Design for the Next Generation
Incorporating Cradle-to-Cradle Design into Herman Miller Products

Mark Rossi, Scott Charon, Gabe Wing, and James Ewell

Summary
In the late 1990s, office furniture manufacturer Herman Miller, Inc., entered into a collaboration with architect William McDonough to create a system for designing cradle-to-cradle products. This collaboration led to the creation of a tool—the Design for Environment (DfE) product assessment tool—that evaluates progress towards cradle-to-cradle products. The first product Herman Miller designed using the DfE product assessment tool was the Mirra chair. Over the course of the chair’s development, the DfE process generated a number of design changes, including selecting a completely different material for the chair’s spine, increasing recycled content in chair components, eliminating all PVC (polyvinyl chloride) components, and designing the chair for rapid disassembly using common tools.

The areas of greatest success in designing the Mirra chair for the environment were the increased use of recyclable parts and increased ease of disassembly, whereas the areas of greatest challenge were increasing recycled content and using materials with a green chemistry composition. The success in recyclability reflects the use of metals, materials that have a well-established recycling infrastructure. The success in disassembly reflects the high degree of control that Herman Miller has over product assembly. The challenge to increasing recycled content is the use of plastics in chairs. Unlike the metals, which all contain some recycled content, most plastics are made from virgin polymers. The challenge to improving materials chemistry is the limited range of green chemicals and materials on the market.

The Mirra chair exemplifies the value of incorporating the environment into design and the need for tools to benchmark progress, as well as the challenges of creating a truly cradle-to-cradle product. Herman Miller recognizes that working toward cradle-to-cradle products is a journey that will involve continuous improvement of its products.
Introduction

If humans are truly going to prosper, we will have to learn to imitate nature's highly effective cradle-to-cradle system of nutrient flow and metabolism, in which the very concept of waste does not exist. To eliminate the concept of waste means to design things—products, packaging, and systems—from the very beginning on the understanding that waste does not exist. It means that the valuable nutrients contained in the materials shape and determine the design: form follows evolution, not just function. (William McDonough and Michael Braungart, 2002)

In their 2002 book, Cradle to Cradle, architect William McDonough and chemist Michael Braungart issued a challenge to manufacturers to change how they design products and to make them truly compatible with ecological systems. For McDonough and Braungart (2002), it is not sufficient to make products that are merely “less bad” products—that is, products (and processes to create products) that make incremental steps toward reduced toxic or solid waste generation, energy use, or ecological impacts—because such products are still unhealthy for ecological systems. To move from less bad to cradle-to-cradle products requires making products from biological and technical nutrients. “Biological nutrients” are safe and healthy materials that create food for natural systems across their life cycle. “Technical nutrients” are materials or products that can be continuously and safely recycled into new materials or products (McDonough and Braungart 2002).

It was through dialogue with William McDonough in the 1990s that the office furniture manufacturer Herman Miller decided to establish a Design for Environment (DfE) program to meet the cradle-to-cradle challenge. Herman Miller's decision emerged from a corporate culture that has nourished environmental stewardship. Back in the 1950s, then CEO D. J. De Pree stated that Herman Miller would “be a good corporate neighbor by being a good steward of the environment.” That environmental awareness led the firm to construct green buildings that fit into their community in the 1970s and to establish a comprehensive corporate-wide environmental program in the 1980s. By the 1990s, Herman Miller had received a Pioneer Award from the U.S. Green Building Council for the energy efficiency and site design features in its GreenHouse—a combined manufacturing plant and office space built in collaboration with McDonough.

In agreeing to develop cradle-to-cradle products, Herman Miller made a decision that would affect its product development process and the tools it uses for analyzing environmental performance. This article examines how Herman Miller is implementing the cradle-to-cradle system through the example of one of its products, as well as the challenges confronted and lessons learned as the company works toward the design and manufacture of cradle-to-cradle products.

Setting the Context

The cradle-to-cradle system is an example of a “goal-driven” approach to addressing environmental problems: establish the goals to be achieved, and then develop the tools and metrics needed to measure progress and help achieve those goals. McDonough and Braungart have established the goal—cradle-to-cradle products made entirely from a combination of biological and technical nutrients—and through their firm (McDonough Braungart Design Chemistry or MBDC) and collaborations with companies such as Herman Miller, have developed the tools needed for evaluating progress toward cradle-to-cradle products.

The value of a goal-driven approach for addressing environmental problems is that it guides behavior to specified ends and it shapes the development of the tools that are needed to evaluate progress toward those ends. A good example of the goal-driven approach is the approach taken by Sweden, which in 1999 established 15 national environmental objectives and subsequently defined intermediate benchmarks to be achieved within one generation. Among the 15 objectives is achieving a nontoxic environment. “The environment must be free from manmade or extracted compounds and metals that represent a threat to human health or biological diversity” (Swedish Environmental Objectives Council 2004). To help achieve this goal, the Swedish Chemicals Inspectorate created a web-based tool—PRIO—for
evaluating the hazards associated with chemicals (Swedish Chemicals Inspectorate 2006).

Life-cycle assessment (LCA) is an example of a “tool-driven” approach to addressing environmental problems: use a tool to evaluate the environmental performance of a product or products, and then make improvements to the product (for example, see Graedel 2000) or make a product selection based on the conclusions the tool generates (for example, NIST BEES software [NIST 2006]). The value of a tool-driven approach, such as LCA, is that it informs ignorance—provides information and data where before there was little to none—and provides data about the relative environmental performance of products.

The danger of a tool-driven approach is that it comes to define the goals, or worse, the goals for using the tool are intentionally hidden. LCAs, for example, have a history of being used in support of and in opposition to specific product types by those with vested economic interests—for example, the disposable versus reusable diaper wars of the 1990s. In such cases the stated goal of the LCA is to evaluate the environmental performance of the products, but invariably the product of the funder of the LCA looks environmentally preferable, raising the question of hidden bias in the LCA.1

The diaper LCA wars illustrate the risks of tool-driven approaches: there is the potential that the debate will shift to the tool, the assumptions made, the data used, the boundaries drawn, and so forth, from the goals that are aspired to and how they will be attained. For example, in the case of diapers, a goal-driven approach would first define the goal—for example, design and manufacture of an ecologically healthy product for handling the bodily wastes of infants, toddlers, and incontinent adults—and then would select tools appropriate for making progress toward the goal. A goal-driven approach shifts the first-order question to what is desired rather than to the results the tool is capable of delivering.

Although goal-driven approaches still need tools, the difference is that tools are selected or designed to be in service of the goals. As with the choice of any analytic tool, a host of decisions must be made that will affect outcomes—that is, the degree of success in achieving the goal. Decision-making rules, assumptions, and algorithms need to be transparent; otherwise the tool is vulnerable to vested interests.

In setting the goal of creating cradle-to-cradle products, Herman Miller needed tools to facilitate progress toward this ideal. Similarly to other organizations implementing DfE programs, Herman Miller did not turn to quantitative LCA as its analytical tool. The need for other tools besides LCA in DfE has been remarked upon by others (Hoffman 1997; Sheng and Worhach 1998; Bauer and Sheng 2000), who have noted the limitations of LCAs in the design context—especially in the early design stages when the design process is fluid and the “size, material composition, and construction is not known” (Hoffman 1997). Another limitation of LCAs in the design context is the lack of the fine-grained analysis needed by the manufacturer. For example, Sheng and Worhach (1998) note the dependence of LCAs on historical data and the aggregation of data on an industrywide rather than site-specific level, neither of which meets the needs of designers. Moreover, LCA conclusions may be heavily influenced by impacts from a single issue area, such as energy, due to the availability of higher quality data in this area compared with other issue areas. The availability of such data may induce action to address a single concern (e.g., energy) and downplay the importance of other critical issues such as toxicity, design for disassembly, and design for recyclability (for example, see Stevels et al. 1999; Boustead 1999).

Product development at companies such as Herman Miller required an approach that is consistent with the increasingly rapid pace of bringing new designs to the market. Working with MBDC, Herman Miller developed the DfE product assessment tool, which evaluates the extent to which a product meets the goal of the cradle-to-cradle ideal—that is, made from 100% biological and/or technical nutrients. The tool allows Herman Miller to answer the following questions: Are the products using chemicals and materials that are safer for humans and the environment? What is the recycled content of a material? Can the material be disassembled easily from the product? LCAs are not designed to answer these questions. For example, most LCAs are an attempt
APPLICATIONS AND IMPLEMENTATION

Figure 1  Photo of the Mirra chair.

To systematically catalog material flows and selected impacts for every processing step, from raw material extraction through product disposal. Although well-designed LCAs can be used to compare materials and products, they typically do not evaluate the inherent hazards of a chemical input or the chemical composition of a material, particularly during use.2 LCAs do not meet the needs of a product development organization striving to create safer products for which the materials of construction can be used in closed-loop cycles.

Evaluating Progress toward Cradle-to-Cradle Products: The DfE Product Assessment Tool and the Mirra Chair

The first product Herman Miller ran through the DfE product assessment tool from design to production was the Mirra chair (see the photograph in figure 1). Over the course of the chair's development the DfE process generated a number of design changes, including selecting a completely different material for the chair's spine (a critical element in the chair's design that made possible better material safety characteristics), increasing recycled content in a number of components, eliminating all PVC components, and designing the chair for rapid disassembly using common tools.

MBDC's Materials Assessment Protocol

To evaluate the extent to which a product is manufactured using safe nutrients, Herman Miller works with MBDC to calculate a “material chemistry score” for the product. Figure 2 illustrates the eight key stages involved in calculating a product’s material chemistry score.

In the first stage Herman Miller asks its suppliers for the chemical constituents, down to 100 parts per million (ppm), of all of the components that are planned for use in a product from its suppliers. The threshold of 100 ppm was set to capture as many of the chemical inputs as realistically possible, recognizing that some chemicals are hazardous at 0.01% of the product. For the Mirra chair, this meant collecting data on 180 different components that are constructed largely from four material types: steel, plastic, aluminum, and foam. By weight, the material proportions of the chair are steel—56%, plastics—29%, aluminum—12%, foam—2%, and other—1%. Among “other” are the powder coatings used to coat steel and aluminum components.

Identifying the chemical constituents of the “other” materials—such as plastics, colorants, and coating finishes—proved to be exceptionally difficult. Constituents and formulations vary across the petrochemical supply chain. In addition, there are no industry standards as with metals, and the manufacturers consider their formulations proprietary.

Initial attempts to gather the data by emailing and faxing forms to suppliers failed: the suppliers did not respond with chemical constituent data of their products. It quickly became apparent that a much different approach would be required to gather these data: Herman Miller needed to develop closer relationships with its material suppliers. To gather the data, Herman Miller’s DfE team scheduled face-to-face meetings with over 200 members of its supply chain. After these face-to-face meetings, where Herman Miller explained the purpose of the data collection, how the data would be used, and that future business was contingent upon providing the data, nearly all the suppliers furnished data on chemical constituents after nondisclosure agreements were signed. To alleviate supplier concerns with
confidential business information (CBI), Herman Miller assigned a chemical engineer to be the sole proprietor of the CBI data.

Herman Miller’s preference is to work within its established supply chain, and it invests heavily in the education of suppliers about the goals and requirements of the DfE program. Supplier support of these goals is crucial. The usual interaction between the DfE team and a supplier is as follows: (1) introduce the DfE program and associated metrics; (2) explain the purpose of the material assessment process; (3) guide the supplier through the material inventory process; (4) provide feedback about the assessed materials; (5) work with supplier to find substitute inputs or, if necessary, new materials; and (6) if supplier refuses to provide data or is unable to make needed formulation changes, seek an alternative supplier. In the course of designing the Mirra, a supplier did refuse to disclose the additives used to manufacture its polypropylene plastic. Herman Miller selected another supplier that was willing to share its data.

When the chemical constituent data are received, they are entered into Herman Miller’s database and the formulation information is sent to MBDC—excluding supplier and product trade name—for assessment. The Mirra’s components involved 40 different materials constituted from 200 different chemicals.

**Figure 2** Herman Miller material chemistry evaluation process. MBDC = McDonough Braungart Design Chemistry.
In stage two, MBDC uses its materials assessment protocol—based upon a hazard assessment of each of the chemical constituents used to manufacture the material—to classify each material into one of four categories: green (little to no hazard), yellow (low to moderate hazard), orange (incomplete data), and red (high hazard) (McDonough et al. 2003). For each chemical constituent in a material, MBDC assesses its hazard profile on the basis of the human health and ecological endpoints listed in table 1 and assigns a color ranking for that chemical. Then MBDC assesses all of the chemical constituents of a material and assigns a color ranking for that material.

The method MBDC uses to rate a chemical as red, orange, yellow, or green—and then to aggregate these color ratings into a single color rating for a material—is not available to the public. Herman Miller, which has been made privy to the details of the material assessment protocol, is comfortable with the integrity of the protocol. Yet the fact that the protocol has not been independently verified remains an issue of concern to MBDC, which plans to have the method independently reviewed.

In stage three, MBDC evaluates how Herman Miller uses the materials and decides whether to adjust the rating downward, for example, from red to yellow, because of minimal exposure concerns. For example, carbon black if evaluated by itself would be red; carbon black is a known carcinogen when the fine particles are inhaled—a mechanical route of exposure. But if carbon black were used in a polymer where it was bound during its use and recycling phases, the assessment would change to yellow. Further details on the contextual filter method are not publicly available at this time.

In stage four, Herman Miller searches for alternatives to materials that were rated as red or orange by MBDC. Herman Miller’s goal for the Mirra chair and all new product launches is to use materials that rank yellow or better—that is, no red or orange. The target “red” materials and chemicals include brominated flame retardants (BFRs), hexavalent chromium plating, and polyvinyl chloride (PVC) plastic. All of these materials are manufactured with or contain chemicals that are persistent, bioaccumulative, and/or chronic toxicants.

Polyurethane foam containing BFRs was eliminated when the design team decided not to use traditional foam materials for seat and back support (see the photograph in figure 3 for absence of cushions among the Mirra parts). Interestingly, environmental concerns were not the motivating force behind eliminating the foam cushions. Rather, the motivation was to provide aeration for thermal comfort, which led to the development of the Airweav suspension fabric and the TriFle polymer back. These materials provide greater comfort than polyurethane foam while improving the chair’s performance. The elimination of foam cushions exemplifies how product
and environmental performance can be simultaneously enhanced through innovative design choices.

In 2001, Herman Miller made an organizational commitment to phase out the use of PVC plastic in new product launches wherever possible. According to MBDC’s material protocol, PVC is considered to be an ecologically inappropriate material because of its organochlorine content, its use and generation of chronic toxicants in manufacturing (including the known carcinogens vinyl chloride monomer and dioxins), and its generation of dioxins and furans when burned (including in incinerators) (see Thornton 2000; for MBDC’s position see Ewell 2005). Other factors motivating Herman Miller’s decision to phase out PVC use are customer demand for PVC-free products and shareholder opposition to PVC use.

Eliminating the possible use of PVC in the Mirra proved to be a significant challenge. During the design process, PVC was included as an engineering option for the armpad skin and jacketed cables. Task chairs, for example, typically contain PVC jacketed cables. In the Mirra, these were replaced at no additional cost with nylon jacketed cables. Armpad skins, however, were more of a challenge. PVC is the plastic commonly used to cover the foam padding used on armrests. In addition, the tooling for the armpads had already been designed and cut for PVC.

The challenge to the DfE team was to quickly find a suitable alternative to PVC armrest skins. Although armrests may seem to be trivial components on a task chair, the actual performance requirements are substantial. They include abrasion resistance, tear resistance, UV stability, and, most importantly, comfort. Abrasion resistance and comfort were the key barriers to finding suitable alternatives. The list of options included styrenic-based elastomers including SEBS (styrene ethylene butadiene styrene) copolymers and thermoplastic polyolefins (TPOs). Neither SEBS copolymers nor TPOs could provide the abrasion resistance required. In addition, the TPO alternatives were too tacky. All of the alternatives were more expensive than PVC. The purchasing team wanted to stay with PVC because it was a known entity with regard to performance and cost. The product team argued for launching the Mirra with PVC and then developing an alternative. The DfE team believed that changing the design after the product launch would be difficult, because engineering resources for evaluating alternatives would be reallocated to new projects and the cost baseline would be established using PVC.

Figure 3  Mirra parts. Left photograph: recyclable parts, 96% by weight. Right photo: nonrecyclable parts, 4% by weight—mixed plastic armpads (white parts), seat pan, and leaf springs (black parts).
The DfE team ended up recommending thermoplastic urethane (TPU), which met or exceeded all of the technical and environmental performance measures at a slightly higher cost than PVC. Senior management decided that the correct business decision, considering environment and economy, was to eliminate PVC from the Mirra chair. The higher costs of the TPU armpads were offset by other material and design choices that lowered the total cost of the chair (discussed below).

In stages five through seven, Herman Miller calculates a single material chemistry score for all of its products by

1. Identifying the weight of each component (stage five).
2. Multiplying the component’s weight by its material chemistry assessment color code, which is translated into a percentage—Green = 100%, Yellow = 50%, Orange = 25%, and Red = 0% (stage six).
3. Adding up the material chemistry weights of all products and dividing by the total weight of the products to calculate a material chemistry score for the entire product (stage seven).

Table 2 details how the material chemistry score is calculated for a fictional product, the ECO Chair.

Over the course of its development, the Mirra’s final material chemistry score increased from 48% for the initial design to 75% for the final chair. A key change that improved the material chemistry score was the elimination of the PVC-based products. The color code breakdown of materials by weight in the Mirra is as follows: Yellow = 51%; and Green = 49%. The green materials in Mirra include certain grades of steel and aluminum.

**Disassembly**

Herman Miller evaluates the ease of disassembling products based upon four questions:

1. Can the component be separated as a homogeneous material, with no other materials attached? Mixed materials, if inseparable, have little to no value in recycling programs. The goal is for disassembly to create individual components that may have value when recycled.
2. Can the component be disassembled using common tools—a screwdriver, a hammer, and a pair of pliers? The goal is for the chairs to be easily disassembled anywhere in the world.
3. Does it take less than 30 seconds for one person to disassemble the component? The product development team disassembled many products and concluded that 30 seconds is too long for any component to be removed.
4. Is the material identifiable and marked? If parts are not marked, then disassemblers will not know which recycling bin to place them in.

Each component receives a disassembly score of either 100%—if all four answers are “yes”—or 0%—if one or more answers are “no.” The disassembly score for each component is multiplied by the weight of the component to achieve a disassembly weight for each component. The final disassembly score is the ratio of the total disassembly weight to the total weight of the chair.

Table 3 illustrates how the disassembly score is calculated for a fictional product.

Herman Miller’s disassembly goal for all new product launches is 100%. The Mirra came close. Over the course of developing the Mirra, the chair’s disassembly score increased from 40% to 93% in the final chair. Many features were added to enhance ease of disassembly of the Mirra. Figure 3 presents all the components disassembled from the Mirra chair. The foam used in the arm pads and the suspension seat cannot be recycled because they contain multiple materials that are not easily separated.

The easiest change to make was labeling the parts for material content (Question #4). When material labeling is specified in the design phase, there is no additional upfront cost to Herman Miller. Herman Miller uses the American Society for Testing Materials’ standards for labeling components.

Based upon the experiences of the product team in disassembling products, changes were made to ease and quicken the disassembly rate. For example, arm pads, which are typically stapled
### Table 2  Material chemistry calculation for fictional product ECO Chair

<table>
<thead>
<tr>
<th>Part #</th>
<th>Qty</th>
<th>Description</th>
<th>Material—Print</th>
<th>Supplier</th>
<th>Wt (g)</th>
<th>Rating</th>
<th>Wt Credit (%)</th>
<th>Wt Credit (g)</th>
<th>Final Score</th>
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<td>Steel—SAE 1010</td>
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<td>50%</td>
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<td>123458</td>
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<td>Fastener Land</td>
<td>42</td>
<td>Green</td>
<td>100%</td>
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<td></td>
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<tr>
<td>123460</td>
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<td>Bumper</td>
<td>EPDM rubber</td>
<td>Importers R’Us</td>
<td>26</td>
<td>Orange</td>
<td>25%</td>
<td>6.5</td>
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<tr>
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<td>Molders Plus</td>
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<td>Yellow</td>
<td>50%</td>
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<td>Red</td>
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<td>0</td>
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**Note:** One gram (g) = 10^{-3} kilograms (kg, SI) ≈ 0.035 ounces (oz). GF = glass-filled; PU = polyurethane; EDPM = ethylene propylene diene monomer; RH = right hand; LH = left hand.

### Table 3  Disassembly assessment for fictional product ECO Chair

<table>
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<tr>
<th>Part #</th>
<th>Qty</th>
<th>Description</th>
<th>Material—Print</th>
<th>Supplier</th>
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<th>#2</th>
<th>#3</th>
<th>#4</th>
<th>Wt credit (%)</th>
<th>Wt (g)</th>
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<td>123456-BK</td>
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<td>20% GF polypropylene</td>
<td>Molders Plus</td>
<td>600</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>0%</td>
<td>0</td>
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<tr>
<td>123458</td>
<td>4</td>
<td>Fastener—PU</td>
<td>Sintered metal</td>
<td>Fastener Land</td>
<td>42</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>100%</td>
<td>42</td>
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<tr>
<td>123460</td>
<td>4</td>
<td>Bumper</td>
<td>EPDM rubber</td>
<td>Importers R’Us</td>
<td>26</td>
<td>Yes</td>
<td>Yes</td>
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to a rigid plastic substrate, were designed to slip on and off with no need for any mechanical attachments. The result in comparison to the typical task chair is dramatic. It takes less than 15 minutes to disassemble the Mirra, whereas it takes up to 60 minutes to completely disassemble an Ergon task chair that is constructed using a similar number of components.

**Recyclability + Recycled/Renewable Content**

Ideally, at the end of the useful life of a chair, the components can either be recycled over and over again into the same component or composted into healthy, nonhazardous biological nutrients for soil. Herman Miller evaluates the recyclability/compostability of a component based upon three criteria:

1. Is material a technical or biological nutrient and can it be recycled (or composted) within an existing commercial collection and recycling infrastructure? If yes, the component receives a score of 100%.
2. Can the component be down- recycled (recycled but into a lesser value product) and does a commercial recycling infrastructure exist to collect and recycle it? If yes, the component receives a score of 50%.
3. Is there no recycling potential or infrastructure for the product? If yes, the component receives a score of 0%.

The recyclability score for each component is calculated by multiplying the recyclability percentage by the weight of the component. The final recyclability score is the ratio of the total recyclability weight to the total weight of the chair (see table 4). Herman Miller’s goal for all products is to attain a recyclability ranking of 75%.

Recyclability is of particular concern for plastics, which are more difficult to recycle than metals with their well-established recycling infrastructure. Among the plastics commonly used in furniture products:

- Nylon 6 and PET (polyethylene terephthalate) can be depolymerized, thus theoretically making it possible to closed-loop recycle. A recycling infrastructure for PET bottle recycling built upon for engineering-grade PET materials is well established.
- The polyolefins—polyethylene (PE) and polypropylene (PP)—can be downcycled and a well-established recycling infrastructure exists for high-density PE (HDPE).
- The styrenic polymers—acrylonitrile butadiene styrene (ABS), high-impact polystyrene (HIPS), and polystyrene (PS)—and polycarbonate (PC) can all be downcycled, although the recycling infrastructure is not well developed.
- Polyurethane (PU), which is used in the Mirra armrests, lacks a well-developed recycling infrastructure, although it can be downcycled.
- Polyvinyl chloride (PVC) is a concern for the PET recycling industry, where it is a significant contaminant in the recycling process. If PVC is mixed into PET during reprocessing it can form acids that degrade the physical and chemical structure of PET, causing it to become brittle and yellow and lowering the value of the recycled PET (California Integrated Waste Management Board 2003; CWC 1997).
- Thermoset plastics (e.g., phenolic, urea, and melamine, as well as epoxy and certain catalyzed polyester resins) are not recyclable.

The nonrecyclable materials include a leaf spring made from a fiberglass-like composite and the pellicle-fiber seat, which is made from three different plastic fibers. Figure 4 illustrates the plastics recycling spectrum that has emerged at Herman Miller.

Over the course of developing the Mirra, the chair’s recyclability score increased from 75% to 83%. Figure 3 shows which parts of the Mirra are and are not recyclable. An important change made during the development of the chair to increase its recyclability was a change in the Y-spine design. This was originally designed from steel over-molded with a thin layer of plastic, which could not be recycled and certainly could not be disassembled (disassembling plastic coating from steel in less than 30 seconds is impossible). The DfE team challenged the engineer to create a sustainable component. The resulting
### Table 4: Recyclability + recycled/renewable content assessment for fictional product

<table>
<thead>
<tr>
<th>Part #</th>
<th>Qty</th>
<th>Description</th>
<th>Material—print</th>
<th>Supplier</th>
<th>Wt (g)</th>
<th>Wt credit (%)</th>
<th>Wt (g)</th>
<th>Recyclability score (%)</th>
<th>Recyclability content</th>
<th>Recyclability + rec./ren. content score</th>
</tr>
</thead>
<tbody>
<tr>
<td>123456-BK</td>
<td>1</td>
<td>FRAME, seat</td>
<td>Steel—SAE 1010</td>
<td>Frame Inc.</td>
<td>2,500</td>
<td>100%</td>
<td>2,500</td>
<td>28%</td>
<td>700</td>
<td>2050</td>
</tr>
<tr>
<td>123457</td>
<td>1</td>
<td>PAN—seat</td>
<td>20% GF polypropylene</td>
<td>Molders Plus</td>
<td>600</td>
<td>50%</td>
<td>300</td>
<td>0%</td>
<td>0</td>
<td>22.5</td>
</tr>
<tr>
<td>123458</td>
<td>4</td>
<td>FASTENER—PU</td>
<td>Sintered metal</td>
<td>Fastener Land</td>
<td>42</td>
<td>100%</td>
<td>42</td>
<td>20%</td>
<td>8.4</td>
<td>33.6</td>
</tr>
<tr>
<td>123460</td>
<td>4</td>
<td>BUMPER</td>
<td>EPDM</td>
<td>Importers R’Us</td>
<td>26</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>123461</td>
<td>4</td>
<td>CONNECTor clip</td>
<td>Nylon 6/6</td>
<td>Molders Plus</td>
<td>26</td>
<td>100%</td>
<td>26</td>
<td>0%</td>
<td>0</td>
<td>19.5</td>
</tr>
<tr>
<td>123464</td>
<td>2</td>
<td>ARM assy, RH &amp; LH</td>
<td>Aluminum—AA 380.0</td>
<td>Importers R’Us</td>
<td>404</td>
<td>50%</td>
<td>202</td>
<td>0%</td>
<td>0</td>
<td>151.5</td>
</tr>
<tr>
<td>123468</td>
<td>2</td>
<td>O-ring</td>
<td>Silicone</td>
<td>Importers R’Us</td>
<td>1</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Total:** 3,599 g, 3,070 g (85%), 708 g (20%), recomputed average: 2,967 g (69%)
innovative solution is the Mirra Y-spine, which is constructed from two nylon 6 components that are easily recycled and is less costly than the original steel design. In addition, Herman Miller created intellectual capital, because the design resulted in patentable technology that can be leveraged into new products.

The nonrecyclable materials include a leaf spring made from a pultruded thermoset composite, the AirWeave seat, which is made from three different plastic fibers, and the foam arm pads, which are a combination of PU foam permanently affixed to a plastic substrate.

Today, Herman Miller does not distinguish between postindustrial and postconsumer recycled content in calculating the recycled content score. Data for both types of recycled content are collected and both contribute to the recycled/renewable content score.

The method for scoring recycled/renewable content is straightforward: the percent weight of a component made from recycled or renewable content equals the recycled/renewable content score for that component. The recycled/renewable content score is multiplied by the weight of the component to achieve a recycled/renewable weight for each component. The final recycled/renewable score is the ratio of the total recycled/renewable weight to the total weight of the chair. Table 5 demonstrates how both the recycled/renewable content score and the combined score for recyclability and recycled/renewable content are calculated. The combined “recyclability and recycled/renewable content score” is a weighted average of recyclability (75% of the recyclability weight credit) and recycled/renewable content (25% of the recycled/renewable weight credit). The corporate-wide goal for new product launches is 50%. The Mirra almost attained that goal, with a recycled content level of 42%.

Herman Miller is working with its suppliers to maximize recycled content in its steel and aluminum products. For example, the initial tilt mechanism specified for in the Mirra was originally manufactured from virgin steel. Herman Miller changed the specification to steel with recycled content at no additional cost.
Table 5  Calculating the final DfE score for fictional product ECO Chair

<table>
<thead>
<tr>
<th>Part #</th>
<th>Qty</th>
<th>Description</th>
<th>Material</th>
<th>Supplier</th>
<th>Wt (g)</th>
<th>Potential DfE wt</th>
<th>Final score</th>
</tr>
</thead>
<tbody>
<tr>
<td>123456-BK</td>
<td>1</td>
<td>Frame, seat</td>
<td>Steel—SAE 1010</td>
<td>Frame Inc.</td>
<td>2,500</td>
<td>1,933.3</td>
<td>77.3%</td>
</tr>
<tr>
<td>123457</td>
<td>1</td>
<td>Pan—seat</td>
<td>20% GF polypropylene</td>
<td>Molders Plus</td>
<td>600</td>
<td>175.0</td>
<td>29.2%</td>
</tr>
<tr>
<td>123458</td>
<td>4</td>
<td>Fastener—PU</td>
<td>Sintered metal</td>
<td>Fastener Land</td>
<td>42</td>
<td>39.2</td>
<td>93.3%</td>
</tr>
<tr>
<td>123459</td>
<td>4</td>
<td>Fastener—ST</td>
<td>EPDM rubber</td>
<td>Fastener Land</td>
<td>1</td>
<td>0.8</td>
<td>76.7%</td>
</tr>
<tr>
<td>123460</td>
<td>4</td>
<td>Bumper</td>
<td>Nylon 6/6</td>
<td>Importers R’Us</td>
<td>26</td>
<td>10.8</td>
<td>41.7%</td>
</tr>
<tr>
<td>123461</td>
<td>4</td>
<td>Connector clip</td>
<td>Aluminum—AA 380.0</td>
<td>Molders Plus</td>
<td>26</td>
<td>10.8</td>
<td>41.7%</td>
</tr>
<tr>
<td>123464</td>
<td>2</td>
<td>Arm assy, RH &amp; LH</td>
<td>Silicone</td>
<td>Importers R’Us</td>
<td>404</td>
<td>84.2</td>
<td>20.8%</td>
</tr>
<tr>
<td>123468</td>
<td>2</td>
<td>O-ring</td>
<td>Steel—SAE 1010</td>
<td>Importers R’Us</td>
<td>1</td>
<td>0.0</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Part #</th>
<th>Qty</th>
<th>Description</th>
<th>Material</th>
<th>Supplier</th>
<th>Wt (g)</th>
<th>recyclability (g)</th>
<th>Final score</th>
</tr>
</thead>
<tbody>
<tr>
<td>123456-BK</td>
<td>1</td>
<td>Frame, seat</td>
<td>Steel—SAE 1010</td>
<td>Frame Inc.</td>
<td>2,500</td>
<td>1,933.3</td>
<td>77.3%</td>
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<td>600</td>
<td>175.0</td>
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<tr>
<td>123458</td>
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<td>Fastener—PU</td>
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<td>42</td>
<td>39.2</td>
<td>93.3%</td>
</tr>
<tr>
<td>123459</td>
<td>4</td>
<td>Fastener—ST</td>
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<td>1</td>
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<td>123464</td>
<td>2</td>
<td>Arm assy, RH &amp; LH</td>
<td>Silicone</td>
<td>Importers R’Us</td>
<td>404</td>
<td>84.2</td>
<td>20.8%</td>
</tr>
<tr>
<td>123468</td>
<td>2</td>
<td>O-ring</td>
<td>Steel—SAE 1010</td>
<td>Importers R’Us</td>
<td>1</td>
<td>0.0</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CHA-1234</th>
<th>ECO Chair</th>
<th>DfE score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DfE Weight</th>
<th>Mat. chem. + disassembly + recyclability (g)</th>
<th>Potential DfE wt</th>
<th>Final score</th>
</tr>
</thead>
<tbody>
<tr>
<td>3,599</td>
<td>2,253</td>
<td>3,599</td>
<td>63%</td>
</tr>
</tbody>
</table>
Calculating a Product’s DfE Score

The DfE product assessment tool calculates a single DfE score for each product. To derive this score Herman Miller

- Calculates a final DfE score for each part in the product. The DfE score for each part is determined by the scores received in each of the three assessment categories: material chemistry, disassembly, and recyclability–recycled/renewable content. These scores are summed and divided by the total potential DfE weight of the part to create a final DfE score for each product:

\[
\text{Final DfE score (g)} = \frac{1/3 \text{ Material score (g)} + 1/3 \text{ Disassembly score (g)} + 1/3 \text{ Recyclability–recycled/renewable content score (g)}}{\text{Total potential weight (g)}}
\]

Thus the highest potential score of 100% requires a part receiving its full weight for each of the three assessment categories.

- Weights each of the three assessment categories equally: material chemistry, disassembly, and recyclability–recycled/renewable content. Within the last category, recyclability of materials carries a higher weight than recycled/renewable content (to promote the development of materials that can be closed-loop recycled).

- Adds the DfE weights for all the parts divided by the “total potential DfE weight” of the parts to calculate the final DfE score for the product, for example, the Mirra chair.

Table 5 details the calculation process for the fictional product ECO Chair. Included in table 5 are the data points collected by the DfE team for each part, including part description, material content, supplier, and weight. The final DfE score for the fictional product is 62.6% of a possible score of 100%. For the Mirra chair, the final DfE score was 80%, which represented a 63% improvement in environmental design from the initial design score of 49%.

All of the data collected in evaluating the DfE performance of the Mirra and other products are incorporated into a database (see figure 5) that allows the DfE and product development staff to sort by the material or type of production process (e.g., plastics can be injection-molded, extruded, or blow-molded), the material chemistry score (human health and ecotoxicity score), the recycled/renewable content, and the recyclability.

Assessment and Next Steps

The impact of implementing the DfE program with the Mirra chair was largely positive. Although there was a slight cost increase in moving from a PVC to a TPU armrest, this was offset by the decrease in moving from a steel-coated to a nylon Y-spine. By incorporating environmental considerations into the earliest stages of design possible, Herman Miller minimized the costs of internal change, while also minimizing the material chemistry hazards of the chair. The environmental attributes of the Mirra, along with its original design, enhanced the chair’s market reception. The Mirra received a Gold Award in the Best of NeoCon 2003 (the industry’s premier conference), a Silver Award from 2004 Industrial Design Excellence Awards (IDEA), a GOOD DESIGN Award in 2003 from the Chicago Athenaeum Museum of Architecture and Design, and a “Top 10 Green Building Product” for 2003 from BuildingGreen.

A strength of the DfE product assessment tool is that it facilitates making relatively rapid, yet disciplined and scientifically sound decisions in pursuit of Herman Miller’s environmental goals. Time is always a constraint in the product development process. Product development teams need quick access to quality information, especially when altering materials midway through the process. Incorporation of the DfE method into Herman Miller’s design process did have an impact on the development time. Learning for the first time how to incorporate environmental quality into product design required extra time on the part of the product design teams. The additional time needed to incorporate DfE into products is expected to decline, though, as the
Using the DfE product assessment tool also yielded unanticipated benefits, as has already been mentioned with the spine example (see Table 6 for a summary of the impacts of implementing DfE on the Mirra chair).

The Mirra chair example illustrates both the value of incorporating environment into the design process and the need for tools to benchmark progress, as well as the challenges of creating a truly cradle-to-cradle product. As successful as the Mirra chair was in terms of employing cradle-to-cradle design principles, it is not yet an ideal cradle-to-cradle product where all materials have been optimized to be either biological or technical nutrients. This reflects the reality that creating cradle-to-cradle products is truly a stretch goal—it will take years to attain, and for some complex products, such as office chairs, it will be more difficult to attain than for products with simpler construction, such as fabrics. More importantly, there is a serious dearth of ecologically intelligent materials in the market, making material selection options even more difficult and constrained.

Based on the DfE product assessment tool, which creates a scale of 0–100%, with 100% being a truly cradle-to-cradle product, the Mirra chair achieved a score of 80%. The areas of greater success were in the use of recyclable parts (83% of the parts by weight are recyclable) and ease of disassembly (93% of the product by weight can be readily disassembled). The areas of greater challenge were in the use of recycled content (42% pre- and postconsumer recycled content by weight) and the use of materials with a green chemistry composition (the chair has 75% green chemistry composition).
The success in recyclability reflects the availability of products made from materials that have an established recycling infrastructure. The success in disassembly reflects the high degree of control that Herman Miller has over how the product is assembled. The design team increased its disassembly score from 40% to 93% over the course of product development by making assembly adjustments such as moving from adhered and stapled covers to slip on/off covers.

The challenge to increasing recycled content is the use of plastics in chairs. Unlike the metals, which typically contain some recycled content, most plastics are made from virgin polymers. Additionally most postconsumer recycled plastics do not meet the performance specifications for demanding structural applications.

The challenge in improving materials chemistry is the limited range of green chemicals and materials on the market. Very few chemicals have been designed to meet the second of the 12 Principles of Green Chemistry: “to be fully effective, yet have little or no toxicity” (see Anastas and Warner 1998). The result is that the majority of the commodity chemicals and materials on the market are likely to be inherently hazardous for at least one endpoint (e.g., carcinogenicity).

The greatest weaknesses of the DfE product assessment tool are the lack of any transparency and independent validation of the method, and in the case of specific products, the lack of independent verification of the claims. Many questions surround the evaluation methods ranging from the criteria used to categorize materials into the different color codes (red, orange, yellow, or green) to how the terms “recycling infrastructure” and “renewable” are defined. Similarly none of the claims of the Mirra chair have been independently verified, ranging from disassembly in 15 minutes to materials chemistry containing 47% green materials by weight.

The independent verification of claims for any given product for materials chemistry is in fact impossible because of the nondisclosure agreements signed by Herman Miller with its suppliers. Herein lies a dilemma between needs for broader transparency with customers and the public and Herman Miller’s need for accurate and reliable chemical composition data of materials. In the short term there is no quick fix for this dilemma.

In the long term suppliers may become more public about their chemical formulations (in a manner similar to ingredient labels on food products) if there is a concerted set of demands by their major customers.

In terms of progress toward more sustainable products, both the Herman Miller and MBDC staff have seen marked improvements in this area at Herman Miller. The difficulty is how to market these achievements to Herman Miller customers. Herman Miller currently relies upon customer recognition of the firm’s long history of environmental stewardship, reinforced by MBDC’s reputation in the marketplace for trying to change material selection and product design criteria.

As part of its next steps, Herman Miller has committed to using the cradle-to-cradle protocol for all future products, as well as reexamining existing products. In addition, President and CEO Brian Walker has established a 2010 DfE goal that 50% of all sales must come from products that have passed through the cradle-to-cradle protocol. Among the goals that products must achieve to pass the protocol are the following:

- Develop a “yellow” or better palette for major commodities
- Eliminate “red” materials
- Design for disassembly
- Maximize recycled content and recyclability
- Eliminate PVC
- Develop biobased materials

As Herman Miller moves forward with its DfE program, it has established a solid foundation for future implementation that includes three key pillars. First, and critical to the initial success of the program, has been hiring dedicated, full-time staff who are a resource for the product development teams. These are staff that understand the environmental issues, work in collaboration with MBDC, and are part of the design process. As Lenox and colleagues (2000) concluded in their assessment of DfE practices in electronics firms, the “successful firm provided living specialists to assist designers.”

Second, they now have a comprehensive database to manage data and to transmit complex
information to design teams in a simplified presentation. This is an essential tool for learning organizations that wish to leverage valuable information gleaned from single projects across many product platforms.

Finally, they created solid partnerships with both MBDC and their suppliers. MBDC has brought both a vision of what Herman Miller should aspire to in product design and expertise in how to evaluate progress toward that vision. The suppliers now understand what Herman Miller is trying to achieve, the data that the company demands, and that Herman Miller can be trusted in its handling of proprietary formulation data.

A challenge that Herman Miller and MBDC will confront as they move forward in using the DfE product assessment tool is that the method behind the chemical and material evaluation is not completely transparent to a more critical and interested public. Thus the tool is open to criticism, which may or may not be fair, because its workings are not as transparent as the intent of their methodology. Plans for independent validation of the tool need to move forward; otherwise substantiating valid claims of environmental improvement by Herman Miller will not be possible.

As the work on the Mirra chair illustrates, designing products made entirely from a combination of technical and biological nutrients is a challenging path to choose. Yet Herman Miller has committed substantial organizational resources to designing its products to be ecologically healthy and to evaluating the extent to which its products achieve that goal. Creating cradle-to-cradle products is a journey and Herman Miller, with help from MBDC, is learning how to walk down this path.

Notes
1. For example, see Franklin Associates’ LCAs (1990, 1992), funded by those with vested economic interests in disposable diapers—the American Paper Institute and Diaper Manufacturers Group; Arthur D. Little’s LCA (1990) funded by Proctor & Gamble; and Lehrburger and colleagues’ LCA (1991), funded by The National Association of Diaper Services. In all of these LCAs, the findings of the authors supported the market interests of the funders.

2. Concerns with the inherent toxicity of chemicals and the materials that contain them are on the rise, especially in the buildings sector. For example, in 2000, one cover story in Business Week was “Is Your Office Killing You?” where the authors emphasized that “The modern office is home to as many as 350 different volatile organic chemicals released by building materials, furnishings, and office equipment” (Conlin and Carey 2000). Similarly, studies of households have found that the dust contains a soup of toxic chemicals, including phthalates, brominated flame retardants, alkylphenols, organotins, and perfluorinated compounds (for example, see Betts 2003; Costner et al., 2005). These findings are helping to grow demand for the use of healthy materials in the interior furnishings sector.

3. For example, see the U.S. Environmental Protection Agency’s High Production Volume Information System at <www.epa.gov/hpvis/index.html>.

References


**About the Authors**

**Mark Rossi** is research director at Clean Production Action in Medford, MA, USA. **Scott Charon** is program manager, Design for the Environment; and **Gabe Wing** is Design for the Environment manager, both at Herman Miller, Inc., Zeeland, MI, USA. **James Ewell** is senior project manager, at McDonough Braungart Design Chemistry, Charlottesville, VA, USA.