

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

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1 Clean Production Action

2 Herman Miller, Inc.

3 McDonough Braungart Design Chemistry

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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. To implement this system, Herman Miller created a Design for Environment (DfE) program and, with McDonough Braungart Design Chemistry (MBDC), created the DfE product assessment tool. 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 (a critical element in the chair's design), increasing recycled content in a number of components, eliminating all PVC 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 in the increased use of recyclable parts and increased ease of disassembly, while the areas of greatest challenge were increasing the recycled content of parts and using materials with a 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 challenge to increased 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 improved materials chemistry is the limited range of green chemicals and materials on the market.

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. Herman Miller recognizes that working towards cradle to cradle products is a journey that will involve continuous improvement of its products.

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, it is not sufficient to make products that are merely “less bad” products—i.e., 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 (for McDonough and Braungart) 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 its 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 paper 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.

1 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, then develop the tools and metrics needed to measure progress and help achieve the 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 like 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 non-toxic 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, then make improvements to the product (for example, see Graedel, 2000) or make a product selection based on the conclusions the tool generates (e.g., see NIST BEES software). The value of a tool-driven approach like 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 yet, 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—e.g., the disposable v. 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 the actual goal is to make the product of the funder of the LCA to look environmentally preferable. For example, see: Franklin Associates’ LCAs (1990, 1992) funded by those with vested economic interests in disposable diapers—American Paper Institute and Diaper Manufacturers Group; Arthur D. Little’s LCA (1990) funded by Proctor & Gamble; and Lehrburger, et al.’s 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.

The diaper-LCA wars illustrate the fundamental dangers of tool-driven approaches: they shift the debate to the tool, the assumptions made, the data used, the boundaries drawn, etc., rather than to 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—e.g., design and manufacture an ecologically healthy product for handling the bodily wastes of infants, toddlers, and incontinent adults—then would select the tools most appropriate to evaluating progress toward the goal. A goal-driven approach shifts the first order question to what is desired rather than to what is the tool.

Goal-driven approaches still need tools, the difference is they are designed to be in service of the goals. Similar to any analytic tool, a host of decisions still needs to be made in a tool designed to meet goals, and these decisions will affect outcomes—i.e., how far along the path to the goal a product is. Decision-making rules, assumptions, and algorithms all need to be transparent, otherwise the tool will become vulnerable to vested economic interests.

In agreeing to strive toward cradle-to-cradle products, Herman Miller needed tools to assess progress towards this ideal. Similar 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 with 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 LCA’s on historical data and the aggregation of data on an industry-wide rather than site-specific level, neither of which meets the needs of designers. Finally, since LCA conclusions are often heavily influenced by impacts from energy because of superior data quality in this area and the reality that for some products, such as windows and automobiles, energy consumption over the life of the product does represent the most significant impact, they slant action to addressing energy concerns while downplaying the importance of addressing

toxicity, design for disassembly, and design for recyclability (for example, see Stevels, et al., 1999; Boustead, 1999).

Product development companies such as Herman Miller need an approach that can keep pace with the rapid pace required to bring new products to the marketplace. Instead of using LCA, Herman Miller worked with McDonough Braungart Design Chemistry (MBDC) to develop the DfE product assessment tool, which evaluates the extent to which a product is truly a cradle to cradle product—i.e., made from 100% biological and/or technical nutrients. To assess the extent to which a product is made from biological and technical nutrients requires answering the following questions: Are the products using inputs—chemicals and materials—that are safe and healthy for humans and the environment? What is the recycled content of a material? Can the material be recycled into another product of similar quality at the end of its useful life? Can the material be easily disassembled from the product?

LCAs are not designed to answer these questions. For example, LCAs do not evaluate the inherent hazards of a chemical or the chemical composition of a material. Instead LCAs are an attempt to systematically catalogue the impacts for every processing step, from raw material extraction through product disposal. The effects of material consumption and emissions are aggregated in impact categories that are weighted in terms of importance. While well-designed LCAs can be used to successfully compare materials and products, they do not meet the needs of a product development organization striving to create safe products where the materials of construction can be used in closed-loop cycles.

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 highlighted 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; and Costner, et al., 2005). These findings are helping to grow demand for the use of healthy materials in the interior furnishings sector.

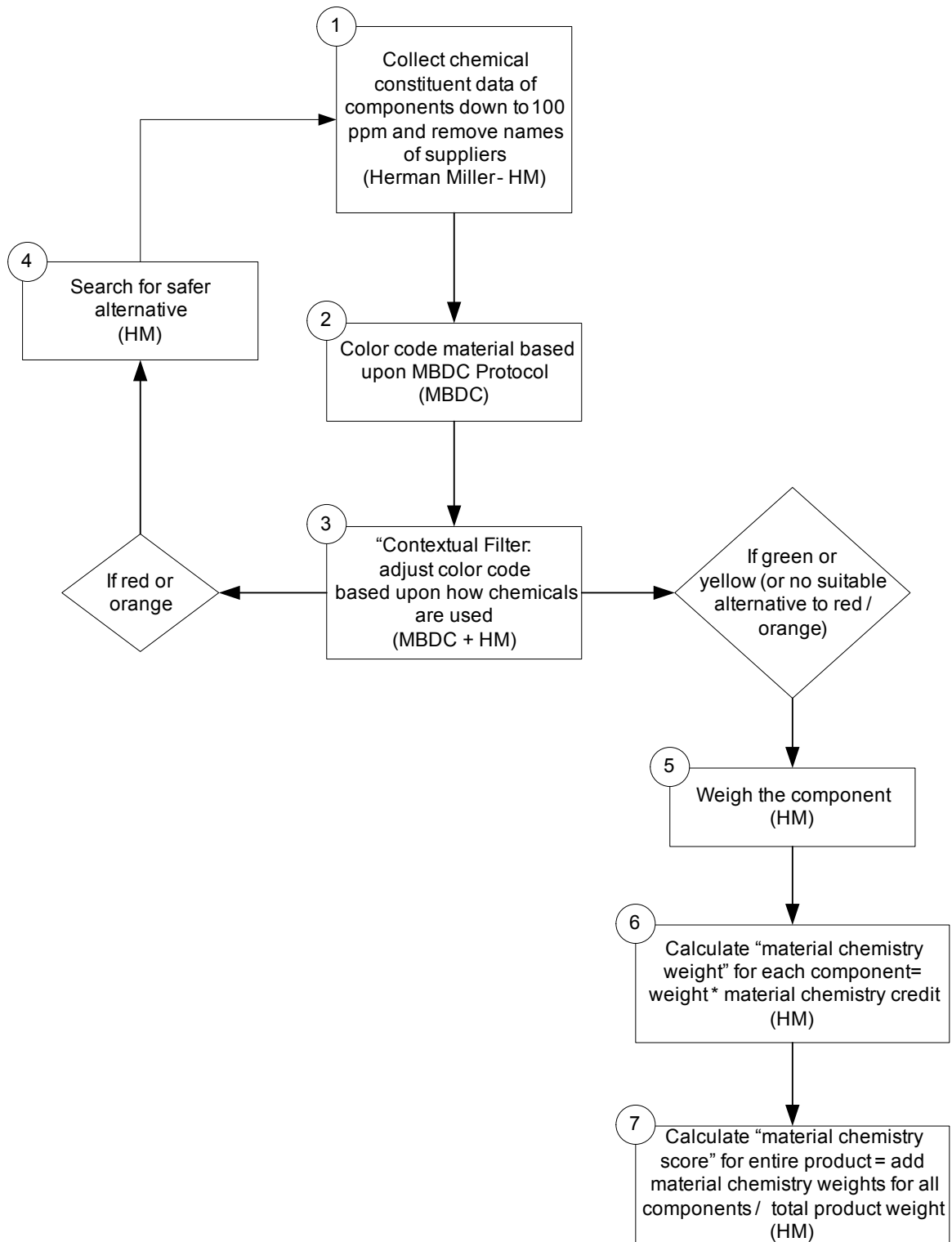
2 Evaluating Progress toward Cradle-to-Cradle Products: the DfE Product Assessment Tool and the Mirra Chair

The first product Herman Miller ran through the DfE product assessment tool from design to production was the Mirra chair (see Photo 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), increasing recycled content in a number of components, eliminating all PVC components, and designing the chair for rapid disassembly using common tools.

2.1 Moving to Biological Nutrients: 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 1 illustrates the eight key stages involved in calculating a product’s material chemistry score.

Figure 1. Herman Miller Material Chemistry Evaluation Process



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. 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 other materials—such as plastics, colorants and coating finishes—proved to be far more 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 this 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 non-disclosure 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.



Photo 1. Mirra Chair

Herman Miller’s preference is to work within its established supply chain and invests heavily into 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: 1) introduce DfE program and metrics; 2) explain purpose of material assessment process; 3) guide supplier through the material inventory process; 4) provide feedback about assessed material; 5) work with supplier to find substitute inputs or, if necessary, a new material; 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 who was willing to share its data.

Upon receiving the chemical constituent data, it is 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.

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 the chemical constituents of a material and assigns a color ranking for that material.

The method MBDC uses to rate a chemical as red, yellow, orange, 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 material chemistry ranking system has not been independently verified remains an issue of concern to MBDC, which plans to have the method independently reviewed.

Table 1. Human and Ecological Health Endpoints included in MBDC's Materials Assessment Protocol (McDonough, et al, 2003)

Human Health Endpoints	Ecological Health Endpoints
Carcinogenicity	Algae toxicity
Teratogenicity	Bioaccumulation
Reproductive toxicity	Climatic relevance
Mutagenicity	Content of halogenated organic compounds
Endocrine disruption	Daphnia toxicity
Acute toxicity	Fish toxicity
Chronic toxicity	Heavy metal content
Irritation of skin/mucous membranes	Persistence/biodegradation
Sensitization	Other (water danger list, toxicity to soil organisms, etc.)
Other relevant data (e.g., skin penetration potential, flammability, etc.)	

In stage three, MBDC evaluates how Herman Miller uses the materials and decides whether to adjust the rating downward, e.g., from red to yellow, because of minimal exposure concerns. As part of this process, MBDC employs a “contextual filter” that evaluates an identified hazard within the context of its actual use. 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. However, if carbon black is used in a polymer where it is 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—i.e., 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 were eliminated when the design team decided not to use traditional foam materials for seat and back support (see photo 2 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 that led to the development of the Airweave™

suspension fabric and the TriFlex™ polymer back. These materials provide greater comfort than polyurethane foam while improving chair 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. 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) (for example, see Thornton, 2000; and 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. While armrests may seem like 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 copolymers (styrene ethylene butadiene styrene) 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.

As the Mirra moved closer to launch date, no alternative material had been found to PVC armpad skins. The pressure was on the DfE team to find a suitable alternative. The purchasing team wanted to stay with PVC because it was a known entity on performance and cost. The product team argued to launch with PVC, then develop an alternative. Yet the DfE team knew that changing design after product launch would be difficult: engineering resources for evaluating alternatives would be reallocated to new projects and the cost baseline would be established using PVC.

Finally the DfE team settled upon thermoplastic urethanes (TPUs), which met or exceeded all the performance measures but 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:

- Identifying the weight of each component (stage five).
- Multiplying the component's weight by its material chemistry assessment color code, which is translated into a percent -- Green = 100%, Yellow = 50%, Orange = 25%, and Red = 0% (stage six).

- Adding up the material chemistry weight of each product and dividing by the total weight of the product to calculate a final material chemistry score for the entire product (stage seven).

Table 2 details how the material chemistry score is calculated for Fictional Product ECO Chair.

Table 2. Material Chemistry Calculation for Fictional Product ECO Chair

CHA-1234		ECO Chair							
Bill of Material						Material Chemistry			
Part #	Qty	Description	Material - Print	Supplier	Wt (g)	Rating	Wt Credit (%)	Wt Credit (g)	Final Score
123456-BK	1	FRAME, SEAT	16 Ga. 1008-1010 Steel	Frame Inc.	2,500	Yellow	50%	1250	
123457	1	PAN - SEAT	20% GF Polypropylene	Molders Plus	600	Yellow	50%	300	
123458	4	FASTENER - PU	Sintered Metal	Fastener Land	42	Green	100%	42	
123460	4	BUMPER	Super Rubber	Importers R'Us	26	Orange	25%	6.5	
123461	4	CONNECTOR CLIP	Nylon 6/6	Molders Plus	26	Yellow	50%	13	
123464	2	ARM ASSY, RH & LH	380 Aluminum	Importers R'Us	404	Orange	25%	101	
123468	2	O-RING	Silicone Rubber Fill	Importers R'Us	1	Red	0%	0	
					3,599			1,713	

Over the course of its development, the Mirra's final material chemistry score increased from 47% to 69% in the final chair. A key change improving the material chemistry was eliminating the PVC products. The color code breakdown of materials by weight in the Mirra is: Yellow = 53%; and Green = 47%. The green materials in Mirra include certain grades of steel and aluminum.

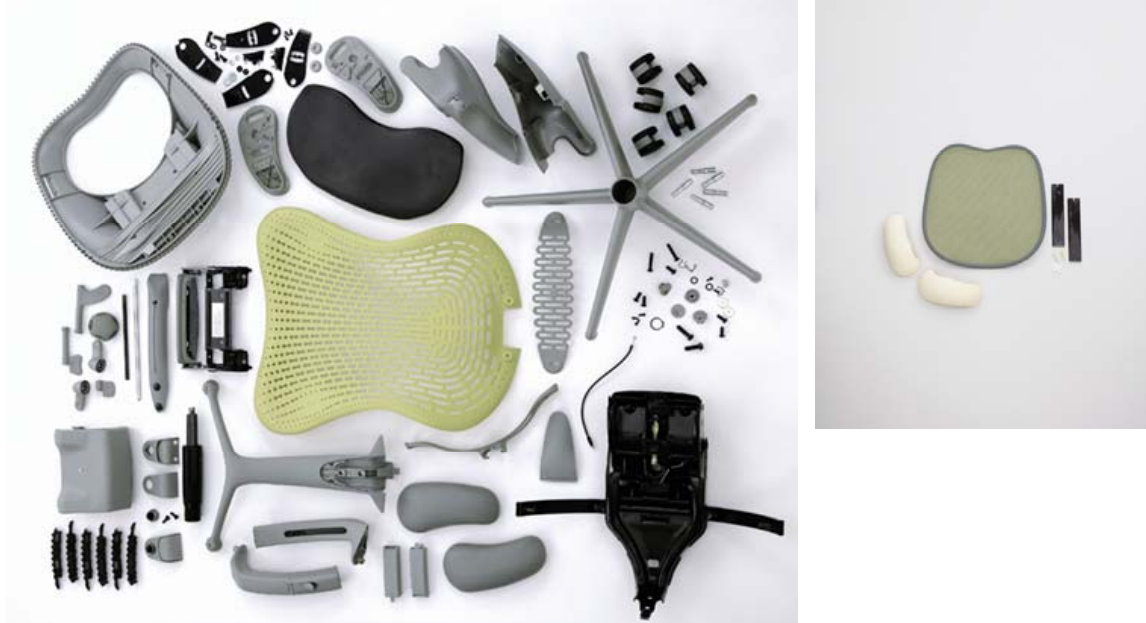
2.2 Disassembly

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 -- screwdriver, 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 any component that takes greater than 30 seconds to remove is too long.
4. Is the material identifiable and marked? If parts are not marked, then disassemblers will not know which recycling bin to place them in.

Photo 2. Mirra Parts. Left Photo: recyclable parts, 96% by weight. Right Photo: non-recyclable parts (4% by weight) -- mixed plastic armpads (white parts), seat pan, and leaf springs (black parts)



Each component receives a disassembly score of either 100% -- if all four answers are “yes” -- or 0% -- if one or more answer is “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 disassembling ease of the Mirra. Photo 2 presents all the components disassembled from the Mirra chair. The foam used in the armpads 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, armpads, which are typically stapled 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 Equa® task chair.

Table 3. Disassembly Assessment for Fictional Product ECO Chair

CHA-1234		ECO Chair										
Bill of Material						Disassembly Assessment				Disassembly Score		
Part #	Qty	Description	Material - Print	Supplier	Wt (g)	#1	#2	#3	#4	Wt Credit (%)	Wt (g)	Final Score
123456-BK	1	FRAME, SEAT	16 Ga. 1008-1010 Steel	Frame Inc.	2,500	Yes	Yes	Yes	Yes	100%	2,500	
123457	1	PAN - SEAT	20% GF Polypropylene	Molders Plus	600	No	Yes	Yes	Yes	0%	0	
123458	4	FASTENER - PU	Sintered Metal	Fastener Land	42	Yes	Yes	Yes	Yes	100%	42	
123460	4	BUMPER	Super Rubber	Importers R'Us	26	Yes	Yes	Yes	Yes	100%	26	
123461	4	CONNECTOR CLIP	Nylon 6/6	Molders Plus	26	Yes	Yes	Yes	No	0%	0	
123464	2	ARM ASSY, RH & LH	380 Aluminum	Importers R'Us	404	Yes	Yes	Yes	No	0%	0	
123468	2	O-RING	Silicone Rubber Fill	Importers R'Us	1	Yes	Yes	Yes	No	0%	0	
					3,599						2,568	71.4%

2.3 Recyclability + Recycled/Renewable Content

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

1. Material is a technical or biological nutrient and can 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%.

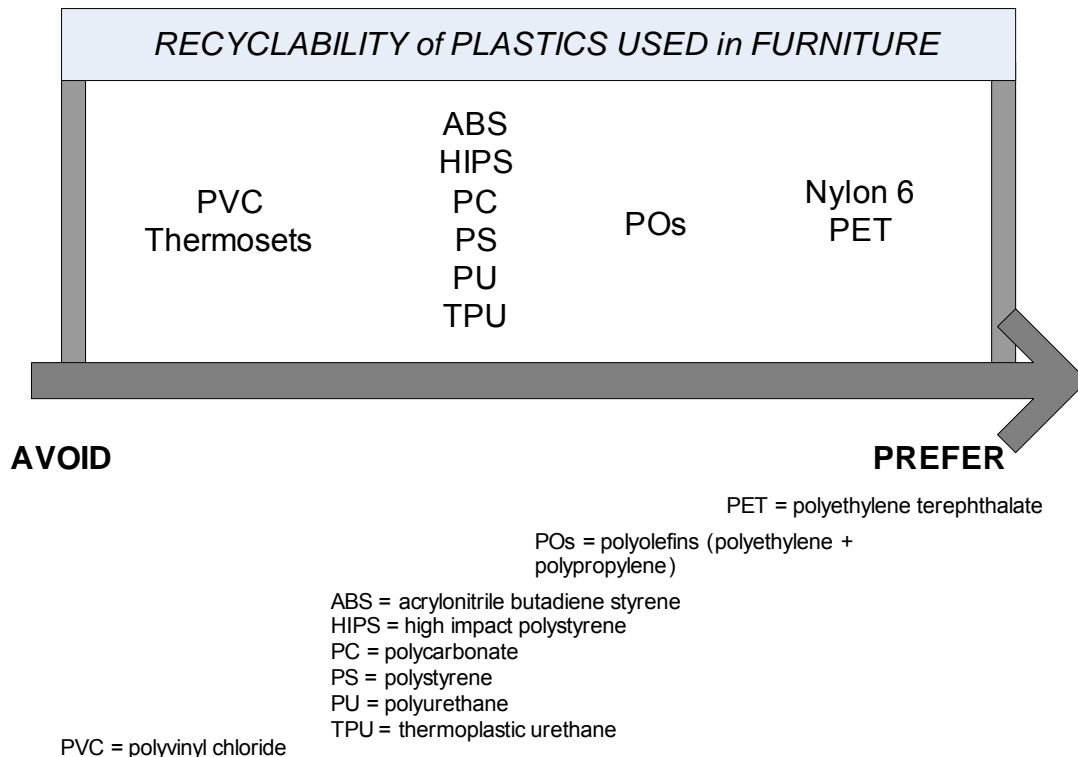
The recyclability score for each component is calculated by multiplying the recyclability percentage by the weight of the component. The final recyclability score is the ratio of the total recyclability weight to the total weight of the chair (see Table 4 below). Herman Miller's goal for all products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

Recyclability is of particular concern for plastics, which are more difficult to recycle than the 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 close-loop recycle. There is a well-established recycling infrastructure for PET bottle recycling which can be built upon for engineering-grade PET materials.
- 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 recycled, although the recycling infrastructure is not well-developed.
- PU, which is used in the Mirra armrests, lacks a well-developed recycling infrastructure, although it is a recyclable material.
- Polyvinyl chloride (PVC) has a minimal recycling infrastructure and is difficult to recycle into new products. But of greater concern for the recycling industry is that PVC is the primary contaminant in the PET recycling process. If PVC is mixed into PET during re-processing 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; and CWC, 1997).
- Thermoset plastics are not recyclable.

The non-recyclable 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 2 illustrates the plastics recycling spectrum that has emerged at Herman Miller.

Figure 2. Herman Miller Assessment of the Recyclability of Plastics



Over the course of developing the Mirra, the chair's recyclability score increased from 75% to 96%. Photo 2 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. 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 result is a truly innovative solution. The Mirra Y-spine is constructed from two components made from 100% nylon, which is easily recycled and is less costly than the original steel design. In addition, Herman Miller created intellectual capital as well, since the design resulted in patentable technology that can be leveraged into new products.

The non-recyclable 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 armpads -- which are a combination of PU foam permanently affixed to a plastic substrate.

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).

Table 4. Recyclability + Recycled/Renewable Content Assessment for Fictional Product

CHA-1234		ECO Chair											
Bill of Material						Recyclability			Recycled / Renewable Content			Recyclability + Rec./Ren. Content Score	
Part #	Qty	Description	Material - Print	Supplier	Wt (g)	Wt Credit (%)	Wt (g)	Final Score	Wt Credit (%)	Wt (g)	Final Score	Wt'd Ave. (g)	Final Score
123456-BK	1	FRAME, SEAT	16 Ga. 1008-1010 Steel	Frame Inc.	2,500	100%	2,500		28%	700		2050	
123457	1	PAN - SEAT	20% GF Polypropylene	Molders Plus	600	50%	300		0%	0		225	
123458	4	FASTENER - PU	Sintered Metal	Fastener Land	42	100%	42		20%	8.4		33.6	
123460	4	BUMPER	Super Rubber	Importers R'Us	26	0%	0		0%	0		0	
123461	4	CONNECTOR CLIP	Nylon 6/6	Molders Plus	26	100%	26		0%	0		19.5	
123464	2	ARM ASSY, RH & LH	380 Aluminum	Importers R'Us	404	50%	202		0%	0		151.5	
123468	2	O-RING	Silicone Rubber Fill	Importers R'Us	1	0%	0		0%	0		0	
					3,599		3,070	85%		708	20%	2,967	69%

Today, Herman Miller does not distinguish between post-industrial and post-consumer recycled content in calculating the recycled content score, although data for both types of recycled content are collected. 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 tilt mechanism in the Mirra was originally coated with virgin steel. Herman Miller changed the coating to recycled content at no additional cost.

2.4 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:

$$\frac{\frac{1}{3} \text{ Material Chemistry Score (g)} + \frac{1}{3} \text{ Disassembly Score (g)} + \frac{1}{3} \text{ Recyclability-Recycled/ Renewable Content Score (g)}}{\text{Total Potential Weight (g)}} = \text{Final DfE Score for each part}$$

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

- Weighs 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.
- 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, e.g., the Mirra chair.

Table 5 details the calculation process for Fictional Product ECO Chair. Included in Table 1 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, its final DfE score was 70.6%, which represented a 43% increase in environmental design improvements from the initial design.

All of the data collected in evaluating the DfE performance of the Mirra and other products is incorporated into a database that allows the DfE and product development staff to sort by material or type of production process (e.g., plastics can be injection molded, extruded, blow molded, etc.) for the material chemistry score (human health and ecotoxicity score), recycled/renewable content, and recyclability (Figure 3).

Table 5. Calculating the Final DfE Score for Fictional Product ECO Chair

CHA-1234		ECO Chair						
Bill of Material					DfE Score			
Part #	Qty	Description	Material	Supplier	Wt (g)	DfE Weight: Mat. Chem. + Dis-assembly + Recyclability (g)	Potential DfE Wt	Final Score
123456-BK	1	FRAME, SEAT	16 Ga. 1008-1010 Steel	Frame Inc.	2,500	1933.3	2500	77.3%
123457	1	PAN - SEAT	20% GF Polypropylene	Molders Plus	600	175.0	600	29.2%
123458	4	FASTENER - PU	Sintered Metal	Fastener Land	42	39.2	42	93.3%
123459	4	FASTENER - ST	Spring Steel	Fastener Land	1	0.8	1	76.7%
123460	4	BUMPER	Super Rubber	Importers R'Us	26	10.8	26	41.7%
123461	4	CONNECTOR CLIP	Nylon 6/6	Molders Plus	26	10.8	26	41.7%
123464	2	ARM ASSY, RH & LH	380 Aluminum	Importers R'Us	404	84.2	404	20.8%
123468	2	O-RING	Silicone Rubber Fill	Importers R'Us	1	0.0	1	0.0%
					3,599	2,253.4	3,599	62.6%

Figure 3. Herman Miller Database Inventory



Materials and Mechanical Properties Database

Print Specification: Steel - SAE 1008 Cold Rolled

Info	Property Name	Property Description	Info	Property Name	Property Description
ⓘ	HMI Code	E00015	ⓘ	HH/EcoTox Score	Green
ⓘ	Purchasing Commodity	Steel	ⓘ	Green Certification	
ⓘ	Purchasing Sub-Commodity	Raw Steel	ⓘ	Total Recycle Renewable Content	20%
ⓘ	Material Commodity	Steel	ⓘ	Post Consumer Recycled Content	0%
ⓘ	Material Sub-Commodity	Steel	ⓘ	Post Industrial Recycled Content	0%
ⓘ	Material Name		ⓘ	Renewable Content	0%
ⓘ	Material Trade Name	SAE 1008 Cold Rolled	ⓘ	Recyclability	100%
ⓘ	ASTM Recycling Code		ⓘ	Sustainability Certification	
ⓘ	Material Distributor		ⓘ	Material ID	0000000229
ⓘ	Material Manufacturer	Inland Steel			
ⓘ	Manufacturer Hyperlink	http://www.inland.com			

Material Comments

Info	Comment Type	Comment Text
ⓘ	General	Minor impurities in the steel are Yellow as assessed in the context of material. Overall assessment is Yellow based on the presence of impurities.
ⓘ	Typical Use	General grade steel coil.
ⓘ	Special Properties	Weldability (spot, projection, butt, and fusion) and brazeability are excellent. Applications include extruded, cold headed, cold upset, and cold pressed parts and forms.
ⓘ	Recycled Content Notes	Industry average.
ⓘ	Recyclability Notes	Steel is a technical nutrient.

3 Assessment and Next Steps

The impacts of implementing the DfE program with the Mirra chair were largely positive. While there was a slight cost increase in moving from a PVC to 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 as possible, Herman Miller is minimizing the costs of internal change, while also minimizing the life cycle impacts of a chair. The firm is also creating a market advantage for its new product by coupling high environmental performance with high product performance.

A strength of the DfE product assessment tool is it facilitates making relatively rapid, yet disciplined and scientifically sound decisions. Time is always a constraint in the product development process. Product development teams need quick access to quality, especially when altering materials midway through the process.

The DfE method did alter Herman Miller’s design process. Learning for the first time how to incorporate environmental quality into product design required extra time on the part of the product design teams. However, the additional time needed to incorporate DfE into products is expected to decline as the engineers become familiar with the process. There were also unanticipated benefits from using the DfE product assessment tool, as have already been mentioned with the spine example (see Table 6 for a summary of the impacts of implementing DfE on the Mirra chair).

Table 6. Summary of Impacts of Implementing DfE on the Mirra Chair

Factors	Impact
Quality	No Impact ↔
Time to Market	No Impact ↔
Engineering	Slight Increase ↑
Material Costs	Increases and Decreases ↓↑
Market Features	Increased Functionality ↑

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, like chairs, it will be more difficult to attain than for products with simpler constructions, like fabrics. More importantly, there is a serious dearth of ecologically intelligent materials which are available 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 71%. The areas of greatest success were in the use of recyclable parts (96% of the parts by weight are recyclable) and ease of disassembly (93% of the product by weight can be readily disassembled). The areas of greatest challenge were in the use of recycled content (42% pre- and post-consumer recycled content by weight) and the use of material with a green chemistry composition (the chair has 69% 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 increased 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. Additionally most post-consumer recycled plastics do not meet the performance specifications of virgin plastics.

The challenge to improved 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 12 Principles of Green Chemistry: "to be fully effective, yet have little or no toxicity" (see Anastas and Warner, 1998). The result is 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 to 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 term "recycling infrastructure" is defined. Similarly none of the claims of the Mirra chair have been independently verified, ranging from disassembly in 15 minutes to material chemistry containing 47% green material chemistry by weight.

The independent verification of claims for any given product for material chemistry is in fact impossible because of the non-disclosure agreements signed by Herman Miller with its suppliers. Herein lays 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 to 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 towards 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 re-examining 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:

- Develop a "YELLOW" or better palette for major commodities.
- Eliminate "RED" materials.
- Design for disassembly.
- Maximize recycled content and recyclability.

- Incorporate energy concerns into material selection.
- Eliminate PVC for a product set.

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 to 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 such, they are part of the product development teams, helping them to evaluate environmental issues. As Lenox, et al. (2000), concluded in its 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 in a simplified presentation to design teams. This is an essential tool for learning organizations who wish to leverage valuable information across many product platforms versus a single project.

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 towards 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 tool is an unknown to a more critical and interested public. Thus the tool may be subjected to criticism, which may or 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 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.

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