pressure without hazardous chemical ingredients or byproducts. This is in stark contrast to prevailing industrial approaches that rely on large energy inputs and/or potentially toxic materials to make durable composite materials. Innovative organizations have identified many opportunities to apply these concepts to product design. For example, Columbia Forest Products' Purebond® manufactured wood products use an adhesive based on the adhesion properties of mussels. These concepts are reflected in the [Biomimicry protocol](#) and in a set of [online case examples](#).

GREEN CHEMISTRY

Green chemistry is an approach to chemical and process design that reduces or eliminates the need for and generation of hazardous substances through the application of 12 design principles. The philosophy behind green chemistry is that if chemicals and chemical processes are designed in an inherently safer and benign manner, there will be less need for controls to mitigate exposure, ultimately reducing risk over the life cycle of a given material. Employing green chemistry requires educating chemists and incorporating safer chemicals and processes into the earliest stages of product design to minimize the potential impacts of chemicals while optimizing the chemical structure to give the desired properties.

TWELVE PRINCIPLES OF GREEN CHEMISTRY

1. **Prevent waste.** Design chemical syntheses to prevent waste rather than treat it or clean it up afterward.
2. **Maximize atom economy.** Design synthetic methods to maximize the incorporation of all materials used in the process into the final product.
3. **Design less hazardous chemical syntheses.** Design syntheses to use and generate substances that minimize toxicity to humans and the environment.
4. **Design safer chemicals and products.** Design chemical products to achieve their desired function while minimizing their toxicity.
5. **Use safer solvents and auxiliaries.** Avoid using solvents, separation agents, or other auxiliary chemicals. If these substances are necessary, use benign chemicals.
6. **Increase energy efficiency.** Minimize energy requirements by conducting chemical reactions at ambient temperature and pressure whenever possible.
7. **Use renewable feedstocks.** Use raw materials and feedstocks that are renewable (e.g., made from agricultural products or wastes from other processes) rather than depleting (e.g., made from fossil fuels or mined).
8. **Avoid chemical derivatives.** Minimize or avoid unnecessary derivatization, which requires additional reagents and generates waste.
9. **Use catalysts, not stoichiometric reagents.** Minimize waste by using catalytic reactions. Because they are used in small amounts and can carry out a single reaction many times, catalysts are preferable to stoichiometric reagents, which are used in excess and work only once.
10. **Design chemicals and products to degrade after use.** Design chemical products to break down to innocuous substances that do not persist in the environment.
11. **Analyze in real time to prevent pollution.** Include in-process, real-time monitoring and control during syntheses to minimize or eliminate the formation of byproducts.
12. **Minimize the potential for accidents.** Choose substances and the form of a substance used in a chemical process to minimize the potential for chemical accidents, including releases, explosions, and fires.

Adapted from P.T. Anastas and J.C. Warner, *Green chemistry theory and practice* (Oxford: Oxford University Press, 1998).

SUSTAINABLE PRODUCT DESIGN

Two precursor concepts, ecodesign and green product design, were introduced in the 1990s as strategies to reduce the environmental impacts associated with production processes and products. The United Nations Environment Programme (UNEP) published its first ecodesign manual in 1997 as part of an effort to stimulate environmental stewardship and developing countries' economic growth through sustainable use of locally sourced materials.² In the past decade, these two concepts have evolved into a more encompassing idea.

Sustainable product design, or design for sustainability, considers not only life cycle health and environmental impacts but also social and economic benefits to communities, workers, and others. Several frameworks have been developed to help firms measure the sustainability implications of design choices, including the [UNEP/Technical University of Delft Design for Sustainability model](#) and the [Lowell Center for Sustainable Production Framework for Sustainable Products](#) (Figure 4-2).



Figure 4-2. Framework for sustainable products
Courtesy: Lowell Center for Sustainable Production

PREVENTION THROUGH DESIGN

The National Institute for Occupational Safety and Health currently leads a nationwide initiative called [Prevention through Design](#), which addresses occupational safety and health by seeking to eliminate hazards and minimize risks to workers throughout a product's life cycle. The initiative

² Find more information [here](#).

addresses work premises, tools, equipment, machinery, substances, and work processes, including products' construction, manufacture, use, maintenance, and ultimate disposal or reuse. Prevention through Design is based on the idea that the best way to prevent occupational injuries, illnesses, and fatalities is to eliminate hazards and minimize risks early in the design or redesign process and incorporate methods of safe design into all phases of hazard mitigation.

ALTERNATIVES ASSESSMENT

Mary O'Brien, a biologist and environmental writer, notes that "One of the most essential and powerful steps to change is understanding that there are alternatives." She uses the analogy of a woman standing by the edge of a river considering whether to wade across. Scientists give her their expert opinions that it is safe—the water is neither too cold nor too deep, nor has a flow that will topple her (although she will get wet). When she doesn't enter the river, they ask, "Why?" She responds, "Because there is a bridge over there."³

Changing the questions we ask about chemical and materials problems is consistent with a focus on precaution and prevention and can ultimately converge interests around innovation in safer chemicals, materials, and even whole buildings, rather than deeper, and often contentious, evaluations of problems. For example, instead of asking, "Is it safe to use this chemical?" it may be more prudent to ask, "Is there a better chemical I can use?" or "Can I change my process to eliminate the need for a particular chemical of concern?"

Alternatives assessment is an action-oriented process for identifying and comparing potential alternatives to replace chemicals or technologies of concern on the basis of their hazards, performance, and economic viability and can help answer these questions in chemicals and materials design and evaluation.

GOALS OF ALTERNATIVES ASSESSMENT

The primary objective of alternatives assessment is to reduce risk to humans and the environment by selecting safer alternatives in a thoughtful manner thus avoiding potential unintended consequences of uninformed materials substitutions. The assessment has the following specific goals:

- **TO STIMULATE PREVENTIVE ACTION.** Alternatives assessment is action oriented. The intent is to prioritize substitution of substances of concern with safer alternatives over mitigating the potential harm from using these substances. The orientation toward considered action is critical to ensure a balance that encourages analyses sufficient to make decisions while avoiding lengthy studies and "paralysis by analysis."
- **TO ENSURE THOUGHTFUL CONSIDERATION OF THE PROS AND CONS OF ALTERNATIVES.** Reducing or eliminating the use of a substance—even a relatively dangerous one—can result in unintended adverse consequences or trade-offs, particularly

³ M. O'Brien, *Making better environmental decisions: An alternative to risk assessment* (Cambridge, Massachusetts: MIT Press, 2000).

when a change is made with inadequate information or evaluation of possible substitutes and their implications. The alternatives assessment framework guides the informed transition to safer processes and products.

- **TO BROADEN THINKING ABOUT CHEMICAL AND MATERIAL HAZARDS BASED ON FUNCTION.** By focusing on the function or “service” of a particular chemical, an alternatives assessment can move beyond looking for substitute chemicals to considering a broader range of solutions, such as elimination of unnecessary functions (e.g., antimicrobials in hand soap), process or product redesign (e.g., replacing phthalate plasticizers in a shower curtain with another polymer or glass), or an alternative means of meeting the function (e.g., electronic receipts rather than a substitute for bisphenol A in cash register receipts).

Achieving these goals requires a commitment to reducing hazards, minimizing exposures, and using the best available information to assist in distinguishing among possible choices and avoiding alternatives that may have unintended adverse consequences. Requiring disclosure of ingredients and technical information across the supply chain helps ensure a thorough assessment. In some instances, the existing suite of alternatives may present only a marginal improvement in impact reduction over existing options. In these cases, alternative designs, incorporating concepts of cleaner production may be necessary.

THE ALTERNATIVES ASSESSMENT PROCESS

Principles and frameworks have been developed over the past decade to guide the process of alternatives assessment. For example, in 2014 a group of academic experts, advocates, government representatives, and business professionals developed the [Commons Principles for Alternatives Assessment](#). Most such frameworks have three parts:

- **I. SCOPE.** Goals and guidelines for the assessment are formed.
- **II. ASSESSMENT.** Possible alternatives are identified and their pros and cons are compared.
- **III. SELECTION AND IMPLEMENTATION.** The preferred alternative is selected and adopted, and continuous monitoring is undertaken to minimize unintended consequences and support continued improvement in impact reduction.

STEPS IN AN ALTERNATIVES ASSESSMENT

PART I. SCOPE

- **Step 1. Define goal and scope.** Outline the goals and guidelines for the assessment. Consider questions such as which impacts are important, whether the entire life cycle of the chemical or product will be considered, and what methods will be used.

PART II. ASSESSMENT

- **Step 2. Characterize chemical of concern.** Investigate the function, performance requirements, hazards, and life cycle impacts of the chemical of concern. Identify characteristics that may make alternatives problematic.
- **Step 3. Identify and prioritize alternatives.** Identify chemical and design alternatives, including those on the horizon. Perform a prescreen to eliminate those that are problematic from a toxicity or performance point of view.
- **Step 4. Assess comparative hazards.** Perform a comparative hazard assessment using a tool such as GreenScreen or BizNGO's [Chemical Alternatives Assessment Protocol](#). Consider how changes in chemicals or materials may lead to exposure trade-offs.
- **Step 5. Compare performance and consider impacts.** Consider life cycle impacts, like environment, energy, and resource consumption impacts, from raw materials extraction through end of life. For alternatives that are less hazardous, consider other attributes, like performance and cost.

PART III. SELECTION AND IMPLEMENTATION

- **Step 6. Select preferred alternative.** Based on all steps above, determine the best alternative.
- **Step 7. Implement adoption of safer alternative.** Occasionally the best alternative may be a “drop in” substitute. For others, plan a process for changes, invest in any necessary further research and testing, and collaborate with suppliers and customers to make the

INTEGRATING OPTIMIZATION INTO THE MATERIALS INNOVATION PROCESS

In addition to understanding the concepts and processes underlying sustainable materials design, evaluation, and selection, building professionals can also benefit from an appreciation for the materials innovation process. It is important to understand the general steps and, critically, to have a general sense of the pace of innovation. This can help create reasonable expectations about timelines and potential for change. Architects and specifiers are critical partners in this process as they often identify the desired attributes (e.g., impact reduction goals, cost, performance) of the building and its interior components, which then guide optimization and innovation.

When an opportunity for a safer material or product has been identified, researchers and product designers have options for the type of innovation strategy they would like to pursue. Some of these strategies may fall within the alternatives assessment framework, but some may require a more complete re-envisioning of the product beyond replacing an ingredient with a safer alternative. Manufacturers have different scientific, technological, economic, and market considerations for determining which strategy to pursue. The costs, timeframes, and business risks vary considerably.

REFORMULATION

Reformulation replaces an undesirable ingredient with a more desirable alternative. This often happens after a particular ingredient has been identified as a substance of concern. The advantage of reformulation is that it can pose less business risk, since the product and consumers' expectations are well defined and the reformulation should cause minimal disruption to current processes and change to the final product. Assuming a suitable substitute ingredient can be found (which may itself be a costly and somewhat lengthy process), the reformulated product can often make it to market very quickly. For example, the availability of chemical substitutes helped accelerate the adoption of aggressive policies to reduce the emission of substances linked to stratospheric ozone depletion and thinning of Earth's protective ozone layer.⁴

However, reformulation also has the greatest risk for regrettable substitution, in which a "drop-in" alternative may later prove, after more study, to be no better than the ingredient it replaced. (See Section 3.3 for an example regarding the replacement of bisphenol A with bisphenol S.) In addition, in some cases there may not be a known substitute for a particular ingredient that still meets the desired performance and cost criteria. In this case, the manufacturer may be forced to make a trade-off between performance and the undesirable qualities of the ingredient of concern.

Reformulation can be a relatively inexpensive and simple process or it can be very complex if alternatives do not have equal functionality, need approval, or necessitate manufacturing changes.

⁴ United Nations Environment Programme, Montreal Protocol on substances that deplete the ozone layer: 2002 report of the Solvents, Coatings and Adhesives Technical Options Committee, <http://ozone.unep.org/pdf/stoc-2002-assessment.pdf>.

FABRICATION FROM FUNGI

Ecovative Design, a biomaterials company founded in 2007, has developed a compostable material made from agricultural waste and mushroom mycelium (branched, tubular filaments of fungus). The material is created when mycelium—a natural glue—digests the crop waste. Heat treatment then renders the fungus inert. As the material grows, it can be molded into a variety of shapes useful for packaging, insulation, and other applications, offering an ecofriendly alternative to Styrofoam packaging or petroleum-based insulation. The material—called Mushroom Materials—has received a Cradle to Cradle Gold certification.

REDESIGN

Redesign relies on existing materials and formulations to create a new product design that eliminates the use of undesirable ingredients or processes. This strategy requires thinking broadly about the potential ways to accomplish a desired function, even if they are a radical departure from the way things have been done in the past. For example, instead of searching for a chemical alternative, a manufacturer could redesign a chair with cushions containing flame-retardant chemicals to have a mesh seat instead.

This type of strategy is best led by experienced designers in consultation with materials experts who can help them select the best available materials and think creatively about strategies to deliver essential functions. Since this approach results in a completely new product, the development time and time-to-market vary widely, depending on the regulatory and market standards that the new product will need to meet. It is also relatively risky because the eventual markets and consumers are not easily characterized.

NEW MATERIALS DISCOVERY

Basic science can create materials and products that may have significantly improved performance and unique properties and functionality, and it may open up completely new design paradigms. This strategy for innovation is the most disruptive and has the highest potential risk (and reward). New materials are often developed in academic or industry laboratories, and it can take anywhere from several years to a decade or more to bring them to market, and even longer to reach scale, depending on market and regulatory factors. Because of the investment in time and resources, it is particularly important for researchers and manufacturers to consider health and environmental impacts early in the design process and anticipate what attributes future consumers will value.

TOOLS TO ACCELERATE OPTIMIZATION AND INNOVATION

A variety of scientific and market tools can help speed optimization and innovation, condensing otherwise lengthy timelines to bring new and improved products to market. Four examples follow:

- **MARKET TOOLS.** Market-driven optimization and innovation can be an effective alternative to policy changes, as discussed in more depth in Chapter 3. These tools include preferred purchasing policies, product certifications, and comprehensive rating systems like LEED. Market-driven solutions avoid government involvement and the bureaucracy that it can entail, but because they are not legally required, the amount of time they take to create change can vary, and there is no guarantee that the entire market will respond.
- **PREDICTIVE SCIENCE.** Computer models and other high throughput assessments simulate experiments that would take much more time and cost to carry out in the laboratory. These models, when combined with more traditional tools, can assist in determining the toxicity of chemicals or help forecast what chemical or material formulation might best yield the desired properties.
- **POLICY TOOLS.** Changes in policy can be an important tool to drive innovation. Government or market restrictions on certain practices or substances can force a manufacturer to prioritize changing a particular product or process to stay in compliance. Further, governments can encourage design and adoption of preferable materials through research and development funding, favorable tax treatment, low-cost loans, and technical assistance.
- **COLLABORATIONS ACROSS THE SUPPLY CHAIN.** Regardless of the strategy or framework a manufacturer might use to approach optimization and innovation, the involvement of the entire supply chain—including raw materials suppliers, manufacturers, specifiers, contractors, and procurement officers—will help increase the likelihood of innovation. Those who purchase, install, and use products can work with manufacturers to communicate their needs and priorities. Manufacturers working in conjunction with their suppliers can ensure that a product meets human health and environmental as well as performance goals.

The concepts outlined in this chapter are designed to help project teams better connect with the tools and approaches used by chemists, product designers, and manufacturers to optimize their materials and products. By understanding these concepts as well as the process of product design and innovation, building professionals can more effectively direct their choices to guide the transition toward more preferable materials.

SUMMARY

- Cleaner production is a process and product design concept that involves the continuous application of an integrated process to identify opportunities to prevent impacts to humans and the environment at all stages of a product's life cycle. Approaches to achieving cleaner production include extended producer responsibility, biomimicry, green chemistry, sustainable product design, and prevention through design.
- Alternatives assessment is an action-oriented process for identifying and comparing potential alternatives to replace chemicals or technologies of concern on the basis of their hazards, performance, and economic viability. Most alternatives assessment frameworks have three parts: scope, in which goals and guidelines are formulated; assessment, in which possible alternatives are identified and their pros and cons are compared; and selection and implementation, in which the preferred alternative is selected and adopted.
- Strategies for approaching innovation include reformulation, redesign, and new materials discovery. Some of these strategies may fall within the alternatives assessment framework, but some may require a more complete reenvisioning of the product beyond replacing an ingredient with a safer alternative. The costs, timeframes, and business risks vary considerably.
- Tools to accelerate materials optimization and innovation include market tools, predictive science, policy tools, and collaborations across the supply chain.

4.3 The current state and future outlook for materials and products

- What is the current state of the movement toward preferable materials and products?
 - How are other sectors working to improve materials and products?
 - What is the future outlook?
-

CURRENT STATE

Although the movement toward more sustainable building products is far from complete, the building industry and allied industries have made progress. The past two decades have seen a significant increase in scientific, government, industrial, and consumer concern about the human health and environmental impacts of materials and products across multiple industries. In particular, the past 10 years have brought rapid growth in the science linking materials and products to health outcomes, public and market-driven policies addressing impacts of substances of concern, greater supply chain collaboration on sustainable materials, and initiatives to develop frameworks for finding safer substitutes. Concerns about ecosystem impacts of materials have led manufacturers to develop products that avoid or reduce impacts by reducing energy and water requirements, reducing waste, using feedstocks with recycled content, finding beneficial uses for process wastes, and other actions. In areas where a lack of a comprehensive and coordinated legal framework has limited regulatory progress, preferential selection and evaluation systems and standards led by industry and nonprofits have stepped in to drive change.¹

Following is a summary of highlights discussed throughout this guide.

SCIENTIFIC ADVANCES

Thirty years ago, scientific concerns about materials and products focused on large workplace and environmental exposures to a small number of chemicals from manufacturing sources. Most attention was paid to acute effects and cancer. Through enhanced analytical approaches to monitoring chemicals in the environment and in our bodies, scientists are discovering that humans are exposed to low doses of a wide range of substances from a variety of products, such as pesticides, pharmaceuticals, cosmetics, furniture foams, soft plastics, detergents, clothing, and building products. Continuous exposures from multiple sources may result in aggregate and cumulative impacts, making it difficult to trace exposures back to a particular substance.²

1 J. Tickner, From reactive chemicals control to comprehensive chemicals policy: An evolution and opportunity, in E. Bingham and B. Cohrssen (eds.), *Patty's toxicology* (Hoboken: John Wiley & Sons, 2012), vol. 7, 29–47.

2 J. Tickner, Risk assessment is not enough to protect public health: Rationale for the precautionary principle, in W. Toscano and M. Robson (eds.), *Risk assessment in public health* (San Francisco: Jossey Bass, 2006), 423–62.

This emerging science has led major scientific organizations to recommend a focus on sustainable materials as a pathway to prevention. For example, in 2010 the U.S. President's Cancer Panel reported that "the true burden of environmentally induced cancer has been grossly underestimated ... the prevailing regulatory approach in the United States is reactionary rather than precautionary ... the burgeoning number and complexity of known or suspected environmental carcinogens compel us to act to protect health, even though we may lack irrefutable proof of harm."³

New tools are allowing scientists to better understand chemical toxicity and potential exposures. [Toxicology in the 21st Century](#), a collaboration involving the National Institutes of Health, the Food and Drug Administration, and EPA, is developing rapid, relatively inexpensive methods to assess chemicals and give scientists a more holistic picture of all the available evidence needed to weigh potential adverse health effects. Tools for chemical prioritization and hazard assessment will allow researchers to more rapidly categorize chemicals as higher or lower concern to facilitate decision making. Furthermore, tools for evaluating the life cycle impacts of materials, such as life cycle assessment, are evolving rapidly and will increasingly integrate health knowledge.

Scientific advances have also enabled manufacturers to identify priorities for improving their products. Products on the fringe two decades ago, such as low-emitting sealants, adhesives, paints, and coatings, are now mainstream. As companies increasingly compete based on the green attributes of their products, scientific information that can lead to innovation becomes even more valuable.

POLICY ADVANCES

The U.S. federal government has been slow to reform decades-old policies, such as the Toxic Substances Control Act, but the European Union and some U.S. states have been innovators in designing policies to identify and restrict the use of chemicals of concern and support the application of safer alternatives. The passage of the European Union's REACH legislation in 2006 represented a wholesale revamping of chemicals management policy to increase supply chain information on chemical use and toxicity as well as encourage substitution for those chemicals of highest concern.

Policy changes in Europe and internationally (such as REACH, European product directives, and the Stockholm Convention on Persistent Organic Pollutants) have given momentum to developments below the federal level in the United States. Since 2005, hundreds of bills related to chemicals and materials have been introduced at the state and local levels. Single-chemical restrictions on substances like bisphenol A, mercury, brominated flame retardants, triclosan, and phthalate plasticizers have expanded to include the following:

- requirements to evaluate alternatives to specific problem chemicals;
- chemical prioritization processes and mandatory reporting;

³ *Environmental cancer risk: What we can do now*, 2008–2009 Annual Report, National Cancer Institute, President's Cancer Panel (Washington, D.C.: U.S. Department of Health and Human Services, April 2010), http://deainfo.nci.nih.gov/advisory/pcp/annualReports/pcp08-09rpt/PCP_Report_08-09_508.pdf.

- requirements for institutional purchasing of lower-hazard cleaning chemicals and other products; and
- California's Safer Consumer Products regulations requiring firms to evaluate alternatives to chemicals used in products of concern.

State policies will continue to drive change as they increasingly address supply chain management of chemicals and materials of concern.

CONSUMER DEMAND

Consumers are asking more questions about the products they purchase. Increased media attention to bisphenol A, phthalates, mercury, triclosan, and brominated flame retardants has led to stronger public pressure for restricting these and other substances. Sophisticated advocacy efforts—for instance, broad coalitions at the state level—have brought together groups as diverse as medical professionals, mothers' organizations, health-affected communities (e.g., cancer groups), workers, and traditional environmental groups to advocate for change. They have developed tools to inform the public about chemical hazards and safer alternatives with resources such as healthystuff.org, Environmental Working Group's [Skin Deep database](#), and UL's [GoodGuide](#).

Consumers have also become more informed about the ecosystem effects of their decisions. For example, they routinely engage in recycling in homes and offices and many have become aware of issues like the impacts of fuels on climate change and of plastic wastes on ocean ecosystems.

LARGE-SCALE PURCHASER DEMANDS

Architects, specifiers, and building owners already recognize the power of government purchasing rules in advancing energy efficiency in buildings. The power of purchasing to advance safer and environmentally preferable materials is no different. An executive order issued in 2009 calls for the U.S. federal government to purchase safer or nontoxic chemical products that meet agency performance requirements. Large agencies, such as the Department of Defense, General Services Administration, and National Institutes of Health, have instituted sustainable materials programs designed to increase information on purchased products and ensure the safest alternatives that meet specific performance needs. The federal government has had guidelines on environmentally preferable purchasing for more than a decade. Similarly, other large institutional purchasers, such as hospital organizations and major retailers, have instituted programs to increase information on chemicals in products and use substitutes for chemicals of highest concern. The [Sustainable Purchasing Leadership Council](#), a nonprofit organization that supports and recognizes purchasing leadership, has released guidance for sustainable purchasing.

SUPPLY CHAIN AND MARKETPLACE PRESSURE

Initially, supply chain improvement efforts were limited to companies viewed as leaders in social responsibility. However, increasing advocate pressure and, in some cases, legal demands (or specification requirements) have prompted whole sectors to be more transparent about their

products. Several private efforts have emerged to help connect businesses, nonprofits, and others to advance supply chain dialogue about preferable products. For example, the [Green Chemistry and Commerce Council](#) engages more than 70 firms across sectors in identifying opportunities to advance the design and adoption of safer chemicals. The [BizNGO](#) working group brings together companies and nonprofits to encourage government and industrial adoption of safer materials policies. The [American Sustainable Business Council](#) brings together small and medium-sized businesses and advocates to help incentivize economic development based on sustainable products.

INITIATIVES IN OTHER SECTORS

The building industry is not alone in driving improved human health and environmental outcomes of materials and products. Most sectors have established restricted substances lists, and some have established approaches and tools to collect chemical information, evaluate substitutes, and measure progress toward more preferable chemicals and materials. Many sectors have also developed sustainability programs to reduce climate impact, address social concerns associated with product life cycles, and reduce resource use.

The following sections highlight efforts in other sectors. These efforts are directly related to the building sector in that some are in peripheral sectors (e.g., they manufacture products used in buildings) or address similar life cycle concerns as the building sector.

HEALTH CARE

Major hospital chains, such as Kaiser Permanente and Dignity Health, are leading the trend toward requiring greater information on chemical ingredients and environmental impacts of products. Such requirements apply to consumer products purchased for use in their facilities and to the design and construction of their facilities. A broad international coalition of advocates, health professionals, and hospitals called [Health Care Without Harm](#) has spurred efforts in the sector to find products with lower environmental life cycle impacts and safer alternatives to ingredients of concern, such as latex, mercury, orthophthalates, and brominated flame retardants. Stakeholders in this sector also formed the nonprofit [Practice Green Health](#) to develop guidelines and support sustainable purchasing in health care. The [Green Guide for Health Care](#), the result of a collaboration among health care providers and green building experts, provides guidelines that help optimize sustainable materials in buildings in this sector.

CONSUMER PRODUCTS

Formulated consumer products are a public concern because of their potential for direct human exposure. Government purchasing organizations have focused attention on purchasing products with ecolabels, leading to initiatives in this sector. Pioneering companies—SC Johnson, for example, has an [ingredients disclosure initiative](#) and a Greenlist chemical ingredient scoring system, and Seventh Generation has a sustainable design approach—set the stage for a variety of corporate and sector efforts. The [Consumer Specialty Products Association](#) has developed guidelines for ingredients disclosure that have been adopted by many firms. Boots, in the United Kingdom,

became an early leader in identifying safer chemistries for its personal care products. More recently, Johnson & Johnson and Procter & Gamble have announced efforts to use substitutes for certain chemicals of concern in their products. The [Campaign for Safe Cosmetics](#) has obtained commitments from many personal care product companies to eliminate carcinogens, mutagens, and reproductive toxicants in the products they sell, to comply with an EU directive restricting such chemicals.

BETTER DECISIONS THROUGH THE SIX CLASSES APPROACH

The Green Science Policy Institute has developed an approach to alternatives assessment and purchasing decisions referred to as the Six Classes. Rather than depend on lengthy lists of hazardous substances, which may be incomplete and lead to regrettable substitutions, the Six Classes approach has identified six families or “classes” of chemicals that contain many of the harmful substances found in everyday products and should be avoided. Their [webinar series](#) informs manufacturers, retailers, and consumers about where these chemicals can be found, how they can be avoided, and what alternatives might be available.

ELECTRONICS

Corporate and sector-wide efforts to better track chemical ingredients in components and products have been prompted by European restrictions on hazardous ingredients and increased attention on electronic waste disassembly and disposal, particularly in developing countries. Companies like [HP](#) and [Apple](#) have developed sustainable materials programs to identify safer alternatives to ingredients of concern. The industry association [IPC](#) has standardized materials ingredient information requests in the sector by developing the IPC 1751 materials declaration and data exchange standards. The [Electronic Product Environmental Assessment Tool](#) (EPEAT) is a sustainability assessment framework for electronic products that is required under many government institutional purchasing policies. The [Electronics Industry Citizenship Coalition](#) provides tools for use in assessing social, environmental, and ethical risks in supply chains.

RETAIL

In 2013, both Walmart and Target announced efforts to increase information on chemicals in the products they sell and require safer alternatives to chemicals of concern in health and beauty, consumer, and baby products. In 2014, the two retail giants organized a [health and beauty products summit](#), at which they jointly outlined their goal of more sustainable health and beauty products to suppliers. Home Depot created the [Eco Options Program](#) to provide consumers with more environmentally friendly building materials choices. Some European-based retailers, such as Marks and Spencer, Ikea, B&Q, H&M and COOP, have long had chemicals management strategies. Many retailers have begun their chemicals management efforts by focusing on their own brands, where they have greater control over production specifications. The Green Chemistry and Commerce Council established a [retailer portal](#) that provides information on many of the efforts being undertaken by retailers.

FOOTWEAR AND APPAREL

Because of concerns about life cycle, environmental, and health impacts, the footwear and apparel sector has been engaged in increasing materials information and identifying chemicals of concern for substitution. This sector's complex global supply chain creates significant challenges in obtaining chemical information. Through the Greenpeace-spurred [Zero Discharge of Hazardous Chemicals](#) initiative, several leading footwear and apparel brands are committed to eliminating a range of toxic chemicals from their supply chains by 2020. The Sustainable Apparel Coalition, set up by Patagonia and Walmart, has developed the [Higg Index](#), which provides a framework to measure the impacts of material choices. Several sustainable manufacturing certification systems also exist in this sector, and the sector has developed a materials disclosure tool, the [Voluntary Product Environmental Profile](#), to enhance chemical information through supply chains.

OUTDOOR PRODUCTS

The sustainable orientation of the outdoor products industry has been led by companies such as Patagonia and REI. The [Outdoor Industry Association](#) (OIA) has developed a series of tools to help support increased chemical information and safer materials. The OIA Eco-Index provides a tool for manufacturers to measure the sustainability impacts of their products, and the OIA Chemical Management Framework provides an approach to benchmark company efforts to adopt safer chemicals and materials.

AUTOMOTIVE

European Union regulations on end-of-life recyclability and producer responsibility led to the development of an innovative database to track materials ingredients in automotive products. The [International Material Data System](#) (IMDS) provides a portal for suppliers to disclose information on the chemical ingredients of thousands of parts. This information, accessible to auto manufacturers, can then be checked against the industry's [Global Automotive Declarable Substances List](#)—a list of chemicals used in the auto industry that are restricted in different parts of the world. In addition to sector-wide efforts, some companies, like Ford, have invested significant resources in researching more sustainable alternatives, such as bio-based materials.

FUTURE OUTLOOK

The efforts currently under way to increase materials information and improve products in multiple sectors have created momentum that will drive future change and, ultimately, superior products benefiting people and the environment. Outlined below are predictions for continued progress.

- **GREATER PUBLIC PRESSURE.** Media attention will continue to raise public awareness and demands for more product information. Advocacy coalitions will capitalize on this growing public awareness to pressure leading companies and those with significant market influence, such as large retailers, to use their market pull to improve products. In turn, retailers and brands will pressure their supply chains for transparency and leadership.

- **INCREASED FOCUS ON SUPPLY CHAIN IMPACTS.** Concern about materials will spread beyond the use phase and increasingly include consideration for the health and ecosystem impacts of materials during raw material extraction and processing, product manufacturing, and end of life. This will be accompanied by greater attention to environmental justice and human rights in the supply chain and in communities surrounding manufacturing facilities. These issues are particularly acute in developing countries, and we can expect manufacturers and suppliers in these countries to be a focus of discussions about sustainable materials and products.
- **MORE REGULATIONS.** Regardless of changes in U.S. federal regulations, states and local governments will establish new policies that increase the availability of information and restrict certain substances or activities. Leadership in policy regulation will spread beyond Europe, likely into in Asia and developing economies. International demands for greater disclosure are also likely to increase, potentially expressed through action in bodies such as the United Nations.
- **BETTER INTRA- AND CROSS-SECTORAL COLLABORATION.** Increasing transparency and improving products will require the shared experiences, data, tools, and aggregate demand within supply chains and across sectors. Better collaboration within the building industry can help spread the cost of research and development, as well as increase the leverage of combined purchasing power to demand change.
- **NEW TOOLS.** Scientific and supply chain efforts will lead to an abundance of data over the coming years. It will become increasingly important to develop new tools that can store, organize, and translate this new information to make it actionable for firms, government agencies, and other stakeholders. In addition, although assessments are becoming increasingly multiattribute and life cycle based, the tools for human health and the environment are still separate. More integrative tools will be needed to help project teams weigh trade-offs among highly rated products on these different scales to find the optimal choice.

Realizing this vision for the future in the building industry will require the combined efforts of all stakeholders—from manufacturers, engineers, and construction workers to architects, specifiers, contractors, and building owners. Your interest and motivation to read this guide was the first step. We hope you now feel empowered to take on a greater role in the ongoing efforts to enhance the human health and environmental aspects of our shared built environment.

SUMMARY

- The past two decades have seen a significant increase in scientific, government, industrial, and consumer concern about the human health and environmental impacts of materials and products across multiple industries. These concerns have led manufacturers to develop products that avoid or reduce impacts.
- The building industry is not alone in driving improved materials and products. Most sectors have established restricted substances lists, and some have established approaches and tools to collect chemical information, evaluate substitutes, and measure progress toward more preferable chemicals and materials. Many sectors have also developed sustainability programs to reduce climate impact, address social concerns associated with product life cycles, and reduce resource use.
- The efforts currently under way to increase access to materials information and improve products in multiple sectors include greater public pressure, increased focus on supply chain impacts, regulatory reform, enhanced intra- and cross-sectoral collaboration, and new analytical tools.

TIPS FOR PRACTICE

LEARN FROM OTHER SECTORS. The building sector is part of a broad-based movement to better understand the health and environmental attributes of materials. Developments in some tools and approaches to sustainable materials management in other sectors could be applied to the building sector.

FOLLOW SCIENTIFIC, MARKET, AND POLICY TRENDS. Markets are changing quickly in response to evolving scientific understanding, growing demand, and emerging regulation. It is important to track these developments to manage risks and identify new opportunities to select and purchase better materials.

COMMUNICATE AND COLLABORATE BROADLY. There is no reason to “go it alone.” A growing network of professionals are interested and informed about materials issues. Engaging with peers through groups such as the Green Chemistry and Commerce Council, the Sustainable Purchasing Leadership Council, BizNGO, and many others can help tap emerging expertise and better anticipate fast-changing market conditions within and outside the building sector.

CHAPTER 4. RESOURCES

ALTERNATIVES ASSESSMENT

- BizNGO: [Chemical alternatives assessment protocol, version 1.1](#)
- Interstate Chemicals Clearinghouse: [Alternatives assessment guide, version 1.0](#)
- National Research Council: [A framework to guide selection of chemical alternatives](#)
- OECD: [Substitution and alternatives assessment toolbox](#)
- OSHA: [Transitioning to safer chemicals toolkit](#)

BIOMIMICRY

- [Biomimicry 3.8](#)
- [Biomimicry Institute](#)

EXTENDED PRODUCER RESPONSIBILITY

- [Extended producer responsibility](#) at the Organisation for Economic Co-operation and Development

GREEN CHEMISTRY

- [American Chemical Society Green Chemistry Institute](#)
- [Green chemistry](#) at the U.S. EPA

PREVENTION THROUGH DESIGN

- [Prevention through Design National Initiative](#)
- [Pollution prevention](#) at the U.S. EPA

SUSTAINABLE PRODUCT DESIGN

- [D4S: Design for sustainability](#)
- [Design for sustainability](#) at the United Nations Environment Programme
- [Sustainable Products Initiative](#) at the Lowell Center for Sustainable Production

ADDITIONAL READING AND RESOURCES

- [The toxics release inventory in action: Media, government, business, community, and academic uses of TRI data](#), report from U.S. EPA
- [Late lessons from early warnings: Science, precaution, innovation](#), report from European Environment Agency
- [Massachusetts Toxics Use Reduction Institute](#)
 - ▶ [Publications, including technical reports, case studies, and factsheets](#)
- [Videos from USGBC's materials and health event series](#)

5.

CHAPTER 5. VISIONS FOR THE FUTURE— PERSPECTIVES FROM THE AUTHORS

The authors of this guidebook represent a wide range of backgrounds—from chemists, materials scientists, and physicians to building, environmental, and policy experts. In this chapter, they provide their perspectives on the future for transparent, healthful, and environmentally preferable building materials.

- The road toward better building materials: The need for speed and endurance
CHRIS PYKE, PH.D., U.S. GREEN BUILDING COUNCIL
- The next evolution of materials selection
BRENDAN OWENS, P.E., LEED FELLOW, U.S. GREEN BUILDING COUNCIL
- Information transparency and cultural change
KEN GEISER, PH.D., UNIVERSITY OF MASSACHUSETTS LOWELL
- Optimism about health-centered building design
CHARLENE BAYER, PH.D., HYGIEIA SCIENCES LLC
- Beyond the building inhabitants: Health and equity in the materials supply chain
JOEL ANN TODD, ENVIRONMENTAL CONSULTANT
- Healthful materials are a social equity issue
HEATHER ROSENBERG, USGBC GINSBERG FELLOW
- Biological inspiration for the next generation of building materials
MEGAN SCHWARZMAN, M.D., M.P.H., UNIVERSITY OF CALIFORNIA, BERKELEY
- Multifunctional, responsive, resilient, and healthy building materials: A vision for the future of green building
MARTIN MULVIHILL, PH.D., UNIVERSITY OF CALIFORNIA, BERKELEY
- Accelerating change through cross-disciplinary collaboration on “functional substitution”
JOEL TICKNER, SC.D., UNIVERSITY OF MASSACHUSETTS LOWELL
- Pioneering businesses and states will lead in transforming materials
ELIZABETH BEARDSLEY, P.E., U.S. GREEN BUILDING COUNCIL
- Three tactics to enable a human health and environmental transformation
ASHLEY WHITE, PH.D., U.S. GREEN BUILDING COUNCIL

THE ROAD TOWARD BETTER BUILDING MATERIALS: THE NEED FOR SPEED AND ENDURANCE



CHRIS PYKE, PH.D., U.S. GREEN BUILDING COUNCIL

In preparing this guide, we heard many times that building practitioners “just want to know what to do.” They want simple, clear guidance on which products they should *specify* and *purchase*. They feel a sense of urgency to make better-informed decisions and a frustration with the lack of information and the complexity of many choices. This is a fair representation of the world we live and work in today. Data are incomplete. Materials choices are often challenging or ambiguous. Magic quick fixes are elusive, and today’s quick fix often turns into tomorrow’s problem.

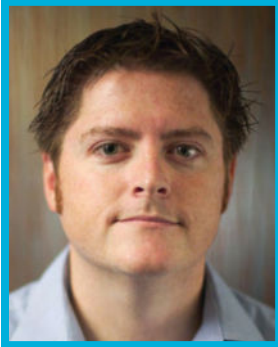
Changing this status quo will require both speed and endurance. We have opportunities to take action today. We can start by using existing tools to consistently ask for information. Then, we can act on this information to specify and purchase better materials that avoid some of the most problematic health and environmental impacts. In the short term, our questions and our purchasing decisions provide the clearest possible signal that we recognize and value better materials.

At the same time, we should be realistic about the magnitude of the challenge and our long-term goals. We must accept that many vexing issues will not have simple answers or immediate solutions. We face fundamental issues of personal and societal values and potentially irreducible scientific and technical uncertainties. These circumstances are real, and we cannot wish them away. However, these realities do not need to be paralyzing.

As we have shown in this guide, we can act deliberately to learn more about the attributes and history of materials. We can use this information to systematically evaluate options. We can act to make the best choice available, whether it is rewarding responsive manufacturers or avoiding the need for a given material entirely. We can do this while recognizing the fundamental wisdom of science-based approaches to precaution and the fallibility of risk-based approaches to managing health and environmental hazards. I believe that the weight of the scientific and technical evidence indicates that efforts to systematically reduce the use of hazardous, environmentally damaging materials as early in the supply chain as possible offers the most reliable opportunity to take action today to reduce negative impacts on people and the environment.

For those who still say, “Just tell me what to do,” this may be unsatisfying—too complex or too general. However, I believe that it is a fair, actionable reflection of where we are today. Navigating these issues will not be simple. It will require new skills and new scientific and technical knowledge. Things will get easier as we learn more and take advantage of new tools. Fortunately, we can plan for the long haul while taking action today to ask good questions, make better decisions, and prioritize precaution.

THE NEXT EVOLUTION OF MATERIALS SELECTION



BRENDAN OWENS, P.E., LEED FELLOW, U.S. GREEN BUILDING COUNCIL

The evolution of LEED’s technical requirements is a significant part of my job at USGBC. The new Materials and Resources requirements introduced in LEED v4—which are fundamentally predicated on multiattribute life cycle assessment and optimization—open a wide array of opportunities for building industry professionals to better understand the environmental, health, and economic outcomes associated with decisions they make in the execution of a project.

The increasing amount of product information that is at designers’ and specifiers’ fingertips is being used to make decisions that are better optimized than ever before. From a human health perspective, access to additional information, material ingredients in particular, enables designers to evaluate materials through a new and exciting lens that creates new markets for building materials with fewer chronic and acute health hazards. However, while it is both convenient and intuitive to define a set of ingredients that we do not want in our buildings, this type of thinking is at best limited and at worst counterproductive. There are trade-offs in every decision we make as building designers, builders, or operators. Selecting one product over another to avoid one acutely carcinogenic ingredient without considering other impacts can be a net negative if the selected product has substantially higher embodied manufacturing energy or requires significantly more operational energy use.

Complete assessment of the myriad interrelated, competing, and synergistic trade-offs in materials selection is, given the current state of information available to practitioners, not possible. LEED v4 seeks to fill these information gaps and has already led to progress in areas related to disclosure of environmental and health aspects of various materials. As this information becomes more complete and readily available, our obligation as practitioners evolves as well. We must disabuse ourselves of the notion that there are easily identifiable “good” and “bad” choices for many, if not most, of the materials-related decisions we make.

Instead, we will embark on the next evolution of materials selection—the simultaneous optimization of multiple human health, environmental, and economic attributes. Questions such as when global warming potential trumps biodiversity loss are complicated, but these are the questions we most need to address. Optimization based on these questions will inherently, in the short term, require trade-offs—some more palatable than others. In the long run, a more comprehensive understanding of these trade-offs and the ability to direct research and development as a result of our choices will significantly improve the health, environmental, and economic performance of our materials palette.

INFORMATION TRANSPARENCY AND CULTURAL CHANGE



KEN GEISER, PH.D., UNIVERSITY OF MASSACHUSETTS LOWELL

Early in the 1980s I worked with a coalition of labor and environmental groups to draft and support passage of the Massachusetts Right to Know Act, a law that required state employers to inform employees about the chemicals that they were exposed to at work. One of the most surprising results of that law was that employers across the state began hiring consultants to identify and inventory the chemicals used in their production processes. Even more surprising was the number of reports that firms had begun using safer alternatives to some of the most hazardous chemicals.

This was the first time I stumbled upon the enormous power of information disclosure as a means of driving cultural change. Whether it was firms reporting chemical releases under the federal Toxics Release Inventory or firms required to label products containing carcinogens and reproductive hazards under California's Proposition 65, the results were similar. Requiring firms to disclose chemical information drove them to better manage chemicals and, often, to eliminate truly dangerous ones. Such information "transparency" provides double benefits. It not only helps people make better decisions about the safety of products and conditions, it also prompts suppliers to make products and conditions safer.

Since the early struggles over worker right-to-know laws, the cultural value of knowing about chemicals has grown significantly, and a worldwide movement for chemical ingredient disclosure has emerged. Shoppers throughout contemporary consumer economies are growing more sensitive to information about chemicals in products. Although the expression of this awareness remains episodic and, therefore, is commonly addressed chemical by chemical, there may soon come a time when these concerns reach a tipping point and both firms and customers will come to expect product suppliers to be fully transparent about chemical ingredients. Thereafter, product ingredient declarations will be routinely expected, and a broad range of current chemicals of concern will be eliminated from commercial products. When this point is reached, John Warner, who co-wrote *Green Chemistry: Theory and Practice*, has noted, "all chemistry will be 'green.'"

Will there be such a tipping point? That remains unclear. But it is possible to foresee such a shift, and writer Daniel Goleman suggests it would elevate our "ecological intelligence." We would develop a new lens for seeing the world around us and, in particular, the products we purchase and the chemicals we use. Chemical transparency is a critical step to achieving this culture. It is important that the building construction industry, like other industries, take leadership in this transition by pressing materials suppliers to disclose the chemicals in their products and promoting products that are offered with full material disclosure.

OPTIMISM ABOUT HEALTH-CENTERED BUILDING DESIGN



CHARLENE BAYER, PH.D., HYGIEIA SCIENCES LLC

Every decision about building materials and processes presents compromises. Often, functional and economic parameters take priority over environmental and human health considerations. Although function and cost are critical, the increasing demand for more healthful and environmentally preferable materials is driving manufacturers to make product modifications.

Four years ago, I chaired a session at the USGBC Federal Summit advocating for health as an essential design parameter. At that time, the primary sustainable design focus was energy savings, and health had little traction in the building community. As a result of this session, the Health in Buildings Roundtable (HiBR), a public-private partnership led by the National Institutes of Health, was established to encourage health-centered building design. Today, the focus on health is more widely accepted and promoted. Both for the environment and for people, materials specification is a critical component of health-centered building design.

As transparency in materials ingredients and processes increases and toxicological data become more widely available and understood, consumers will be more empowered to demand healthful materials. Limitations in knowledge and data availability, despite progress for many materials, have slowed the process. It is encouraging that manufacturers are increasingly employing life cycle thinking for their products. The inclusion of life cycle thinking in LEED v4 also will drive increased specification of more environmentally preferable and healthful materials. The tools for determining the environmental and human health impacts are improving, as are disclosures.

In addition to transparency about ingredients and processes, we need a better understanding of environmental and human health endpoints to identify safe alternative chemicals and materials. We need research directly linking health impacts to specific chemical exposures and organ-specific endpoints. For example, certain materials components have not yet been causally linked to endocrine disruption. These data are needed to make informed product modifications and prevent unintended consequences from minimally assessed alternatives. The links between life cycle approaches and human and environmental risk assessment methods in addition to toxicological environmental impacts need to be strengthened.

Overall, I am optimistic that we will continue to move toward specifying more healthful and environmentally preferable materials with increasing adoption of the transparency movement. Many designers, manufacturers, consumers, and policy makers understand the importance and the need. We need to continue to build the databases and tools, and increase their availability and understandability, to have more actionable information. This will result in increasingly healthful materials usage throughout the life cycle, benefiting both humans and the environment.

BEYOND THE BUILDING INHABITANTS: HEALTH AND EQUITY IN THE MATERIALS SUPPLY CHAIN



JOEL ANN TODD, ENVIRONMENTAL CONSULTANT

As we consider materials and health, we need to ask, “Whose health?” Our efforts to date have focused primarily on building inhabitants, but green building certification systems around the world are now expanding concepts of green building and sustainable development to address the experiences of a much broader group. Specifically, we are starting to include the health, well-being, and social equity of those who construct and maintain our buildings, the communities surrounding the buildings, and the people in the supply chain who are engaged in extracting and processing raw materials and manufacturing those raw materials into building products.

We know that some supply chain practices are dangerous and can be unhealthful for workers. The work might involve exposure to hazardous materials or high frequencies of accidents. Workers might live in conditions that are unsanitary and overcrowded. Pay might be low and benefits nonexistent. Workers might be tied to their jobs through debt bondage or other forms of slavery. In some industries, child labor is not uncommon.

We also know that conditions vary around the world and that no country has a perfect record on worker health and human rights. And we are learning more about the environmental concerns in supply chains of building products through life cycle assessment, environmental product declarations, and LEED’s new raw material sourcing credit.

Yet we still don’t know enough about the *people* in these supply chains and how we can ensure that they are treated fairly. This is the purpose of a new LEED pilot credit, Social Equity in the Supply Chain, which provides incentives for product manufacturers to require their suppliers to respect basic human rights for their workers—a prerequisite for worker health, safety, and well-being. (Two other pilot credits address related issues: Social Equity within the Community, and Social Equity within the Project Team; all are available at <http://www.usgbc.org/credits>.)

Although this expansion of scope is a step forward, we still have work to do to make sure human health is protected and promoted in supply chains as well as inside our buildings. For example, higher rates of disease and illness in “fenceline” communities—the places adjacent to factories, refineries, mines, and other sites in the supply chain—have been documented and attributed to increased exposure to hazardous pollutants.

The green building community has responded with enthusiasm to the new social equity pilot credits in LEED. We recognize that this explicit focus on the people who build and maintain our buildings, who live in the communities surrounding our buildings, and who make the products we use in our buildings is an essential component of our work.

HEALTHFUL MATERIALS ARE A SOCIAL EQUITY ISSUE



HEATHER ROSENBERG, USGBC GINSBERG FELLOW

The burden of unsafe and dangerous materials is not evenly distributed across society. The health impacts of materials are particularly significant for people who are already vulnerable, such as children, the elderly, and lower-income populations. For example, low-income communities face higher levels of asthma, cardiovascular disease, diabetes, and cancer.¹ These problems can be exacerbated by the VOCs, dust, and other pollutants associated with some building materials.

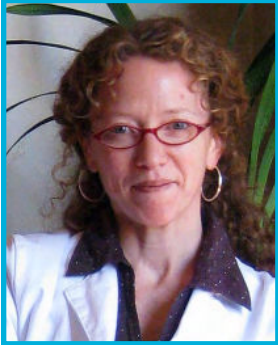
Selection of healthful materials can be a messy process—the trade-offs are complex, the alternative materials are often less well understood, and the research process to find those alternatives can be time consuming. All of these challenges can lead to extra cost for a project (or at least a perception of extra cost). To date, the primary market signals that manufacturers receive in regard to materials and ingredients selection are driven by performance and cost—their goal is to produce the highest-performing materials for the lowest amount of money; health and environmental goals are secondary. As the demand for healthful alternatives grows, the opportunity to charge a premium emerges. And the time required for project teams to explore, test, and adopt new alternatives to their tried-and-true choices can cost more as well, at least initially. This does not mean that all the safer alternatives necessarily cost more—in many cases they will cost the same or less, and strategies that reduce or eliminate the need for unhealthy materials altogether can be cost saving. But rarely does change come free.

Low-income and minority communities are often hit with a double whammy of exposure to toxic materials. Not only is lower-end housing likely to be made of the least expensive materials (which may or may not be properly maintained or replaced), but materials factories are more likely to be located near these same populations (so-called fenceline communities) and their residents are likely to work in those factories. When the societal costs of health impacts are included, toxic materials no longer seem “cheaper.”

Safer materials and more healthful buildings cannot become a luxury available only to wealthy communities and those fortunate enough to live in green buildings or neighborhoods. Removing hazards associated with building materials across all phases of the life cycle is a matter of social equity. To protect all people in all buildings and communities, we need education and tools for project teams, market signals for manufacturers, and better laws and international standards.

¹ Global Status Report on Noncommunicable Diseases 2014, World Health Organization. http://apps.who.int/iris/bitstream/handle/10665/148114/1/9789241564854_eng.pdf?ua=1

BIOLOGICAL INSPIRATION FOR THE NEXT GENERATION OF BUILDING MATERIALS



**MEGAN SCHWARZMAN, M.D., M.P.H.,
UNIVERSITY OF CALIFORNIA, BERKELEY**

In this guide we have reviewed some of the health and environmental consequences of a wide variety of substances in building materials, considering not just their effects on building occupants but also the impacts throughout their life cycles. The ultimate goal of this knowledge is to accelerate the transformation of materials in the built environment into products that truly support human and environmental health.

But how will this transformation occur, and where will these benign materials come from? A revival of traditional, time-tested materials may supply some solutions. Natural fibers, for example, are inherently less flammable than synthetic fibers and don't require the addition of flame-retardant chemicals. New materials that press natural ingredients into novel uses are increasingly available. Already, wood composites can be replaced by structural biocomposites—for example, agricultural waste held together by mycelia, the complex root networks made by mushrooms. These biocomposites could stand in for a variety of formaldehyde-releasing manufactured wood products.

One form of harvesting nature's innovation is biomimicry—using biology's time-tested strategies to inspire the design of new materials, manufacturing processes, or industrial systems. Janine Benyus, founder of the Biomimicry Institute, describes biomimicry as the process of learning from and emulating nature's blueprints, chemical recipes, and design strategies, all the result of billions of years of R&D. Studying how coral reefs are laid down, for example, led to the design of an alternative cement generated by bubbling CO₂ (redirected from a power plant's smokestacks) through mining wastewater or seawater headed for desalinization. By mimicking nature's chemistry, the process transforms the third-largest source of greenhouse gas production in the U.S.—cement manufacturing—into both a useful building material and a carbon sequestration method.

Biomimicry's potential inspires hope that we can create a truly sustainable world—one that allows us to meet our needs while protecting the ability of future generations to meet theirs. Biology evolved within the inherent limits imposed by Earth's ecosystems, such as finite supplies of water, energy, and raw materials. Earth's operating conditions include chemistry that is not toxic to the organisms or ecosystems from which it originates. Natural systems are limited to building with readily available materials and energy from the sun. They must work within the established cycles of nitrogen, phosphorus, and CO₂. Any waste created becomes fuel for another life form or process.

Designers are now using the strategies that have evolved under those life-friendly operating conditions to develop safer materials, ones that tread lightly on the land and are a better match for our human biology. From biology, we too have the potential to learn how to live—and build—within Earth's operating conditions.

MULTIFUNCTIONAL, RESPONSIVE, RESILIENT, AND HEALTHY BUILDING MATERIALS: A VISION FOR THE FUTURE OF GREEN BUILDING



MARTIN MULVIHILL, PH.D., UNIVERSITY OF CALIFORNIA, BERKELEY

We invest a lot in our buildings. In return they offer shelter and comfort by providing a reliable barrier between us and the constantly changing external environment. Many of the technological improvements in the building industry have been aimed at improving this barrier. Our modern construction leverages chemical, material, and engineering prowess to design more efficient ways to create buildings that are stronger, better insulated, and more resistant to wind, water, fire, and sunlight. The materials and design innovations of the future will shift from resisting these natural forces to

harnessing and responding to them in a ways that are more healthful and more resilient for building occupants and our natural environment.

The shift to responsive and resilient design is already under way. The advent of green roofs that provide both protection and habitat are an early example of harnessing, rather than resisting, external forces. Similarly, electrochromic windows that dynamically respond to control light and heat transmission independently and on demand are a great example of responsive design. These are just two examples of how new materials and new design have created more interactive interfaces between the external environment and the internal spaces of buildings. This trend will continue to be enabled by breakthroughs in the way we design the next generation of chemicals and materials.

Historically, the design of chemicals and materials has been driven by very narrow performance criteria and cost. In the future, we will demand more of our materials. They will be optimized for intended function as well as being responsive to changing conditions, human health, and the environment. The next generation of greener and more sustainable materials will promote a fluid and dynamic interface with the natural world at the thresholds of buildings as well as throughout the life cycle of extraction, manufacturing, use, and disposal. Every stage of the life cycle of these materials will be designed to minimize waste and pollution and will ensure the resilience and sustainability of our natural resources. This revolution in materials design will be driven by breakthroughs in green chemistry and sustainable design.

Collaboration and information sharing throughout the supply chain and design of new materials will be an essential component of sustainable design. Communication will ensure that the next generation of greener chemistries is responsive to the needs of the building industry and healthful for humans and the environment. My hope is that the information contained in this guidebook and similar initiatives aimed at promoting dialogue and collaboration will help building practitioners communicate more effectively with stakeholders who are less familiar with sustainability challenges in the building industry.

ACCELERATING CHANGE THROUGH CROSS-DISCIPLINARY COLLABORATION ON “FUNCTIONAL SUBSTITUTION”



JOEL TICKNER, SC.D., UNIVERSITY OF MASSACHUSETTS LOWELL

In their materials focus and priorities there is a disconnect among chemists, material scientists, product designers, architects, environmental health professionals, specifiers, and purchasers that inhibits the use of safer chemicals and materials. Product and building designers and chemists tend to focus primarily on performance. Does the molecule or material perform according to some specification or design criteria? Does it do what we need it to do, efficiently and effectively? Purchasers and specifiers tend to think primarily about cost and sometimes performance. How does this material or product affect the bottom line? Even environmental health professionals tend to ask, “How bad is this substance? Is it problematic? Is there enough exposure to cause risks in this specific context?”

No group has much of an incentive to think about safer materials, in part because of these professionals’ training—to make something that works, to buy something that is inexpensive, to prevent something bad from happening. Thinking about sustainable solutions or safer alternatives is not part of their education, training, or culture.

However, the design and evaluation of safer materials provide an opportunity for convergence of these fields. By reorienting how we manage chemicals and materials and focusing on the sustainable, cost-effective, and high-performing way to meet a particular chemical or material function, we can co-optimize the goals, knowledge, and training of a broad set of fields.

A starting point for this convergence and dialogue among the actors involved in materials design, selection, and management is an approach we call “functional substitution.” One starts with the particular function or service the chemical or material provides and then explores a range of molecular, material, and systems changes that can meet that particular function, opening up opportunities for innovation in product and building design, rather than never-ending battles over the safety of a particular chemical or material.

For example, rather than focus on eliminating a specific flame retardant (which could lead to regrettable substitutions), a functional substitution approach would look at options to achieve the function of flame retardancy. These options might include alternative flame retardants designed on green chemistry principles, barrier materials that limit flammability, alternative designs that eliminate flammable materials, increased sprinklers in a building, or even eliminating the function or lowering the level of performance needed.

This same approach could be applied to any chemical or material of concern in the building space, from adhesives in flooring to insulating materials to pressed wood. In all cases, it starts with a broad understanding of the functional needs for the material or chemical in the building or product and expanded cross-disciplinary thinking as to how that function can be achieved in the most sustainable way possible.

PIONEERING BUSINESSES AND STATES WILL LEAD IN TRANSFORMING MATERIALS



ELIZABETH BEARDSLEY, P.E., U.S. GREEN BUILDING COUNCIL

We can *will* do better.

I believe we are ready for another sea change in improving our buildings. Leadership in energy-efficient buildings moved the market by educating stakeholders, building experience among designers, builders, and trades, demonstrating results, and lowering the cost delta. We can do the same with materials.

Navigating sustainability of building materials can be a challenge. A common misperception is that everything we are able to buy has been tested and deemed “safe” by some government agency. But the reality is much more complex. Our laws and regulations have been designed to address precise problems—such as reducing smokestack emissions or having fire escapes—and do not approach hazards and risks to people, wildlife, our waterways, and air in a comprehensive way. More research is needed, as well, to support appropriate regulation, and research can take years and be very costly. For example, potential effects of the cumulative exposures we have every day—evidenced in biomonitoring—are not well understood. Even where the necessary data are available, our legal systems are designed to be slow so that interested parties have the opportunity to be heard, advancing fairness and adequate deliberation. As a result, our regulations are generally neither nimble nor easily responsive to new information.

For all those reasons, innovative businesses and states are acting, and these leaders will help accelerate the transformation to more sustainable and lower-risk products. Some state legislation will yield important information to consumers and downstream businesses, and other states will establish new regulatory approaches, such as incorporating life cycle assessment. From these initial steps will emerge a better understanding of the potential for reducing the possible health and environmental impacts of our building materials. Leading U.S. manufacturers are tackling sustainability as well. These pioneers have tremendous potential to excel at green product technology and sell into the global marketplace. An important challenge will be how U.S. laws can operate alongside laws like REACH and those of other nations to reduce the burden on multinational companies, create efficient data pools, and support more sustainable materials globally.

A transformation in building materials analogous to what we’ve seen in energy efficiency is starting. It’s exciting that companies small and large are looking at their products through the sustainability lens. When we have the opportunity to use a proven alternative without problematic characteristics, doing so reduces releases to the environment and exposures to workers, waste handlers, and product users. With more than 4 billion pounds of toxic chemicals disposed or released to the environment last year in the United States alone, according to the EPA, we must do better. And, I believe we will.

THREE TACTICS TO ENABLE A HUMAN HEALTH AND ENVIRONMENTAL TRANSFORMATION



ASHLEY WHITE, PH.D., U.S. GREEN BUILDING COUNCIL

The building industry is on the cusp of a paradigm shift that will significantly improve human health and environmental outcomes over the life cycle of building materials. Three tactics can help complete the transformation.

First, we have to reorient our strategy toward a longer-term vision. Energy- and water-efficient designs and products allow us to see the effects of our actions relatively immediately and easily in meter readings and monthly bills.

The human health and environmental outcomes of building materials are harder to grasp. It's difficult to see the impacts of our decisions as small effects add up, sometimes thousands of miles away, possibly affecting someone else. We have to play the long game, investing our efforts further in the future, knowing that small contributions will one day add up to significant accomplishments.

Second, we have to prioritize health and the environment at the most critical time points. Although specification and purchasing decisions are important, as is a manufacturer's choice to reformulate a product, the decisions that have the most potential impact are made earlier. The project team makes them in its first meeting, when the initial project goals are set, and the product design team makes them on a whiteboard, when the product's attributes are first sketched out. Rather than assume we can react by changing goals or fixing a problem if and when it occurs, we must proactively seek opportunities to influence the design process from the start and follow through to ensure design goals are reflected in the final result.

Third, we have to expand whom we involve in creating our built environments. "An architect would never call up a scientist—it's impractical!" someone told me recently. But maybe we need to find a way to make it practical. How better could scientists learn what would help an architect and architects get the expert advice they need?

A huge range of professionals—all with different expertise and motivations—play roles in researching, developing, making, evaluating, choosing, using, and disposing of materials. Although most conversations and decisions, for practicality, will only involve a fraction of these professionals, each can work to expand his or her expertise. For instance, specifiers and purchasers can take time to gain experience interpreting health and environmental information, scientists can work to make their research available and interpretable to others, and manufacturers can converse with those who will purchase and use their products to better understand their needs.

Truly transforming our built environment to bring human health and the environment to the fore will take creative minds, innovation, and patience. Begin with simple steps: invite someone new to the conversation, prioritize setting health and environmental goals early, and trust that our combined efforts will add up to a better future.

6.

CHAPTER 6. LEADERSHIP—CASE STUDIES FROM THE FIELD

The organizations featured in this chapter are leading the way as pioneers promoting more healthful, environmentally preferable building materials. In the case studies that follow, they share their experiences—successes, challenges, and lessons learned.

- Lessons in materials transparency and selection for the Brock Environmental Center, **SMITHGROUPJJR**
- Get a head start: Materials selection lessons for the VanDusen Botanical Garden Visitor Center, **PERKINS+WILL**
- Early lessons pursuing the LEED v4 Materials and Resources credits, **BALFOUR BEATTY CONSTRUCTION**
- Product transparency in practice, **THE DURST ORGANIZATION, VIDARIS, INC., AND HEALTHY BUILDING NETWORK**
- Building health care facilities that safeguard human health, **HOK**
- Promoting health through healthy building materials at Dell Children’s Medical Center of Central Texas, **CENTER FOR MAXIMUM POTENTIAL BUILDING SYSTEMS AND SETON HEALTHCARE FAMILY**
- Healthful environments at Kaiser Permanente, **KAISER PERMANENTE AND CENTER FOR MAXIMUM POTENTIAL BUILDING SYSTEMS**
- Role of transparency in creating a healthy and high-performing built environment, **GOOGLE REAL ESTATE & WORKPLACE SERVICES (REWS)**
- Open letters that urge transparency, **AYERS SAINT GROSS**
- Engaged supply chains are critical to creating HPDs: A comparative case study, **INDUSTRIAL LOUVERS, INC.**
- Elevating health and environmental concerns, **THYSSENKRUPP ELEVATOR AMERICAS**
- Speed EPDing, **ZUMTOBEL GROUP**
- The process of continuous improvement, **CONSTRUCTION SPECIALTIES, INC.**

LESSONS IN MATERIALS TRANSPARENCY AND SELECTION FOR THE BROCK ENVIRONMENTAL CENTER

GREG MELLA, VICE PRESIDENT, SMITHGROUPJJR



View of the Brock Center from the southeast.
Photo: David Chance / Courtesy: SmithGroupJJR

The Chesapeake Bay Foundation (CBF) sought to create the most sustainable building possible for the new Brock Environmental Center, and chose the design and construction team of SmithGroupJJR, Hourigan Construction, and Skanska as the owner's representatives. CBF's aspirations included a new mindset on the materials for the building.

The project team established specific goals for materials selection:

- avoiding materials that contain any of the 14 Living Building Challenge (LBC) Red List ingredients, comprising over 300 distinct substances;
- requiring disclosure of the chemical constituents of building materials;
- pursuing locally sourced materials to the greatest extent possible;
- maximizing the use of salvaged and reclaimed materials; and
- purchasing wood products certified by the Forest Sustainability Council.

These goals were components of the client's pursuit of Living Building Challenge and LEED Platinum certification. Additionally, CBF saw the correlation between material impacts and the health of the Chesapeake Bay and sought to set a high benchmark for others to follow.

The design team met those goals using a systematic but novel process for materials selection. We embraced a philosophy that the safest way to avoid chemicals of concern was to use natural materials and products with minimal processing, like metals, wood, stone, and concrete. This approach was consistent with the project's design goal to connect visitors to the project's unique site through the materials palette.

Our materials research involved all project stakeholders. The contractor, brought on during early design, shared the research effort with the architect, subcontractors, owner, and their representatives. An all-day charrette was used to create and document a methodology for materials research and to "divide and conquer" because of the magnitude of the task.

The design team contacted manufacturers to learn whether their products contained Red List chemicals. Initially, we were satisfied with a manufacturer's letter indicating the product was compliant, but over time we realized that a more rigorous approach was needed. Some manufacturers stated their products complied, but Red List ingredients were found in their literature or in MSDSs. These were not deliberate attempts to deceive, but rather reflect how few individuals within a company actually know what is in the products they make and understand the complexity of chemical accounting.

As a result, our approach was modified to pursue a full accounting of materials, preferably via Health Product Declarations (HPDs). We assumed a product did contain Red List ingredients unless we could vet a complete list of ingredients. Occasional exceptions were needed if manufacturers indicated a small portion of the ingredients were proprietary; we then sent advocacy letters encouraging greater transparency.

Figure 1 illustrates a portion of the selection process and shows the role materials transparency played. Many of a building's components are selected for generic performance specifications instead of proprietary specifications. The architect researched the proprietary products while the contractor and subcontractors vetted the other products. Subcontractor involvement was valuable, given their role in determining the specific products that make up a building.

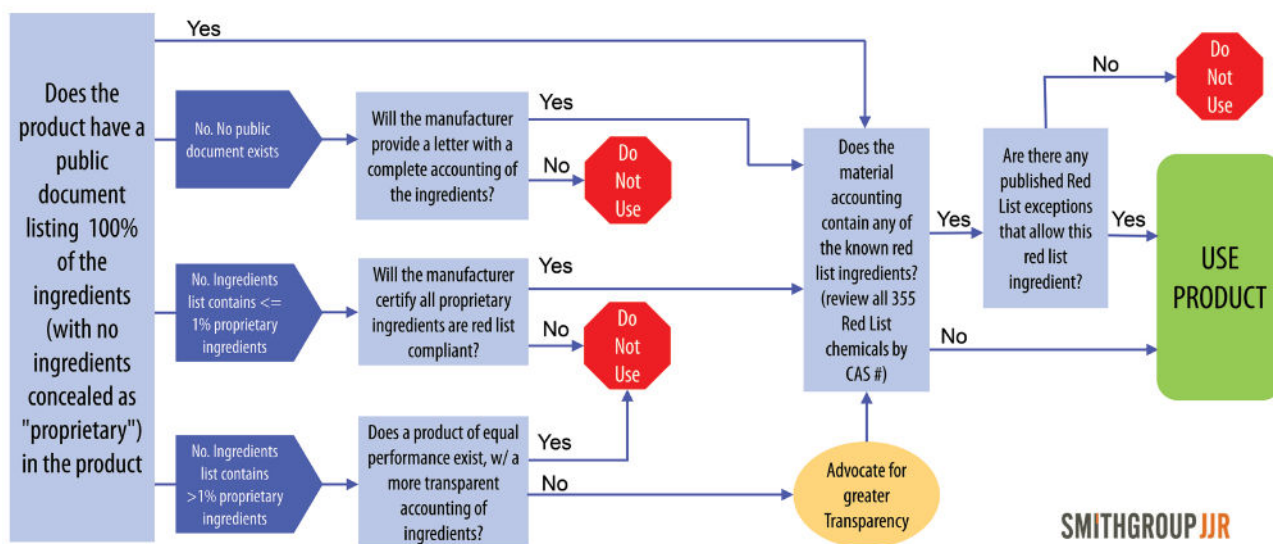


Figure 1. Materials selection process
 Courtesy: SmithGroupJJR

LESSONS LEARNED

We found that products with good disclosure of ingredients do not have a cost premium; however, the potential soft costs associated with material ingredient research can be significant. To reduce the costs, the owner, architect, and contractor each hired interns to assist. Our initial charrette defined the research process and tools, allowing a smooth hand-off to interns. Incorporating salvaged and reclaimed materials wherever possible (siding, flooring, trim, doors, lavatories, tile, granite, and hardware) simplified research, as did selecting natural, biobased materials.

Our work contributed to a building with fewer potentially hazardous chemicals and more intrinsically safe materials based on a thoughtful, intentional decision-making process. These attributes contribute to a better building for people and the environment.

While we knew that getting disclosure of ingredients would be hard, we believe that as more and more teams ask for this information, the burden will be reduced significantly for teams that follow. We committed to publicly sharing our materials research by posting it on our website. We update it regularly, at <http://www.smithgroupjjr.com/info/transparency/>.

The benefits of our efforts are not immediate, but in time, as more teams demand HPDs, we will have the ability to make more informed choices about the products we include in our design. To quote Justice Louis Brandeis, “Sunlight is said to be the best of disinfectants.” As manufacturers embrace greater transparency, we are beginning to see their efforts accompanied by the elimination of chemicals with known health hazards. That is the end goal and our justification for the research and advocacy on this project.

GET A HEAD START: MATERIALS SELECTION LESSONS FOR THE VANDUSEN BOTANICAL GARDEN VISITOR CENTER

MAX RICHTER, SENIOR ARCHITECT, ASSOCIATE, PERKINS+WILL

Located in the heart of urban Vancouver in a temperate rainforest climate, the VanDusen Botanical Garden is a 55-acre oasis. Its Visitor Center, certified as LEED Platinum, is the first building in Canada to apply for the Living Building Challenge.

At the outset of the project, the project team established a comprehensive set of sustainable objectives that included goals for materials selection:

- Avoid building products that contain substances on the Living Building Challenge materials Red List.
- Select locally sourced materials and products.
- Use wood as the primary structural system and utilize 100% Forest Stewardship Council-certified products.
- Choose building products that have a low embodied carbon footprint.
- Source and use reclaimed and salvaged wood.



VanDusen Botanical Garden exterior.
Photo: Nic Lehoux / Courtesy: Perkins+Will

Perkins+Will, as the architect, product specifier, and sustainability consultant, had the primary responsibility to choose materials. The City of Vancouver Board of Parks and Recreation supported the sustainability goals of the project and demonstrated an openness to a materials selection process that was longer and more challenging than for a conventional project.

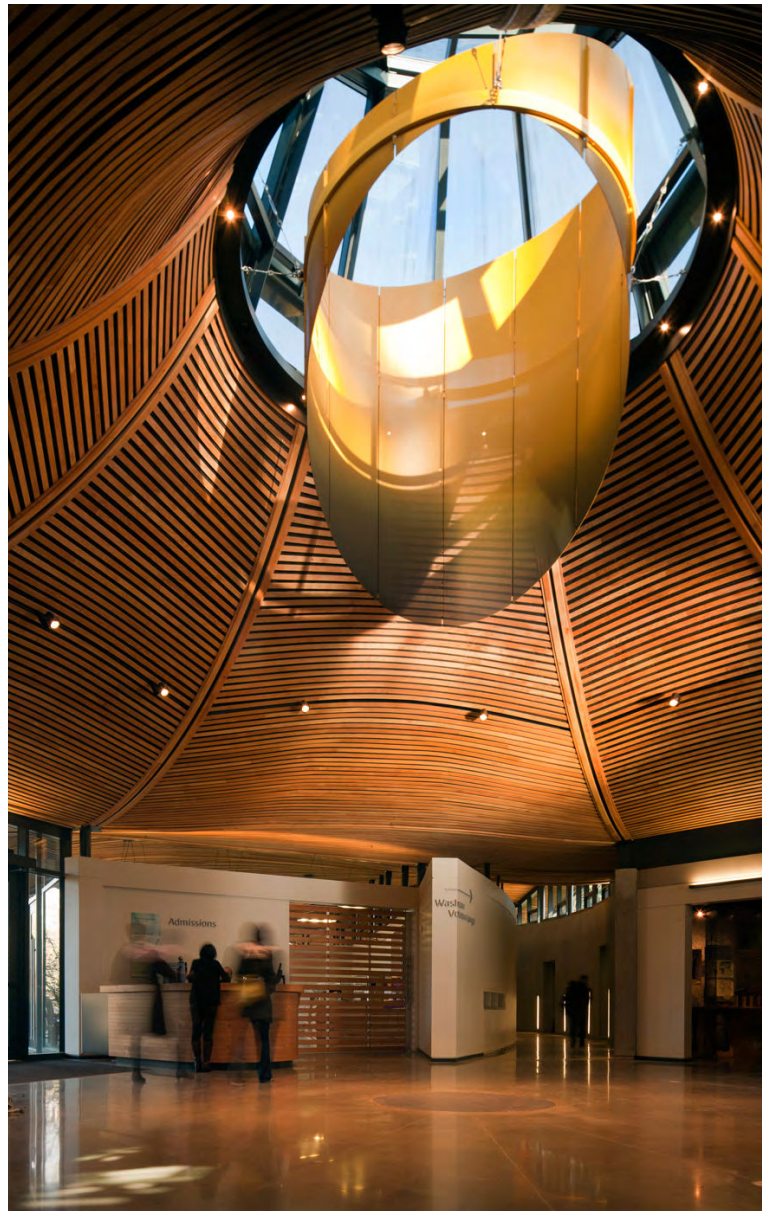
Three sustainable design charrettes were held as the project concept was being developed. It was during this phase that the design team discovered one of the best strategies

to meet the requirements of the Living Building Challenge: use simple materials with simple origin and ingredient stories. Considering the combined challenges of finding Red List-free building products, specifying products available locally, and minimizing the embodied carbon footprint of the project, the project team chose to limit the design to a palette of only a few elemental materials—heavy timber, glass, aluminum, and concrete. This choice had the dual benefits of reinforcing the architectural expression of the building and using local building products that were easily understood in composition and origin.

Schematic design for the project started in early 2008, before the Health Product Declaration was inaugurated and just as the Healthy Building Network's Pharos Project was launched. Because the adoption of transparency in the building materials industry was just getting underway, Perkins+Will and Ledcor, the project's general contractor, developed custom questionnaires to address the documentation requirements of the Living Building Challenge. These were distributed to suppliers whose products were being considered for use in the project.

Building materials manufacturers were familiar with the requirements for LEED certification, such as VOC emission rates and the percentages of recycled content, but were less well acquainted with the aims and requirements of the Living Building Challenge. A common response to the request for transparency and disclosure about materials was, "Why do you need that information? It's not required for LEED." That hurdle was overcome through explanation and communication with the manufacturers. A secondary challenge was that many manufacturers purchase ingredients or parts from other suppliers and either had not investigated the composition of those products and/or were prevented from reporting information by nondisclosure agreements.

The challenge of avoiding substances on the Red List continued into the construction phase of the project. Ledcor played a vital role in communicating and policing the requirements of the Living Building Challenge with all of the subcontractors. Through the construction process, the subcontractors embraced the design and the objectives of the project and took an active role in suggesting construction methods or products that would help the project.



VanDusen Botanical Garden Visitor Center atrium.
Photo: Nic Lehoux / Courtesy: Perkins+Will

LESSONS LEARNED

The primary lesson learned was to start the process of materials research, selection, and specification early in the design process. Because comprehension of the objectives and documentation requirements of the Living Building Challenge was not widespread, educating the manufacturers became one of our primary roles in the process. A second lesson learned was to choose a simple palette of materials. Complex, composite materials necessitate spending additional time and effort in discussion and correspondence with the manufacturers to fully determine their suitability for the project. Despite the extensive research, many products specified for the project had small, unforeseen components that contained Red List substances, such as the neoprene gaskets found in illuminated exit signs. Ultimately, the project team's strategies of starting the research and selection process early and keeping the material palette simple helped the project achieve the challenging set of sustainable objectives.

EARLY LESSONS PURSUING THE LEED v4 MATERIALS AND RESOURCES CREDITS

SUSIE WESTRUP*, SUSTAINABILITY SPECIALIST, BALFOUR BEATTY CONSTRUCTION

In November 2012, after Gensler and Balfour Beatty Construction won a contract to build two additions to a warehouse and distribution center, our design/build team and the environmental and logistics managers of the client elected to participate in the LEED v4 beta program.

The client, an ISO 140001-certified company, was already a leader in energy efficiency, reduction of greenhouse gases from logistics, and improvement in operations processes, and desired a sustainable project. Everyone saw this as a chance to be early adopters of LEED’s new Warehouses and Distribution Centers standard.

Gensler

Required Submittal Form: LEED BD+C v4 Beta, Warehouses & Distribution Centers - New Construction

The LEED Criteria Worksheet is relevant to LEEDv4 Beta Rating System, MR Credit 1-4 and IEQ Credits 2, addressed below. Please complete the sections below and provide information required by LEED. Gensler seeks to support the achievement of LEEDv4 requirements by assessing the information provided on this submittal form, to evaluate whether the project can meet the LEED requirements. Be sure to fill out all fields and check Yes/No/NA for every question below.

Subcontractor:	Submittal No.:
Name of person filling out this form:	Date:
Product Manufacturer:	Model/Description:
Total Product Cost (Excluding labor and tax):	Is this cost estimated or actual?

WHOLE BUILDING LIFE CYCLE ASSESSMENT: MR Credit 1, Option 4
Has this product conducted a life-cycle assessment and have available data sets to evaluate environmental impacts in compliance with ISO 14044? Yes No

If so, does the product meet any of the following impact measures for reduction?

- Global warming potential (greenhouse gases) in Co2e; Yes No
- Depletion of the stratospheric ozone layer, in kg CFC-11; Yes No
- Acidification of land and water sources, in moles H+ or kg SO2; Yes No
- Eutrophication, in kg nitrogen or kg phosphate; Yes No
- Formation of tropospheric ozone, in kg NOx or kg ethane; and Yes No
- Depletion of nonrenewable energy resources, in MJ Yes No

ENVIRONMENTAL PRODUCT DECLARATION (EPD): MR Credit 2, Option 1
Does this product meet one of the disclosure criteria below?

- Product *specific* declaration in conformance to ISO 14044 publicly available with cradle to gate scope Yes No
- Industry wide *generic* declaration in conformance to ISO 14025, 14040, 14044, and 21930 with third party certification (Type III) with a cradle to gate scope Yes No
- Product *specific* declaration in conformance to ISO 14025, 14040, 14044, and 21930 with third party certification (Type III) with cradle to gate scope Yes No

MULTI ATTRIBUTE OPTIMIZATION: MR Credit 2, Option 2
How many miles is this product sourced within the project site? _____ miles
Does the product meet one of the attributes below?

- Product purchased from the manufacturer participates in an extended or direct producer responsibility program Yes No
- Participates in three of the certifications that verify impact reduction in under impact Measures from MR Credit 1, Option 4 Yes No

RAW MATERIAL SOURCE & EXTRACTION REPORTING: MR Credit 3, Option 1
Does this product have publicly released report from their raw material suppliers in the form of one of the following Corporate Sustainability Reports (CSR)?

- Global Reporting Initiative (GRI) Sustainability Report Yes No

The LEED v4 beta would also give our team opportunity to go beyond delivering a v4-certified project by attempting the Building Product Disclosure and Optimization credits and assessing the status of the market. In our pursuit of these particular credits, the team gave subcontractors a new product submittal form (Figure 1) to be filled out for each material. Our sustainability specialists then reviewed these submittals for the required LEED v4 information.

Most subcontractors knew what to provide for a LEED 2009 project and simply included that information, but the higher level of disclosure about health and environmental safety was a new frontier. The incomplete forms and submittals—none contained enough information for us to document any LEED v4-compliant materials—indicated that most subcontractors needed help in obtaining information from their suppliers.

Figure 1. Gensler LEED v4 submittal form (page 1 of 5)
Courtesy: Gensler

* Now Manager, Paladino and Company

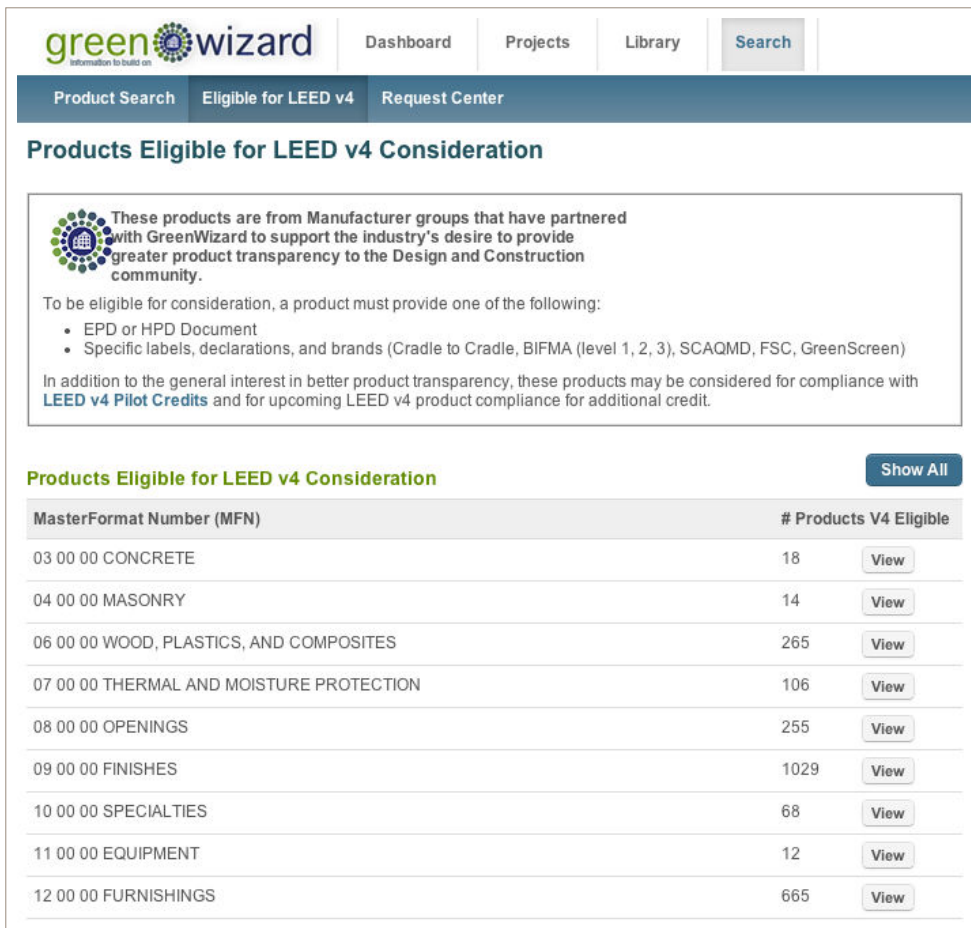


Figure 2. GreenWizard product search with v4 criteria field
Courtesy: GreenWizard, Inc.

In an attempt to get the required data through other channels on a tight schedule, we reviewed the list of materials and identified manufacturers known to have sustainability professionals. We contacted several paint and carpet manufacturers, only to be told that health and environmental product declarations (HPDs and EPDs) and LEED v4 product data were a work in progress: the data would not be available in time for our LEED review. Manufacturers were aware that the requirements for LEED v4 were imminent, but as v4 beta participants, we were ahead of the market.

GreenWizard, the cloud-based software solution for LEED project

management and product tracking, was also reaching out to its contacts at building materials manufacturers to get related product data for LEED v4. Using the GreenWizard product search engine, we located an Armstrong World Industries EPD for the ceiling tiles specified for the project. At that time, no other materials from the project were listed in GreenWizard's "Eligible for LEED v4" list. (Since then, the list has expanded to include multiple products in each specification section; see Figure 2.)

LESSONS LEARNED

From the materials selection process for this project, we learned how little information was available in the market in 2013 (though involving the LEED and design consultants in the process may have resulted in more v4-qualified materials for future projects). The subcontractors' submittal forms showed the gaps in supply chain knowledge of v4 changes and allowed us to distinguish manufacturers with proven sustainability performance and LEED expertise from their peers.

Obtaining information from steel and concrete manufacturers was particularly critical because they supply the largest percentage of the total materials for warehouse and distribution centers.

New specifications and documentation for these industries are becoming available: EPDs have been released by the Metal Construction Association¹ and the National Ready Mixed Concrete Association,² for example.

Although the project did not achieve any points for materials with EPDs and HPDs, the exercise was beneficial in preparing all parties for future projects. We were reminded that engagement with our supply chain is fundamental, as it was with previous versions of LEED. And it was clear that manufacturers need to have dedicated sustainability employees and other resources to ensure transparency and optimization of building materials.

Meanwhile, as the supply chain improves, sustainable design and construction professionals must convince client stakeholders, developers, and brokers of the value of more healthful and environmentally sustainable building materials.

¹ Metal Construction Association, *Environmental product declarations* (2013), <http://www.metalconstruction.org/EPDs>.

² National Ready Mixed Concrete Association, *NRMCA EPD Program* (2013), <http://www.nrmca.org/sustainability/EPDProgram/>.

PRODUCT TRANSPARENCY IN PRACTICE

AMANDA KAMINSKY, SENIOR SUSTAINABILITY MANAGER, THE DURST ORGANIZATION

JOHN AMATRUDA, PRINCIPAL, VIDARIS, INC.

BILL WALSH, EXECUTIVE DIRECTOR, HEALTHY BUILDING NETWORK

The Durst Organization (TDO) has a long history of developing environmentally responsible buildings that reduce energy and water consumption, incorporate innovative design strategies and technologies, and promote the well-being of their occupants. In 2012, at the onset of developing three new multifamily, mixed-use buildings in New York City, we developed a company-specific green building policy that combined lessons learned from previous green projects with new environmental goals. The goals included an aggressive emphasis on building occupant and ecological health, and the use of newly defined product transparency data to make informed product selections. Pursuing these goals required a more integrated process between TDO and our designers, construction teams, and consultants, as well as detailed interactions with various product manufacturers.

One of the first things we realized is that product transparency integration requires a mix of professional expertise. Collecting and evaluating the new information available through EPDs, HPDs, emissions testing, and other sources require both a robust outreach effort and the technical background to understand the data. We have subsequently developed an expanded project team that includes TDO's dedicated sustainability project managers, green building consultants with an in-house industrial hygienist (Vidaris), materials health research experts (Healthy Building Network), and sustainability project managers at the construction management companies assigned to each project.

This expanded team, working in close coordination with the project designers, trade contractors, and product manufacturers, has proven critical in meeting our combined procurement goals: to select products with improved health and sustainability profiles while also meeting critical performance, aesthetic, schedule, and cost parameters.

We started by identifying a set of “focus materials”—material types we felt had the highest potential for health or environmental impacts due to likely exposure and/or scale of application—within each specification section. Examples range from paints and carpet tiles to kitchen cabinetry, countertops, gypsum wallboard systems, concrete, and duct insulations and sealants.

For each focus material, we assembled initial sustainability characteristics based on rating systems, standards, and criteria culled from our team's knowledge base. These parameters guided the initial materials selections proposed by our design teams. As products were proposed, we worked with manufacturers to obtain product transparency resources, with an emphasis on health and environmental product declarations (HPDs and EPDs), emissions testing data, European Commission REACH reporting, GreenScreen analyses, and Declare or Cradle to Cradle certifications. This expanded information was then evaluated both to iteratively vet the proposed products and to recalibrate our sustainability characteristics (which ultimately become integrated

into the specifications). The sustainability research was consistently checked against performance and costs to ensure that proposed products were acceptable to all parties.

Data for many products are becoming more available, and in some cases we've found enough information to perform a "deep dig"—comparing EPDs on multiple similar products while also using HPD data and/or evaluations from the Healthy Building Network's Pharos tool and other resources. We've found that the combination of use-phase health data along with life cycle environmental data gives the most complete profile of a product or material type.

LESSONS LEARNED

It's been somewhat surprising to realize how often the data present trade-offs that require further team dialogue for careful prioritization. We've found that it's rare for a product or product type to be clearly superior in all pertinent areas to a competing product. Table 1, for instance, shows how our assessments of carpet tile backings varied between environmental and health-related profiles. Note that product 1A has higher environmental impacts than products 2A and 2B based on EPD data alone. The product content assessment data, however, indicate that product 1A avoids hazardous compounds more than the other listed options.

These situations require the following approaches:

- Look into the issues behind the data (e.g., what factors cause the products to score higher or lower in the evaluations). A set of preferred-product sustainability criteria often begins to emerge even if an "ideal" product can't be identified.
- Use other performance criteria as screens to assist in the selection process. This requires critical judgments from the whole project team to make selections that best meet integrated performance, health, and environmental goals.

One final issue is how best to communicate the advantages of our decisions. A method we are currently testing is the Avoided Hazards Index, developed by the Healthy Building Network. In this process, the amount of hazardous material in a given product is quantified based on HPDs or other information. It's then possible to estimate the quantities of hazardous substances that have been avoided through the informed selection process, compared with one or more alternatives.

For example, we have calculated that for a 50,000-square-foot installation of carpet tiles in residential corridors, the use of carpet backing type 1A (from Table 1) would avoid approximately 4,750 pounds of persistent bioaccumulative toxicants and 1,650 pounds of astmagens, compared with product type 2C. Although no product may be perfect, these reductions represent significant next steps toward our stated goals of developing more ecologically responsible buildings with reduced health hazards.

Table 1. Carpet tile backing comparison, EPD and product content evaluations

Manuf.	Product #	EPD Cradle to Gate Impacts (Higher impacts in red, lower impacts in green)					
		GWP	ODP	Acidification	Eutrophication	Smog	Total Primary Energy
		kg CO2-Eq	kg CFC11-Eq	mol H+ eq	kg N eq	kg O3 eq	MJ
Mfr 1	Type 1A (Baseline)	11.90	1.1 E-06	2.60	0.024	0.59	195.0
Mfr 2	Type 2A	-47%	-1%	n/a	-96%	-39%	-46%
Mfr 2	Type 2B	-16%	-5%	n/a	-61%	-22%	-12%
Mfr 2	Type 2C	-4%	17%	n/a	-85%	-7%	43%
Mfr 3	Type 3A	75%	595%	12%	-86%	30%	98%

Manuf.	Product #	Product Content Assessment (Primarily obtained from the Pharos Tool)							
		Direct Content Hazard	Potential Residual Hazards	Meets Product Content Exclusions					
				Formald. Cmpnds.	PFCs	Phthalates	Flyash	Asphalt	Anti-microbls.
Mfr 1	Type 1A (Baseline)	Medium (Respiratory)	Very High (PBT)	Y	Y	Y	Y	Y	Y
Mfr 2	Type 2A	High (Cancer)	Very High (PBT)	Y	Y	N	N	Y	N
Mfr 2	Type 2B	High (Cancer)	Very High (PBT)	Y	Y	N	Y	Y	N
Mfr 2	Type 2C	Very High (PBT)	Very High (PBT)	Y	Y	Y	Y	N	N
Mfr 3	Type 3A	Very High (PBT)	Very High (PBT)	N	N	N	Y	Y	N

BUILDING HEALTH CARE FACILITIES THAT SAFEGUARD HUMAN HEALTH

MARA BAUM, HEALTHCARE SUSTAINABLE DESIGN LEADER, HOK

St. Bartholomew's is a 300-bed cancer and cardiac center in London. The Royal London Hospital is an 800-bed women's, children's, and general hospital. Together they constitute the largest teaching, research, and care facility in Europe. The Royal London is now complete; St. Barts will be fully complete in 2016.

The team incorporated the following materials goals into the project:

- High health and safety standards, including low-emitting materials.
- Elimination of 10 "Red List" hazardous substances: arsenic, cadmium, lead, mercury, acrylamide (monomer), asbestos, brominated flame retardants, halons (CFC and HCFC), PCBs and PCTs, and phthalates.
- Select reuse of demolished material, both on site and for private buyers.
- Innovative off-site prefabrication techniques that reduce on-site waste.
- Products transported via returnable transit packaging.
- 100% wood certified through either the Forest Stewardship Council or the Program for the Endorsement of Forest Certification.



The facade manufacturer for the Royal London Hospital removed cadmium from the panel formulation.

Photo: Angus Kennedy / Courtesy: HOK

These goals helped the project achieve an Excellent rating from the National Health Service's Environmental Assessment Tool, used to help develop the Building Research Establishment Environmental Assessment Method (BREEAM) for Health. BREEAM sets standards for best practices in sustainable design of large structures in the United Kingdom.

This project is being delivered via the private finance initiative (PFI) approach commonly used for public projects in the United Kingdom: a consortium finances, designs, builds, and operates the facility. The overall Red List process was initiated and primarily managed by Skanska, the Swedish construction and development company. HOK, a U.S.- and U.K.-based architecture-engineering firm, also played a critical role in product evaluation and selection as the executive and design architect and interior designer.

The team was particularly motivated by the function of the buildings and didn't want an oncology hospital with materials that were known carcinogens if alternatives

were available. The team also recognized that the project would help shape health care design practices for years to come, in addition to providing a healthful environment for the patients, staff, visitors, and contractors who would be constructing and working in the building. Educating the extended team, from designers to manufacturers, was a very important part of this process.

Early research was a critical step to meeting the project goals, particularly for the emissions and toxicity criteria. Each supplier had to identify high-VOC or Red List materials during project planning, allowing the early elimination of potentially harmful substances; it's much easier to eliminate a product option before it's designed into the project than it is to remove it later. If no alternative was available for a Red List substance, the team had to present its research to senior management before the product could be included in the project. Contractors were heavily involved from the outset, further enabling early efforts in researching products and avoiding hazardous substances.

LESSONS LEARNED

In some cases Skanska worked closely with manufacturers to try to change product formulations and other environmental criteria. This partnership was essential to our ability to achieve our goals. For example, the Royal London is clad in 1,200 blue panels. The manufacturer previously used cadmium to achieve a range of blue colors, but through collaboration with Skanska and HOK, it successfully replaced cadmium with cobalt, a less harmful alternative.

This substitution, however, illuminates another lesson: just because an alternative product is less toxic, it's not necessarily free of harm. Although cobalt is considerably more benign, most of this element is mined in the Democratic Republic of Congo under a challenged political system. Replacing a more toxic product with a socially problematic one raises difficult questions. Cobalt is a clear winner from a toxicity perspective, but it's not a cut-and-dry issue.

The rigorous materials selection process yielded several Red List exceptions: lead shielding, mercury in fluorescent lamps, and cadmium in NiCd batteries. For example, there is currently no alternative to lead shielding in imaging suites; its ability to block x-rays and gamma rays is necessary to protect the health of building occupants. The fact that more exemptions were not introduced, however, is telling: many alternatives were available. The exemptions also reflect a specific era in construction: the exemption for mercury in fluorescent lamps, for example, may not have been needed today.

Skanska and HOK have both brought expertise and lessons learned from this project to other work, beyond the health care sector. Skanska also became a member of the international cross-sector ChemSec Business Group. Based in Sweden, ChemSec is a coalition of like-minded companies that are trying to raise public awareness about toxic materials and identify alternatives that will reduce their use.

PROMOTING HEALTH THROUGH HEALTHY BUILDING MATERIALS AT DELL CHILDREN'S MEDICAL CENTER OF CENTRAL TEXAS

GAIL VITTORI, CO-DIRECTOR, CENTER FOR MAXIMUM POTENTIAL BUILDING SYSTEMS

**MICHELE VAN HYFTE, MANAGER, ENVIRONMENTAL STEWARDSHIP,
SETON HEALTHCARE FAMILY**

PHILLIP RISNER, SR., PROJECT MANAGER, SETON HEALTHCARE FAMILY



Dell Children's patient room.

Photo: Marc Swendner / Courtesy: Seton Healthcare Family

Dell Children's Medical Center of Central Texas (Dell Children's) is the first hospital in the world to achieve Platinum certification under both LEED for New Construction and LEED for Healthcare. From its inception, we made it a priority to align every aspect of the project to promote health—from the health and well-being of construction workers on the site, to the healthfulness of materials and products specified and installed, to the health and well-being of our patients and employees.

Starting with the initial LEED charrette in 2003, healthy materials were integral to Dell Children's overall LEED and sustainability goals for the base building design and, later, the W.H. and Elaine McCarty South Tower. Using product manufacturers' data, we evaluated materials options along a spectrum of performance, cost, durability, and maintenance parameters prior to a final procurement decision.

Dell Children's leaders believed that creating the greenest hospital possible was consistent with its healing mission and that its example could serve as a beacon to inspire others. They had support for these efforts within a broader sustainability framework undergirding the hospital campus's three major development phases: the base building, completed in 2007; the MRI Suite addition, completed in 2010; and the W.H. and Elaine McCarty South Tower—a third patient bed tower—completed in 2013. Seton leaders viewed the healthy materials strategy as contributing to a continuum of healthcare.

Our materials selection approach recognized that exposure to carcinogenic, persistent bioaccumulative toxic (PBT) and endocrine-disrupting chemicals in building materials had

potential adverse health outcomes—something particularly relevant to a healthcare organization with health promotion embedded in its mission. Our materials priorities for the project included the following:

- nontoxic materials
- materials that do not release toxic byproducts throughout their life cycle, including
 - heavy metals (e.g., mercury in lighting and in mechanical equipment such as switches and relays; lead in roof flashing and solder; lead and cadmium in paints)
 - urea formaldehyde in engineered wood products
 - PVC in flooring, wall coverings, plumbing pipe, and electrical wiring

We also prioritized materials with recycled, regional, rapidly renewable content and low VOC (volatile organic compound) emissions.



Dell Children's interior main entrance.
Photo: Marc Swendner / Courtesy: Seton Healthcare Family

Dell Children's most recent construction, the McCarty South Tower, opened in 2013. It benefited from the base building's early emphasis on healthy materials and also from LEED for Healthcare's new prerequisites and credits addressing avoidance of PBT chemicals, such as lead, mercury, and cadmium, and chemicals of concern in furniture and medical furnishings. The project team also pursued two LEED pilot credits that expanded the breadth of chemical avoidance: Pilot Credit 2, PBT Source Reduction: Dioxins and Halogenated Organic Chemicals; and Pilot Credit 11, Chemical Avoidance in Building Materials (Phthalates).

LESSONS LEARNED

At the time the South Tower project began, the new LEED for Healthcare credits and two pilot credits were just launched and new to the market. For many on the design team, the expanded materials scope was unfamiliar territory: we had to learn new terminology and evaluative criteria, and it extended the scope of information needed from

manufacturers. This was also new territory for product manufacturers, which had to update their product data sheets with information relevant to these new criteria.

The design and construction teams needed time to identify compliant products that met expanded performance parameters and obtain verifiable documentation from manufacturers. The *Green Guide for Health Care*, a reference standard for LEED for Healthcare, was a valuable resource providing how-to information.

The team's experience highlights the cost and performance challenges of responding to customer demand in this early-phase innovation cycle, particularly regarding PVC avoidance. In some cases, such as irrigation piping, PVC-free HDPE options were available though prohibitively expensive; in others, such as operating room flooring, PVC-free options lacked the requisite performance attributes. In both cases, PVC options were ultimately procured.

The approach to materials selection is informing materials selection for the new Dell Seton Medical Center at The University of Texas—Seton's future teaching hospital, opening in 2017—also pursuing LEED for Healthcare certification. These market signals from consumers to manufacturers, along with health-related declarations and certifications, will drive market transformation, position healthy materials as an achievable criterion, and bring a broader range of cost-competitive and high-performing products to the market.

Dell Children's is part of the Seton Healthcare Family, a member of Ascension, the nation's largest Catholic and nonprofit healthcare system. It is a freestanding pediatric medical facility and the only Level I Pediatric Trauma Center in a 46-county area that includes Austin. For more information about the Dell Children's Medical Center of Central Texas, visit www.dellchildrens.net.

HEALTHFUL ENVIRONMENTS AT KAISER PERMANENTE

KATHY GERWIG, VICE PRESIDENT, EMPLOYEE SAFETY, HEALTH AND WELLNESS AND ENVIRONMENTAL STEWARDSHIP OFFICER, KAISER PERMANENTE

JOHN KOULETSIS, VICE PRESIDENT, FACILITIES PLANNING AND DESIGN, KAISER PERMANENTE

GAIL VITTORI, CO-DIRECTOR, CENTER FOR MAXIMUM POTENTIAL BUILDING SYSTEMS

Kaiser Permanente is a not-for-profit health care provider and insurer with nearly 10 million members. The company is based in Oakland, California, and operates in eight states and Washington, D.C. It has a long-standing commitment to find alternatives to materials containing chemicals that, based on credible evidence, could be harmful to human health. This commitment was articulated in a 2008 statement: “Our aim is to advance an economy where the production and use of chemicals are not harmful for humans or the environment.”¹



Westside Medical Center waiting area, Hillsboro, Oregon.

Photo: Jennifer MacDaniel / Courtesy: Kaiser Permanente

Annual construction budgets at Kaiser Permanente typically exceed \$2 billion, in addition to ongoing operations and maintenance for its 75 million square feet of hospitals, clinics, medical offices, and related facilities. This magnitude of purchasing power has catalyzed market transformation toward more healthful products and materials. Our environmentally preferable purchasing program has enabled us to identify strategic opportunities and contract for safer products and materials while ensuring competitive pricing and equal or better performance for all key performance measures.

A recent example of this commitment to safer products and materials was Kaiser Permanente’s 2014 policy decision to prohibit our suppliers from providing furnishings containing chemical flame retardants, which are typically used to meet flammability standards. Many of these flame retardants, such as polybrominated diphenyl ether (PBDE), are manufactured with halogenated chemicals, including chlorine and bromine. Exposure to these chemicals is linked to a spectrum of adverse health conditions, including endocrine disruption, reproductive toxicity, and cancer.

¹ <http://share.kaiserpermanente.org/article/environmental-stewardship-safer-chemicals/>.

Until January 2014, the ability to act on these concerns was hampered by California's flammability standard (Technical Bulletin 117), which could be met only through the use of halogenated flame retardants in furniture and other products. California's new version of the flammability standard, Technical Bulletin 117-2013, can be met without flame retardant chemicals. That regulatory change made it possible for us to specify furnishings without chemical flame retardant treatments.

Kaiser Permanente's public announcement of new furniture purchasing standards, as well as our partnership with Health Care Without Harm, raised awareness throughout the health care sector about these chemicals. This prompted other hospitals and health care systems to also specify furnishings without chemical flame retardant treatment. The aggregate result is about \$50 million annually in furniture and furnishings without chemical flame retardant treatment.

That is just one action Kaiser Permanente is taking to leverage market pressure toward healthful, high-performing, environmentally preferable building materials. Among the others:

- collaborating with the marketplace to develop new fabric products that eliminate substances of concern, such as polyvinyl chloride (PVC), heavy metals, and volatile organic compounds;
- working with suppliers to create carpet that is PVC-free, made from recycled content, and fully recyclable; and
- purchasing PVC-free resilient flooring, hand and crash rails, and other building materials.

To foster greater environmental performance across the entire health care sector, Kaiser Permanente regularly collaborates with governmental and nonprofit organizations, such as Health Care Without Harm and the U.S. Green Building Council, to increase public awareness and promote public dialogue on the importance of environmental stewardship and creating healthy communities. Kaiser Permanente is also a founding member of the Healthier Hospitals Initiative, a collaboration of major health systems and NGOs working collectively to reduce the sector's environmental footprint. Collaboration is one of the themes of the new book by Kaiser Permanente's Kathy Gerwig, *Greening Health Care: How Hospitals Can Heal the Planet*. Using examples from across health care, it describes opportunities for health care to lead the way to health-promoting environments.

ROLE OF TRANSPARENCY IN CREATING A HEALTHY AND HIGH-PERFORMING BUILT ENVIRONMENT

**PRIYA PREMCHANDRAN, [E]TEAM DESIGN AND CONSTRUCTION PROGRAM LEAD,
GOOGLE REAL ESTATE & WORKPLACE SERVICES (REWS)**

At Google, we apply the same focus to office buildings that we do for our technology products: put the user first. We are committed to creating the healthiest work environments possible where Googlers around the world can thrive and innovate.

People spend up to 90% of their time indoors, where the level of pollutants may be two to five times—and occasionally more than 100 times—higher than outdoor pollutant levels. The potential impact of the built environment on human health is inescapable. Google's Healthy Materials Program was created to bridge the gap between data and knowledge and to create a new paradigm that views sustainability and user experience through the lens of human health and well-being. Using a data-driven approach informed by Google's values of user experience, health, and sustainability, we also strive to provide accurate and relevant information that empowers teams to make informed decisions that will transform our workplaces.



Google office in Mountain View, CA.
Courtesy: Google, Inc.

Started in 2010, Google's Healthy Materials Program seeks to eliminate toxics and harmful man-made chemicals from all Google building projects globally. Supported by Google's Real Estate & Workplace Services (REWS) group, the program engages in a rigorous screening process, sending out detailed information requests to manufacturers and their supply chain, asking for complete transparency about their product ingredients.

Based on the responses received, our internal Healthy Materials Program software tool evaluates the data for completeness and compliance with Google's transparency and material health criteria. The products and materials that meet those criteria are prioritized for specification and installation on the projects.

Starting with two pilot projects in 2010 in the United States, the program quickly expanded to include all global projects in 2012. We work closely with Google project teams in establishing performance metrics and processes for product and materials selection. Though the Healthy Materials Program is intended to support Google building projects, it also presents an opportunity to catalyze the transformation of the broader industry and thereby accelerate the creation of healthier indoor environments for everyone.

Our material health and transparency criteria are based on established global industry standards that address materials health content and emissions, such as the Health Product Declaration, GreenScreen for Safer Chemicals, Cradle to Cradle Certified, and volatile organic compound content and emissions standards. This enables manufacturers to provide product information in a consistent and transparent format across Google's projects globally.

Creating processes and tools that worked across different scales of projects and in different regions, spanning more than 100 Google offices in over 50 countries, was instrumental to establishing and maintaining a relevant and accessible global program, especially in regions where standards vary from the U.S. market or are nonexistent. This approach allowed Google to leverage existing industry standards instead of inventing new ones. The alignment with existing industry standards also supported Google's intent to create a framework and a process that was scalable and replicable outside of Google.

Product information transparency and understanding the human health impacts may seem to be incremental changes. However, both are stepping stones to creating transformational changes that will lead to products optimized for human and environmental health.

SUCSESSES, CHALLENGES, AND LESSONS LEARNED

In addition to eliminating toxics and harmful man-made chemicals in building products, the program demonstrates feasibility for other companies and organizations to take leadership in seeking product transparency and creating healthy, productive workplaces. Similar to any innovative idea coming to the marketplace, the Healthy Materials Program processes and criteria required a lot of interpretation, adjustment, and refinement as we continued to learn more about the challenges and opportunities within the industry. Although the lack of examples to draw from was a challenge, it was also an opportunity to test, launch, and iterate new methods and tools and build a platform for continuous improvement while adapting to changes in the marketplace.

Since its inception, the Healthy Materials Program has evaluated and approved more than 3,200 products. Tools and resources were helpful in illustrating the “what” and “how” behind the effort, but communicating the “why” meant creating long-term relationships and building trust. To date, some 1,500 manufacturers are participating and supporting the program by sharing Google’s vision. The Healthy Materials Program stakeholders and collaborators are working together and establishing combined ownership of a future with healthy and high-performing built environments for everyone, including broader industry.

OPEN LETTERS THAT URGE TRANSPARENCY

ANNE HICKS HARNEY, SUSTAINABILITY DIRECTOR, AYERS SAINT GROSS

How do you inspire change and innovation? How, as an architect, do you make your voice heard in service of getting better products?

Architects design the size and shape of buildings, then render these environments using available building products. Choosing appropriate products is complex, but with environmental and health concerns added to the categories we review, our focus is increasingly on removing detrimental products from our built environment. So how do we accomplish this?

Banning substances by using restricted substance lists is one method, but many people resist additional rules and regulations. We are a market-based economy where goods and services, provided they meet basic requirements, are selected based on supply and demand. We must look to the market and find ways to influence the choices being made.

Since July 2013, Ayers Saint Gross has been involved in a market-based initiative to encourage change and provide a model for moving forward with materials transparency efforts. With other midsize to large architecture firms, we have written open letters to building product manufacturers encouraging and challenging them to provide information about product contents and their associated environmental effects and health hazards. This has resulted in change: the lesson is, make clear what we expect and require, communicate this effectively, and the market will react.

Our effort was initiated by a network of sustainability-focused architects known as A+D Sustainable Design Leaders. Members connect on a common blog to share information, discuss common themes, and provide support and encouragement. A summit is held annually where members engage in wide-ranging discussions on current topics, new ideas, and innovative goals. One goal from the 2013 summit was this letter-writing campaign.



Architecture firms that participated in the letter writing campaign.

Image: Anne Hicks Harney

To date this network has published 30 letters in the marketplace. The letters introduce the concept of materials transparency and give a brief explanation of Health Product Declarations and environmental product declarations, but their purpose is to convey a very simple request:

To understand how our decisions affect human health and the environment, we are asking for you to share information about product contents and their associated environmental and health hazards.

Seven of these letters provided specific and deadline-driven requests, stating that products that did not provide product content transparency would not be allowed in office product libraries or selected for inclusion on projects. The date listed in most of these letters was January 1, 2015.

The feedback we have received from manufacturers has been very positive, and we have been struck by the large number of companies indicating they were already actively working toward creating these documents. A steady stream of product declarations flows to our offices, and some product representatives have referenced our letters as being a driving force. There are so many declarations now available that our group is considering ways to gather these resources into a shared, accessible library.

LESSON LEARNED

These letters provide a great example of how architects and designers, simply by insisting on additional information, can make a difference. Any architecture or design firm can be a part of this effort by simply making “the ask”: write a letter, ask the question, persevere until a response is received, then use the information provided to make more-informed decisions. The more frequently product manufacturers hear the question, the better our chances of getting the information we need to make better product choices. And the more informed our product choices, the better our chances of improving the built environment.

ENGAGED SUPPLY CHAINS ARE CRITICAL TO CREATING HPDs: A COMPARATIVE CASE STUDY

**LISA BRITTON, DIRECTOR OF SALES & MARKETING,
SUSTAINABILITY CHAMPION, INDUSTRIAL LOUVERS, INC.**



Alpar's products, like this corner guard, are simple assemblies.
Courtesy: Alpar Architectural Products, LLC



ILI's products, like this sunshade, help reduce energy loads. Attention to human health is new.
Courtesy: Industrial Louvers, Inc.

Building an accurate Health Product Declaration (HPD) is a challenging exercise for any organization. I have led the process with two organizations: Alpar Architectural Products, LLC, and Industrial Louvers, Inc. (ILI). Although each company has different products and unique challenges, the shared component of success was engaged and informed suppliers.

I founded Alpar Architectural Products, LLC, in 2009. My mission was to provide a more healthful alternative to polyvinyl chloride (PVC) wall protection. Alpar teamed with Interfacial Solutions IP, LLC (IFS), to develop deTerra®, the industry's first fire-rated, biobased polymer, for which Alpar has exclusive license in the construction industry. Alpar's ability to create a fully disclosed HPD began in the very early stages of product development, before the Health Product Declaration Collaborative was established.

The official HPD journey started in 2010, when Alpar was one of 29 manufacturers that participated in the HPD pilot. Because Alpar's competitive advantage was based on providing material without known toxicants, the HPD was an important development that allowed us to lend credibility to our claims. The team at IFS understood this, and rather than resisting disclosure, they worked closely with Alpar to report chemical information completely and correctly. By the time we published an HPD under version 1.0, we also had the support of Natureworks, LLC, supplier of polylactic acid (PLA), the primary ingredient in deTerra biobased polymer.

Having simple product formulations also helped us complete HPDs with limited resources. The deTerra material, a cross-linked PLA, has only two ingredients in its untinted form. Extruded and molded parts are either affixed to the wall with adhesive or combined

with aluminum extrusions. Our first HPDs were based on assemblies with untinted material, our most popular option. Building HPDs that included pigments proved more challenging because colorant suppliers were resistant to sharing information, but eventually they allowed us to share known hazards without disclosing chemical names.

In 2012 Alpar was acquired by the Pawling Corporation, which continued to support disclosure efforts. Pawling realized that because deTerra's competitive advantage was based on its nontoxic formulation, the reward for disclosure outweighed the risk of revealing what most companies would consider trade secrets.

ILI's products posed a different set of opportunities and new challenges for creating HPDs. Unlike Alpar, which developed products with the understanding that disclosure was eminent, ILI had to persuade legacy suppliers to support disclosure.

ILI is a manufacturer of custom architectural metal products, most of which are installed on building exteriors; louvers, sunshades, and equipment screens constitute most of our business. Most products are made from aluminum extrusions that are mechanically fastened together and then finished in-house with a Kynar® finish. Our products, particularly sunshades, are used as part of green building strategies, and the sustainable building market is central to our business. Commitment to reducing our environmental impact is engrained in our culture and operations, so attention to chemical safety in our plant is paramount. Despite this, awareness of potential human health hazards of chemicals in our finished products is new, primarily because market drivers, including the LEED rating system, have until now virtually ignored exterior products.

Although we were committed to HPDs, initially we were not optimistic about being able to publish meaningful data. Our products are rarely used without finishes, which commonly contain health hazards. Paint companies are notorious for protecting their color formulations, considered trade secrets, but one of our major paint suppliers, Valspar, brought on a toxicologist with experience in creating and verifying HPDs. She worked with other experts within her company and with our staff to disclose all the known chemical hazards in the products we use. Our unusually engaged and educated supply chain allowed us to assemble meaningful information, and now ILI expects to be the first in our product sector to publish HPDs under version 2.0.

Both Alpar and ILI had limited resources to devote to creating HPDs, so having relatively simple product formulations enabled both companies to be early adopters. HPD version 2.0 incorporates improved tools, but complex assemblies and products will still pose challenges. Whatever new tools are available, manufacturers can produce accurate HPDs only with cooperation from their supply chains. Market demand for transparency and tools for educating the supply chain will be critical.

ELEVATING HEALTH AND ENVIRONMENTAL CONCERNS

BRAD NEMETH, VICE PRESIDENT, SUSTAINABILITY, THYSSENKRUPP ELEVATOR AMERICAS

ThyssenKrupp Elevator Americas is the largest producer of elevators in the Americas, with more than 15,500 employees and 230 branch and service locations. The company understands that with its size comes environmental and corporate responsibility. We also take our social responsibility initiatives very seriously, making sure there is equality in diversity, race, and gender, plus fair wages and excellent working conditions both within our workforce and among our suppliers.

As a team, the sustainability group has four main objectives: (1) to reduce the company's overall carbon footprint; (2) to eliminate as much waste as possible from decreased productivity and manufacturing inefficiencies, as well as physical, chemical, and material waste; (3) to create customer-centric solutions by working closely with business partners to improve energy efficiencies through upgraded processes and products; and (4) to maintain a high level of social responsibility.

In 2008, we began working with thinkstep (formerly PE International) to perform an audit to help devise a long-term sustainability strategy. The audit uncovered many opportunities for improvement and cost reduction. It also facilitated a greater understanding of the challenges we face and the need to gather metrics to track progress.



Two elevator cabs travel independently—one above the other in the same shaft.

TWIN saves space, reduces passenger travel time, and saves energy.

Courtesy: ThyssenKrupp Elevator

After establishing a strategy to reduce the company's overall footprint, address problem areas, and determine the best approach to meet transparency and disclosure market requirements, our joint team implemented thinkstep's GaBi software platform for life cycle assessment (LCA). With GaBi, we were able to identify materials used at ThyssenKrupp Elevator and quickly pull together a list of substances occurring throughout the life cycle of our products.

The results of the LCA and high-level chemical inventory became the foundation for our company's entire sustainability program. With a thorough inventory of products, we were able to identify areas in which energy and high-VOC ingredient reductions were possible. As a result of this work, we built the first low-emitting elevator cab to meet California's strict indoor air quality standards, an achievement that demonstrates market leadership and strengthens our competitive advantage.

In addition to supporting the initial ingredient inventory, thinkstep urged us toward an even more extensive goal: to provide full transparency in all of our products and processes by creating environmental

product declarations (EPDs). Once our LCA and EPD development processes began, the team progressed toward providing additional transparency into materials. The first step was to identify all ingredients and hazards throughout the supply chain.

To gain additional insight into the full human and environmental impacts of the chemicals in our products, we partnered with ToxServices to pursue the Cradle to Cradle Material Health Certificate (MHC). This is a rigorous, third-party assessment conducted by ToxServices that identifies chemicals in a product down to 100 ppm, assesses all inputs for hazards against 24 human and environmental endpoints, and considers exposure throughout the life cycle.

Through these efforts, ThyssenKrupp Elevator was the first elevator company to publish an HPD, a Declare label, and an MHC, allowing us to communicate to employees, partners, customers, and elevator passengers that ThyssenKrupp Elevator values sustainability and materials transparency. Developing assessments for elevator systems is no small task. Our elevators comprise many distinct functional systems, from electronics and motors to the actual interior cab itself. For truly credible transparency, all of these components needed to be evaluated thoroughly.

These actions elevated our status among prospects, partners, and other audiences demanding full disclosure of all materials used in production throughout the supply chain. In concert with on-going EPD, HPD, and MHC development, we also finalized an enterprise-wide implementation of the thinkstep SoFi platform for tracking and exporting ingredient and environmental data with a high degree of accuracy. This platform enables our team to simply and easily report corporate responsibility metrics, successes, goals, and projections to ThyssenKrupp stakeholders.

Building a cohesive team and using the GaBi and SoFi solutions in conjunction with the thinkstep knowledge base of more than 20 years have been critical to the success of the far-reaching sustainability initiatives at ThyssenKrupp Elevator.

SPEED EPDATING

SEBASTIAN GANN, PROJECT MANAGER FUTURE LIGHTING SOLUTIONS
ACHIM STRAUB, TRAINING MANAGER CUSTOMER DIALOGUE MANAGEMENT,
ZUMTOBEL GROUP

The Zumtobel Group is a leading global player in the lighting industry, represented in the professional luminaire and lighting solutions business by the Thorn and Zumtobel brands and in the lighting components business (control gear, lighting management, LED components and modules) by the Tridonic brand.

Because of growing sustainability concerns and rising interest in green building practices, the Zumtobel Group was receiving as many as 10 customer requests per week for product-specific environmental data. We knew that demand would only keep growing.

With sustainability high on our business agenda, we identified the need to create environmental product declarations (EPDs) for a vast and varied product portfolio across our core brands. EPDs indicate the environmental performance of products and form the basis of our ecodesign strategy as well as a competitive advantage in an increasingly environmentally conscious market.



*i+R Group headquarters, Lauterach, Austria
Photo: Markus Deutschmann / Courtesy: Zumtobel Group*



*La Ronde Couture, Charleville Meziere, France
Photo: Joss Guest / Courtesy: Thorn Lighting*

The Zumtobel Group's innovative approach for generating ISO 14025- and EN 15804-compliant EPDs is based on a process we established that links product-specific data from our Enterprise Resource Planning (ERP) system to environmental information from thinkstep's GaBi database. Working in conjunction with thinkstep consultants, we built a platform over the course of two years that has made the generation of EPDs extremely cost and time efficient.

We began by evaluating our product-specific ERP data and improving their integrity so that this information could be accurately mapped to environmental impact for scoring. Within one year, we were able to introduce the Environmental

Scorecard and Monitor, cocreated with the Swiss EMPA institute (the Swiss Federal Laboratories for Materials Science and Technology). These tools serve as design guidance and help reduce the footprint of our products. The necessary data are based on the platform used to make EPDs.

We have built an automated system to generate EPDs and to date have created more than 1,000. What initially took months is now possible in hours, and customers can quickly and easily obtain EPDs for products by downloading them from the online catalog. The easy availability of EPD data saves time and reduces project management complexity for our customers.

EPD data are now included in the Zumtobel Group's life cycle cost tool, ecoCALC. This allows us to consider environmental factors when analyzing and optimizing the life cycle of lighting solutions for price, energy consumption, and maintenance.

LESSONS LEARNED

Our biggest internal challenges continue to be maintaining a consistent and clean materials database and ensuring high data quality throughout the process. The external tasks include developing and maintaining the underlying environmental models with thinkstep and working with the Institute for Construction and Environment, an independent EPD verifier nominated by the program holder. Working with the verifier while establishing the system was critical for success. It is important to note that the system requires ongoing maintenance of materials and regular audits by an EPD verifier to stay up to date.

Systems connections, such as with the Enterprise Resource Planning system, were rather straightforward. This type of system requires only read access and does not change other business data.

What is the outlook for EPDs? As a possible next step, we see the integration of EPD data into building information modeling. This should lead toward a holistic, sustainable, and integrated approach to new building design.

THE PROCESS OF CONTINUOUS IMPROVEMENT

**HOWARD WILLIAMS, SENIOR VICE PRESIDENT, SUSTAINABILITY,
CONSTRUCTION SPECIALTIES, INC.**

Construction Specialties, Inc. (C/S) has had a solid sustainability initiative for 20 years. In 2003, for example, we received the Pennsylvania Governor’s Award for Environmental Excellence for our work removing certain hazardous air pollutants and persistent organic pollutants from our manufacturing processes, establishing material recovery programs, and repurposing a circa-1930 manufacturing facility.

The May 2007 announcement that USGBC would award Innovation in Design credits for applying Cradle to Cradle (C2C) product certification¹ motivated us to expand our sustainability initiatives. Although the Innovation credit was the only “market call” for C2C certification at the time, we felt it was a leading signal. This certification articulated, and in some ways even animated, our vision of sustainability. Its multiattribute approach was a practical and cultural fit with how we do business.

We are the proverbial “belt and suspenders” company: a single test or attribute claim is never sufficient. For example, the Acrovyn line of wall coverings meets code requirements for interior finishes with its Class 1/Class A flame spread and smoke development performance. However, we would not make that claim without third-party verification from UL’s Certification Mark services. We apply this same standard of performance to our sustainability, material health, and environmental claims through Cradle to Cradle certifications.

Our first C2C certification was for Acrovyn 3000, a non-PVC product. Acrovyn 3000 was developed specifically for Kaiser Permanente and the emerging materials health market; it was first

used at Hackensack University Medical Center, completed 2005. Although market awareness of C2C certification was limited at the time, the University of California–San Francisco at Mission Bay was being designed by Anshen+Allen and McDonough Architects. The owner’s requirements were to “include materials that have undergone unprecedented assessment to eliminate most known toxic elements.”²

When we presented our C2C Silver Acrovyn 3000 coverings to Anshen+Allen as the candidate material

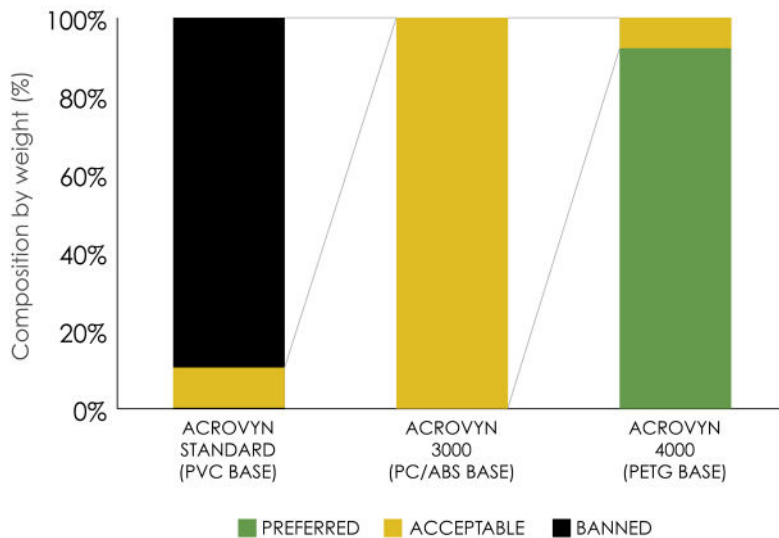


Figure 1. Material health optimization of Acrovyn polymer base (excluding metal attachment)

Courtesy: Cradle to Cradle Products Innovation Institute

1 <http://www.facilitiesnet.com/green/article/USGBCs-System-Now-Awards-quotInnovation-in-Designquot-Credits-for-Applying-Cradle-to-Cradle-Product-Certification--6671>

2 <http://missionbayhospitals.ucsf.edu/about-project/faq>

for this project, Mara Baum, the architect, challenged us to seek C2C Gold. And thus began the deeper optimization of Acrovyn (Figure 1).

In 2010, we introduced Acrovyn 4000, a product line free of PVC and persistent bioaccumulative toxicants. Working with McDonough Braungart Design Chemistry (MBDC), we progressed through C2C’s materials assessment and achieved C2C Gold certification of Acrovyn 4000 in 2012 (Figure 2).



Figure 2. Acrovyn 4000 product scorecard
 Courtesy: Construction Specialties, Inc. and Cradle to Cradle Products Innovation

LESSONS LEARNED

The optimization process is one of continuous improvement. MBDC’s extensive materials knowledge was essential, as was the involvement of C/S staff members from research and development, purchasing, and project management, who helped us gain the support and trust of our supply chain partners.

Two challenges were obtaining a complete list of material ingredients down to 100 ppm, and protecting confidential business information. Nondisclosure agreements between the manufacturers and MBDC, the independent third party, gave our supply chain the sense of security necessary to ensure their participation.

of the important role that the built environment plays in human health and wellness.”³ The Cradle to Cradle Impact Study and Technical Report⁴ details the economic, environmental, and social effects of optimization. Figures 1 and 2 from our own impact study give another perspective on the dramatic product optimization that can be achieved when using a rigorous multiattribute scheme.⁵

Making a business case for optimization is required for acting on the “rapidly growing understanding

Sustainable architecture is not an end, it is a beginning. Both USGBC and C2C have answered the hard “prove it” questions, showing themselves to be environmentally effective, relevant, and qualified to drive the optimization of buildings and products. These two protocols were set in motion by visionaries seeking to move sustainability beyond its static state and into pragmatic and scalable platforms for change.

LEED v4 Materials and Resources positions optimization as its transformative imperative. C2C’s multiattribute protocol answers that imperative within its holistic framework of total sustainability. LEED and C2C combine to define the purpose and the process by which companies like ours can optimize their products and processes in ways that are innovative, healthful, and certifiably supportive of sustainable architecture.

3 <http://www.aia.org/aiaucmp/groups/aia/documents/pdf/aiab100279.pdf>

4 <http://www.c2ccertified.org/impact-study>

5 http://s3.amazonaws.com/c2c-website/resources/FINAL_Construction_Specialties_narrative_formatted.pdf

GLOSSARY.

ABRASION the wearing away of a solid surface by friction (EPA I-BEAM)

ACIDIFICATION POTENTIAL a measure of acidifying compounds, such as sulfur oxides and nitrogen oxides, that are emitted to air and can fall to earth through rain, fog, snow, or dry deposition, contributing to the acidification of lakes, streams, rivers, oceans, and soil, where the effects can harm plants and animals

ACUTE EFFECT an adverse effect on any living organism in which severe symptoms develop rapidly and often subside after the exposure stops (EPA Pesticides Glossary)

ADMINISTRATIVE CONTROL a measure designed to minimize the potential for human exposure to contamination by changing the way workers do their jobs

AGGREGATE EXPOSURE the combined exposure of an individual (or defined population) to a specific agent or stressor via all relevant routes (e.g., inhalation, ingestion, and dermal absorption) and sources (adapted from EPA Exposure Factors Handbook)

ALTERNATIVES ASSESSMENT a process for identifying, comparing, and selecting safer alternatives to chemicals of concern

ASTHAGEN a substance that causes new cases of asthma. Some substances act both as asthmagens and as asthma triggers in people who already have the disease.

BIOACCUMULATION the increasing concentration of a toxic substance in a living organism as it takes in contaminated air, water, or food because the substance is very slowly metabolized or excreted (adapted from EPA Exposure Factors Handbook)

BIOMIMICRY an approach to innovation that seeks sustainable solutions to human challenges by emulating natural patterns and strategies (adapted from the Biomimicry Institute)

BIOMONITORING the assessment of human exposure to chemicals by measuring chemicals or their metabolites in such specimens as blood or urine (CDC Fourth National Report on Human Exposure to Environmental Chemicals)

CARCINOGEN a substance that can cause or contribute to cancer (EPA I-BEAM)

CHEMICAL ABSTRACTS SERVICE (CAS) REGISTRY NUMBER a unique numerical identifier assigned by the Chemical Abstracts Service to every chemical substance described in scientific literature

CHEMICAL HAZARD ASSESSMENT an evaluation of the potential harm a substance may cause

CHEMICAL RISK ASSESSMENT an evaluation of the potential harm a substance may cause, the dose-response relationship, and the extent of exposure to the substance

CHEMICAL SUBSTITUTION the replacement of a chemical of concern with a safer alternative

CHRONIC EFFECT an adverse effect on a human or animal in which symptoms recur frequently or develop slowly over a long period of time (EPA Terms of Environment)

CLEANER PRODUCTION an approach to product improvement that involves the continuous application of an integrated process to identify opportunities to prevent harm to humans and the environment at all stages of a product's life cycle

CRADLE TO CRADLE the extension of a cradle-to-grave assessment to include recycling as the end-of-life disposal step for a product (adapted from AIA Guide to Building Life Cycle Assessment in Practice)

CRADLE TO CRADLE CERTIFIED a multiattribute standard run by the Cradle to Cradle Products Innovation Institute that promotes continuous improvement in a product through five levels of certification

CRADLE TO GATE the assessment of a product life cycle from raw materials extraction and manufacture (cradle) to the factory gate (i.e., before it is transported to the consumer) (adapted from AIA Guide to Building Life Cycle Assessment in Practice)

CRADLE TO GRAVE a full life cycle assessment, from raw materials extraction and manufacture (cradle) through the use phase and to the disposal phase (grave) (adapted from AIA Guide to Building Life Cycle Assessment in Practice)

DEMATERIALIZATION (1) in manufacturing, the alteration of a process or product to avoid waste or use less material without loss of function; (2) in design, the avoidance or reduced use of material without loss of function

DERMAL ABSORPTION a route of exposure by which substances enter the body through the skin (EPA Exposure Factors Handbook)

DETOXIFICATION the reduced use of toxic substances throughout a product's life cycle through development and use of safer chemical and design substitutes

DIOXIN any one of a family of complex but related chlorinated organic chemicals with similar chemical structures and biological activity formed unintentionally by industrial processes and incomplete combustion

DISCLOSURE the reporting by manufacturers about product ingredients, impacts, or other attributes to the public or to third parties

DOSE the amount of a substance to which an organism is exposed and takes in

ECOTOXICITY POTENTIAL a measure of how chemicals affect the environment, including its organisms

EMBODIED ENERGY the amount of energy consumed to produce a product. This includes the energy needed to mine or harvest natural resources and raw materials and to manufacture and transport finished materials (EPA Top Green Home Terms).

ENDOCRINE DISRUPTOR a synthetic chemical that disrupts normal endocrine system functions in humans and wildlife by blocking or mimicking hormones (EPA Chesapeake Bay Glossary)

ENDPOINT (HEALTH) the effect of exposure to a toxic chemical, such as carcinogenicity or reproductive toxicity (EPA Risk-Screening Environmental Indicators Glossary)

ENGINEERING CONTROL a design measure built into a manufacturing plant, equipment, or process and intended to minimize the potential for human exposure to contamination by either limiting direct contact with contaminated areas or controlling migration of contaminants (EPA RCRA profile definitions)

ENVIRONMENTAL PRODUCT DECLARATION (EPD) a standardized format for communicating the environmental effects associated with a product's or system's raw materials extraction, energy use, chemical makeup, waste generation, and emissions to air, soil, and water

EUTROPHICATION POTENTIAL a measure of emissions of nitrogen and phosphorus, nutrients that can cause rapid growth of plant life (e.g., algae in water bodies) whose decay depletes oxygen needed by fish and other organisms

EXPOSURE contact with a substance through inhalation, ingestion, or dermal absorption

EXTENDED PRODUCER RESPONSIBILITY measures undertaken by the maker of a product to accept its own and sometimes other manufacturers' products as postconsumer waste at the end of the product's useful life

FUNCTIONAL UNIT the quantity of product needed to serve an intended purpose, including any auxiliary products that may be required for a complete system

GLOBAL WARMING POTENTIAL a measure of emissions of carbon dioxide and other greenhouse gases that can contribute to climate change

GLOBALLY HARMONIZED SYSTEM (GHS) FOR HAZARD CLASSIFICATION AND LABELLING OF CHEMICALS a system created by the United Nations that uses internationally standardized criteria to classify chemicals according to their health, physical, and environmental hazards, with a globally consistent set of graphics and hazard statements for each hazard category

GREEN CHEMISTRY the design of chemical products and processes that reduce or eliminate the generation of hazardous substances

GREENSCREEN FOR SAFER CHEMICALS a hazard assessment method for individual ingredients and more complex mixtures that helps manufacturers prioritize chemicals of concern and plan for phaseout or find alternatives, and assists in procurement and risk management

GREENSCREEN LIST TRANSLATOR an abbreviated version of the full GreenScreen method that maps authoritative and screening hazard lists to specific hazard endpoints and classification levels, enabling quick identification of some hazardous ingredients

GROUND-LEVEL OZONE FORMATION POTENTIAL a measure of "smog," or ground-level ozone, created by chemical reactions between air pollutants and sunlight

HALOGENATED FLAME RETARDANT (HFR) an organic chemical containing bromine or chlorine that helps resist or inhibit the spread of fire

HAZARD a substance with the potential to cause harm

HEALTH PRODUCT DECLARATION (HPD) a standardized format, managed by the Health Product Declaration Collaborative, for reporting building product contents and their known associated hazard data

HYDROLYSIS the decomposition of organic compounds by interaction with water (EPA Terms of Environment)

INGESTION a route of exposure by which substances enter the body through the mouth

INHALATION a route of exposure by which substances enter the body through the act of breathing

ISOCYANATES a class of highly reactive chemicals used in the manufacture of flexible and rigid foams, fibers, coatings, and elastomers

LEACHING the migration of water- or oil-soluble compounds from materials into the environment

LIFE CYCLE ASSESSMENT (LCA) a standardized process for quantifying the inputs, outputs, and potential environmental impacts of a product from cradle to grave

LIFE CYCLE THINKING an informal thought process for considering all of a product's impacts from cradle to grave

MATERIAL SAFETY DATA SHEET (MSDS) a manufacturer-provided form that contains brief information regarding chemical and physical hazards, health effects, proper handling, storage, and personal protection appropriate for use of a particular chemical in an occupational environment. MSDSs are being replaced by safety data sheets under the Globally Harmonized System (adapted from EPA Environmentally Preferable Purchasing Glossary).

MUTAGEN a substance that can induce an alteration in the structure of DNA (EPA IRIS Glossary)

NEUROTOXICANT a substance that can damage the central nervous system

OPTIMIZATION the use of human health, environmental, and other product information by project teams to select preferable materials and products, and by manufacturers to improve materials and products

OXIDATION a process, such as burning or rusting, that involves the formation of oxides through reaction with oxygen

PERFLUORINATED CHEMICALS (PFCS) a group of fluorine-containing organic chemicals used to make products more resistant to stains, grease, and water. Also known as perfluorochemicals.

PERSISTENT, BIOACCUMULATIVE, AND TOXIC SUBSTANCE (PBT) a highly toxic, long-lasting substance that can build up in the food chain to levels that are harmful to human and ecosystem health (EPA PBT Chemical Program)

PERSISTENT ORGANIC POLLUTANT (POP) a chemical substance that persists in the environment, bioaccumulates through the food chain, and poses a risk of harming human health and the environment (adapted from the United Nations Environment Programme)

PHOTODEGRADATION the rearrangement or breakup of molecules with exposure to sunlight

PHTHALATE one of a class of chemicals used to soften and increase the flexibility of plastic and vinyl. The term phthalates typically refers to ortho-phthalates or phthalate esters. These are distinct from terephthalates, which have a different chemical structure and may have different biological activity.

POLYBROMINATED DIPHENYL ETHER (PBDE) one of a class of bromine-containing organic chemicals used as flame retardants

PRECAUTIONARY PRINCIPLE an approach to risk management that advocates measures to prevent harm when serious or irreversible damage is possible but scientific consensus is lacking

PREFERABLE MATERIAL a substance with desirable human health and environmental attributes that delivers comparable or improved function, durability, and maintainability

PREFERENTIAL SELECTION the choice of products that meet particular design goals and purchasing criteria

PREVENTION THROUGH DESIGN a strategy for avoiding occupational injuries, illnesses, and fatalities by eliminating hazards and minimizing risks early in the design or redesign process and incorporating methods of safe design into all phases of hazard mitigation

PRODUCT CATEGORY RULE (PCR) a set of specific rules, requirements, and guidelines for developing environmental declarations for one or more products that can fulfill equivalent functions. The PCR determines what information should be gathered and how that information should be evaluated for an environmental declaration.

PROGRAM OPERATOR an organization that oversees the development and verification of an environmental product declaration

REDESIGN an approach to product innovation that relies on existing materials and formulations to eliminate the use of undesirable ingredients or processes

REFORMULATION an approach to material or product innovation that replaces an undesirable ingredient with a better alternative

REGISTRATION, EVALUATION, AUTHORISATION AND RESTRICTION OF CHEMICALS (REACH) a European Union regulation that requires all chemicals produced or imported in high quantity into countries of the European Union to be registered in a central database and prioritized for evaluation and possible avoidance based on their hazard profiles

REPRODUCTIVE AND DEVELOPMENTAL TOXICANT a substance that damages fertility, sexual function, and normal prenatal or early childhood development

RESTRICTED SUBSTANCES LIST (RSL) a list of substances that a given organization has determined to avoid based on regulation or evidence of potential human health or environmental harm. Also referred to as a “red list.”

RIGHT TO KNOW the legal principle that individuals should have access to information about potential chemical hazards, uses, and environmental releases in their communities and the workplace

RISK the likelihood that a living organism will be harmed if exposed to a hazard

SAFETY DATA SHEET (SDS) a manufacturer-provided form that contains brief information regarding chemical and physical hazards, health effects, proper handling, storage, and personal protection appropriate for use of a particular chemical in an occupational environment. SDSs are replacing material safety data sheets under the Globally Harmonized System (adapted from EPA Environmentally Preferable Purchasing Glossary).

SEMIVOLATILE ORGANIC COMPOUND (SVOC) a carbon-containing (organic) substance that volatilizes relatively slowly at typical ambient conditions

STRATOSPHERIC OZONE DEPLETION POTENTIAL a measure of emissions, like chlorofluorocarbons and halons, that can degrade the ozone layer

SUBSTANCE OF VERY HIGH CONCERN (SVHC) as defined by the REACH regulation covering countries in the European Union, a chemical or material that may have serious and often irreversible effects on human health and the environment

SUPPLY CHAIN the linear flow of constituent materials along an increasingly complex string of custody. Raw materials suppliers are considered “upstream” and product manufacturers are “downstream.”

SUSTAINABLE PRODUCT DESIGN an approach to product design that considers not only life cycle negative health and environmental impacts but also social and economic benefits to communities, workers, and others. Also known as design for sustainability.

SYNERGISTIC EFFECT a biologic response to multiple substances in which one substance worsens the effect of another substance. The combined effect is greater than the sum of the effects of the substances acting by themselves (adapted from CDC Agency for Toxic Substances and Disease Registry Glossary).

TOXICANT a poisonous substance that is naturally occurring (e.g., arsenic), synthetic (e.g., bisphenol A), or produced by a living organism (i.e., a toxin)

TOXICITY the degree to which a substance can cause harm

TOXIN a poisonous substance produced by a living organism, such as a snake, bee, or fungus. Toxins are a subclass of toxicants.

VOLATILE ORGANIC COMPOUND (VOC) a carbon-containing (organic) substance that volatilizes readily at typical ambient conditions

VOLATILIZATION the conversion of a chemical substance from a liquid or solid state to a gaseous vapor state (EPA Waste and Cleanup Risk Assessment Glossary)

WHOLE-BUILDING LIFE CYCLE ASSESSMENT an analysis of the cumulative energy use and other environmental consequences resulting from all phases of a structure’s life cycle. Such assessments are used to optimize structural and enclosure systems.