Whole System Mapping

Example 2

by Jake Hvistendahl, Nadine Kuemmel, Shari Welsh (2013)

Comments:

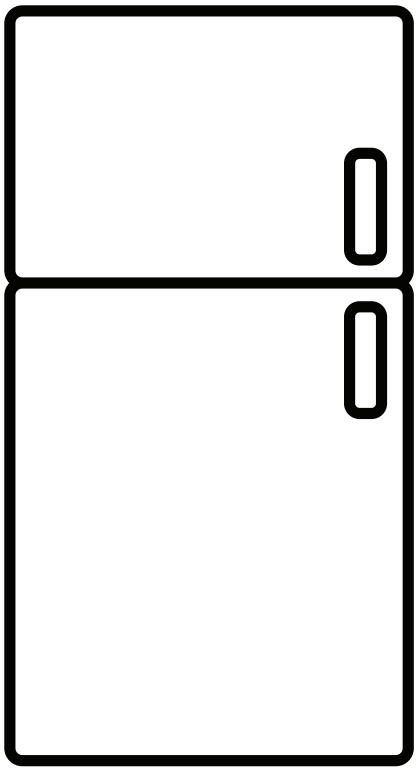
This's a great example from a previous year. They've got a slightly better system map than the other example, but the other example has nicer graphs.

You've got the LCA comparisons, system map, priorities and metrics, decision matrix, and final design choice. Your diagram of where boundaries were different for different objectives was a nice idea; it might be too busy for businesspeople, but ok for engineers.

Good graphs. Nice that you labeled the % improvement for each. The winners were clearly labeled, and the font increase was good. You actually don't even need to have different colors for every different material in every scenario, because here we're just trying to choose between scenarios, not trying to see details for any one particular scenario--our earlier LCAs were trying to find the biggest problems in each scenario, and let me see you'd done the LCAs right, and thus the detail was useful; here we assume the scenarios are set, and we're choosing which ones are best, so a single bar for each is ok. ...However, your extra detail could be useful for combining scenarios. Even then, all of the scenarios here are mostly energy, so if this were for a client, you could graph them by life-cycle phase (materials / mfg, energy use, transport, & EOL) instead of going all the way to the level of the SBOM, without losing important detail.

Your decision matrix was good--I like how you included energy impacts to show it mattered, but at the same time was redundant with LCA improvement. One criticism--your motivation for making material reduction a low weight was bad--you basically said "we made this measurement unimportant because our solutions were bad at it." A stronger justification (that's also true) is "we made this measurement unimportant because LCAs showed materials to be a small percent of impacts." Just FYI, it'll make more sense to your reader if your decision matrix lists objectives in order of highest priority to lowest priority. Then #1 is your #1 priority, etc. Small consistency thing: usually you said "gave" but once you said "give". And why is your key to evaluation units colored, when the values in the table itself aren't colored?

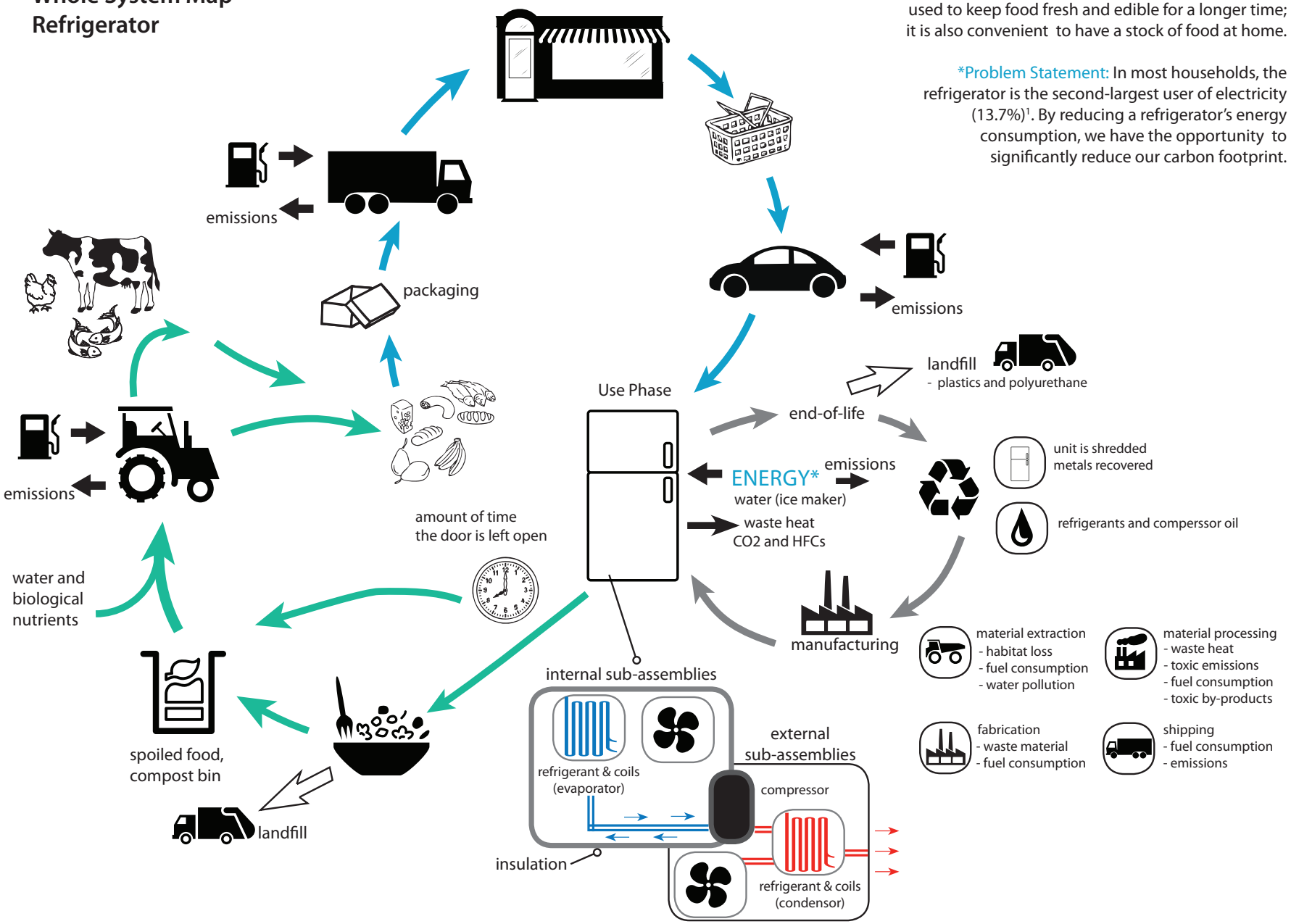
Excellent presentation of the winning design. The user-experience improvements weren't that clear, bust sustainability and cost improvements were. Great graphic of the fridge in the kitchen! Very professional. And it answered my question about "how can you put the directions on the side, because no one will see them there" by showing the fridge sticks out a bit from the cabinets.



Whole System Map
Refrigerator

Why do people use refrigerators? Refrigerators are used to keep food fresh and edible for a longer time; it is also convenient to have a stock of food at home.

*Problem Statement: In most households, the refrigerator is the second-largest user of electricity (13.7%)[1]. By reducing a refrigerator's energy consumption, we have the opportunity to significantly reduce our carbon footprint.



Selected Goals and Priorities

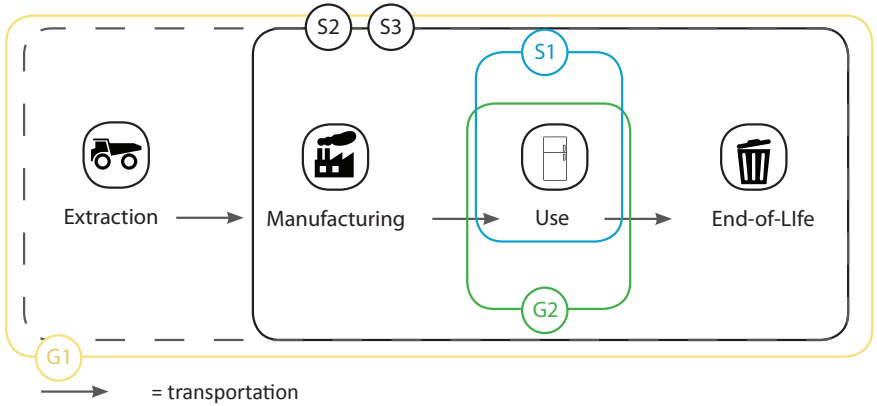
Sustainable Goals:

Priority	Objectives	Metrics
S1	Reduce Energy Impacts	by 25%-50% (as measured by $C0_2$)
S2	Extend Lifetime	by 15 years (entire lifetime = 30 years)
S3	Light-Weighting / Material reduction	reduce material impacts by 20%-50% (as measured by $C0_2$)

General Goals:

Priority	Objectives	Metrics
G1	Reduce Lifetime Costs	by reducing operating costs in relation to purchase price by 10-30%
G2	User Convenience	increase usability and storage options

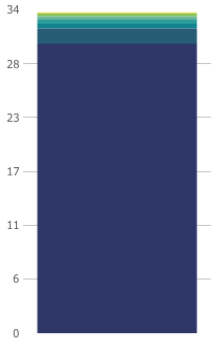
Project Boundaries & Goal Influence



Functional Unit = 1 year of use

Design Exploration Using LCA Analysis | impacts by SBOM Inputs: Total (mPts/func unit)

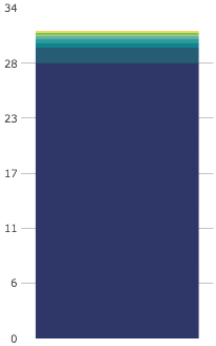
Baseline Concept



Total = 34mPts/func unit

Input	mPts/func unit
Electricity, 120 V, US	30.5
Steel, converter, low-alloyed	1.62
Cast iron	0.462
Sheet rolling, steel	0.426
Aluminium, primary	0.302
Copper, primary	0.163
Polyurethane, rigid foam	0.140
Polystyrene, expandable, PS	0.0876
Acrylonitrile-butadiene-styrene copolymer, ABS	0.0819
Freighter, oceanic	0.0403

Alarm

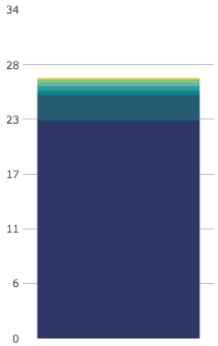


Total = 32mPts/func unit

Input	mPts/func unit
Electricity, 120 V, US	28.4
Steel, converter, low-alloyed	1.62
Cast iron	0.462
Sheet rolling, steel	0.426
Aluminium, primary	0.302
Copper, primary	0.163
Polyurethane, rigid foam	0.140
Polystyrene, expandable, PS	0.0876
Acrylonitrile-butadiene-styrene copolymer, ABS	0.0819
Wire drawing, copper	0.0708

5.9% improvement

Vacuum Panels

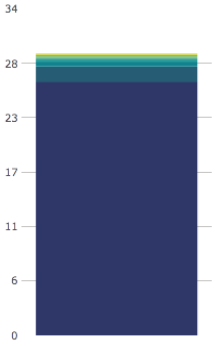


Total = 27mPts/func unit

Input	mPts/func unit
Electricity, 120 V, US	22.6
Steel, converter, low-alloyed	2.67
Cast iron	0.462
Aluminium, primary	0.456
Sheet rolling, steel	0.426
Copper, primary	0.163
Polystyrene, expandable, PS	0.0876
Acrylonitrile-butadiene-styrene copolymer, ABS	0.0819
Wire drawing, copper	0.0708
Injection molding, plastics	0.0676

21% improvement

Glass Doors

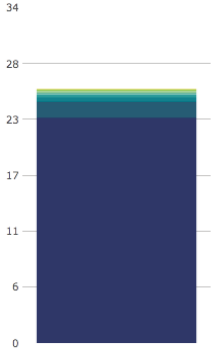


Total = 30mPts/func unit

Input	mPts/func unit
Electricity, 120 V, US	26.4
Steel, converter, low-alloyed	1.62
Cast iron	0.462
Aluminium, primary	0.302
Copper, primary	0.163
Polyurethane, rigid foam	0.140
Flat glass, uncoated	0.103
Polystyrene, expandable, PS	0.0876
Acrylonitrile-butadiene-styrene copolymer, ABS	0.0819
Freighter, oceanic	0.0562

11.8% improvement

Differentiated

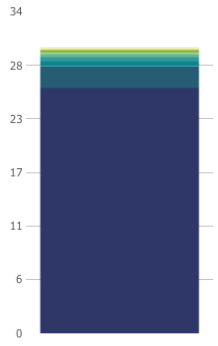


Total = 26mPts/func unit

Input	mPts/func unit
Electricity, 120 V, US	22.9
Steel, converter, low-alloyed	1.62
Cast iron	0.462
Sheet rolling, steel	0.426
Aluminium, primary	0.302
Copper, primary	0.163
Polyurethane, rigid foam	0.154
Polystyrene, expandable, PS	0.0964
Acrylonitrile-butadiene-styrene copolymer, ABS	0.0901
Freighter, oceanic	0.0412

23.5% improvement

Modular

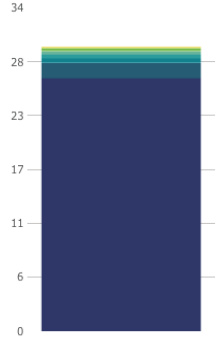


Total = 30mPts/func unit

Input	mPts/func unit
Electricity, 120 V, US	26.0
Steel, converter, low-alloyed	2.26
Cast iron	0.554
Sheet rolling, steel	0.426
Aluminium, primary	0.302
Polyurethane, rigid foam	0.224
Copper, primary	0.180
Polystyrene, expandable, PS	0.123
Acrylonitrile-butadiene-styrene copolymer, ABS	0.115
Freighter, oceanic	0.0553

11.8% improvement

Adjustable



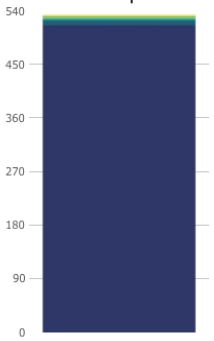
Total = 30mPts/func unit

Input	mPts/func unit
Electricity, 120 V, US	26.6
Steel, converter, low-alloyed	1.62
Cast iron	0.462
Sheet rolling, steel	0.426
Aluminium, primary	0.302
Copper, primary	0.163
Polyurethane, rigid foam	0.154
Polystyrene, expandable, PS	0.0964
Acrylonitrile-butadiene-styrene copolymer, ABS	0.0901
Freighter, oceanic	0.0412

11.8% improvement

Design Exploration Using LCA Analysis | impacts by SBOM Inputs: Carbon Footprint (CO_2 eq. kg/func unit)

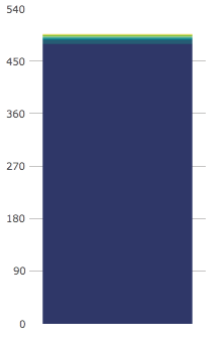
Baseline Concept



Total = 540 CO_2 eq. kg/func unit

Input	CO_2 eq. kg/func unit
Electricity, 120 V, US	516
Steel, converter, low-alloyed	7.22
Aluminium, primary	1.79
Polyurethane, rigid foam	1.63
Polystyrene, expandable, PS	1.40
Sheet rolling, steel	1.34
Incineration, rubber	1.32
Acrylonitrile-butadiene-styrene copolymer, ABS	1.31
Incineration, plastics, mixture	0.799
Injection molding, plastics	0.716

Alarm

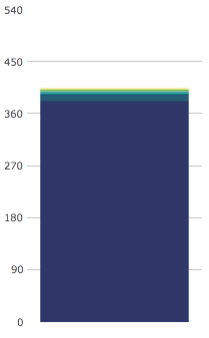


Total = 500 CO_2 eq. kg/func unit

Input	CO_2 eq. kg/func unit
Electricity, 120 V, US	480
Steel, converter, low-alloyed	7.22
Aluminium, primary	1.79
Polyurethane, rigid foam	1.63
Injection molding, plastics	1.43
Polystyrene, expandable, PS	1.40
Sheet rolling, steel	1.34
Acrylonitrile-butadiene-styrene copolymer, ABS	1.31
Wire drawing, copper	1.11
Refrigerant R134a	0.633

7% improvement

Vacuum Panels

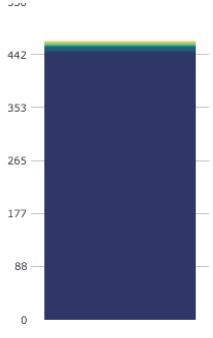


Total = 410 CO_2 eq. kg/func unit

Input	CO_2 eq. kg/func unit
Electricity, 120 V, US	382
Steel, converter, low-alloyed	11.9
Aluminium, primary	2.70
Injection molding, plastics	1.43
Polystyrene, expandable, PS	1.40
Sheet rolling, steel	1.34
Acrylonitrile-butadiene-styrene copolymer, ABS	1.31
Wire drawing, copper	1.11
Freighter, oceanic	0.797
Refrigerant R134a	0.633

24% improvement

Glass Doors

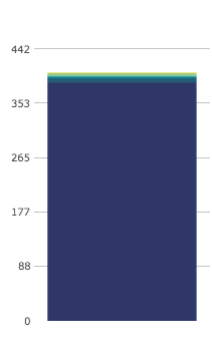


Total = 470 CO_2 eq. kg/func unit

Input	CO_2 eq. kg/func unit
Electricity, 120 V, US	447
Steel, converter, low-alloyed	7.22
Aluminium, primary	1.79
Polyurethane, rigid foam	1.63
Polystyrene, expandable, PS	1.40
Flat glass, uncoated	1.35
Incineration, rubber	1.32
Acrylonitrile-butadiene-styrene copolymer, ABS	1.31
Freighter, oceanic	0.804
Incineration, plastics, mixture	0.799

12.3% improvement

Differentiated

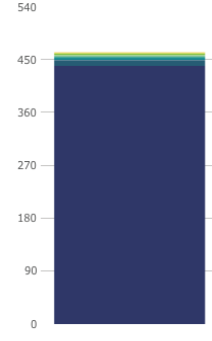


Total = 410 CO_2 eq. kg/func unit

Input	CO_2 eq. kg/func unit
Electricity, 120 V, US	387
Steel, converter, low-alloyed	7.22
Polyurethane, rigid foam	2.04
Aluminium, primary	1.79
Polystyrene, expandable, PS	1.54
Incineration, rubber	1.45
Acrylonitrile-butadiene-styrene copolymer, ABS	1.44
Sheet rolling, steel	1.34
Incineration, plastics, mixture	0.879
Injection molding, plastics	0.716

22.6% improvement

Modular

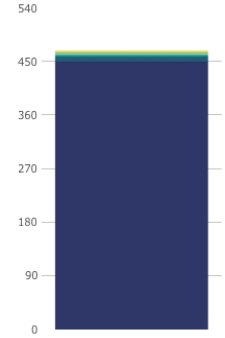


Total = 470 CO_2 eq. kg/func unit

Input	CO_2 eq. kg/func unit
Electricity, 120 V, US	440
Steel, converter, low-alloyed	10.1
Polyurethane, rigid foam	2.61
Polystyrene, expandable, PS	1.96
Incineration, rubber	1.84
Acrylonitrile-butadiene-styrene copolymer, ABS	1.83
Aluminium, primary	1.79
Sheet rolling, steel	1.34
Incineration, plastics, mixture	1.12
Freighter, oceanic	0.791

12.3% improvement

Adjustable



Total = 470 CO_2 eq. kg/func unit

Input	CO_2 eq. kg/func unit
Electricity, 120 V, US	451
Steel, converter, low-alloyed	7.22
Polyurethane, rigid foam	1.79
Aluminium, primary	1.79
Polystyrene, expandable, PS	1.54
Incineration, rubber	1.45
Acrylonitrile-butadiene-styrene copolymer, ABS	1.44
Sheet rolling, steel	1.34
Incineration, plastics, mixture	0.879
Injection molding, plastics	0.716

12.3% improvement

Decision Matrix

Objective	Weight	Alarm	Vacuum Panels	Glass Doors	Differentiated	Modular	Adjustable
LCA improvement	5	3	5	4	5	4	4
Reduce Energy Impacts	*(included in LCA)*						
Extend Lifetime	3	1	3	1	2	4	2
Light-Weighting / Material reduction	2	1	1	1	1	1	1
Reduce Lifetime Costs	3	5	2	4	4	4	3
User convenience	5	3	3	5	5	5	3
Totals		50	57	62	70	71	52

LCA Improvement | 5 We chose to give this objective a very high weight because the LCA's were the main tool used for sustainability analysis. These LCA's also incorporated and reflect our highest design priority, Reduced Energy Impacts.

Reduced Energy Impacts | 0 This objective was incorporated into LCA, therefore we did not weight it or grade it as it would provide redundant scores.

Extend Lifetime | 3 We gave this objective a middle weight because we found this to have a fairly good impact on sustainability in our earlier exploratory LCAs. Although not reflected in the provided LCAs, some of the proposals have the potential to increase the lifetime of the appliance. Therefore, we felt these design options should get a slightly better score.

Material Reduction | 2 We give this objective a low weight because none of our proposed design solutions dealt with reducing materials, and most of them actually increased the overall amount of materials used in fabrication.

Reduce Lifetime Costs | 3 We gave this objective a middle weight because although it is important to customer choices, we didn't have accurate information on what the initial price ramifications (ie: material costs) would be for each of the proposals. Therefore, we felt a middle weight would ensure we weren't improperly directed towards a different solution based upon imperfect knowledge.

User Convenience | 5 We gave this a objective a very high weight because we felt it directly effects whether customers would accept the new technology, plus we could easily assess the level of added convenience through a simple discussion of each proposal's merits.

Evaluation Units

1	bad	worse
2	unsatisfactory	1-5%
3	OK	6-9%
4	good	10-15%
5	best	0.2

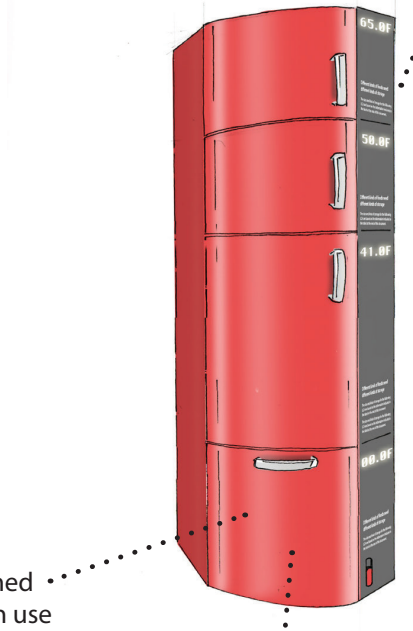
Winning Design | differentiated refrigerator

The differentiated design and the modular design were similar concepts and also very close contendors for our final design choice. However, based on the combination of the LCA results and the weighted decision matrix, the differentiated refrigerator became the clear winner.

The differentiated refrigerator has different refrigeration compartments, each with its own thermostat and controls. One module is set up as a freezer, another is set for meat and dairy, and another for fruits and vegetables or breads. Compartments can be turned off entirely when not in use. Recommended storage guidelines are included on the temperature control panel. Optimal energy savings are realized when each compartment is set at the recommended temperature.

individual temperature controls, by compartment, allow the user to raise or lower the temperature, based on the type of food being stored

recommended storage temperatures for various food groups are listed on the side of each compartment so that compartments are not kept any cooler than needed



up to 65°F	20% of storage space	459,9 kWh
50°F	20% of storage space	919,8 kWh
41° F	40% of storage space	3679,2 kWh
0°F	20% of storage space	1839,6 kWh

energy use in total per year 6898,5 kWh

compartments can be turned off completely when not in use

a variety of colors to choose from, based on the consumer's design preference

Winning Design | differentiated refrigerator

Sustainable Goals:

Priority	Objectives	Metrics
S1	Reduce Energy Impacts	by 25%-50% (as measured by $C0_2$)
S2	Extend Lifetime	by 15 years (entire lifetime = 30 years)
S3	Light-Weighting / Material reduction	reduce material impacts by 20%-50% (as measured by $C0_2$)

General Goals:

Priority	Objectives	Metrics
G1	Reduce Lifetime Costs	by reducing operating costs in relation to purchase price by 10-30%
G2	User Convenience	increase usability and storage options

This differentiated design improves the refrigerators energy use impact (as measured by CO_2) by 22.6%. This design allows for reduced lifetime costs because it allows for portions of the refrigerator to be kept at higher temperatures based on recommended food storage guidelines, thus requiring less energy to operate. It also allows the user to turn off sections completely when not in use, saving even more energy.

The differentiated design has some potential for extended life since the varying compartments will not all need to be run at such low temperatures, which could increase the life of the compressor and cooling components.

This design reduced overall SBOM impacts by 23.5%.

We think that customers will find this design to be both cost efficient and much more convenient than a standard refrigerator. The different compartments allow the consumer to adjust the temperatures of each compartments to meet all of their food storage needs. The variety of colors also allow consumers to add color or sleek simplicity based on their aesthetic decorating preference.

Sources

page 2: designs by The Noun Project: fuel by Ben Johnson; headphones by Ed Harrison; compost bin by Hannah Coward; tractor by Diego Naive; live fish; refrigerator by Nathan Thomson; market by nicolas moles; car by Okan Benn; garbage truck and fan by Edward Boatman; water drop by Ealancheliyan s; dump truck by Will Gausmann; factory by Amelia Wattenberger

[1]Dept of Energy: http://www.eia.gov/energyexplained/index.cfm?page=electricity_factors_affecting_prices

pages 4 & 5: hMp://docs.lib.purdue.edu/cgi/viewcontent.cgi?ar7cle=1500&context=iracc; hMp://m.evonik.com/inm/evonik/?lang=en&jumpto=/en/products/productstories/Pages/aviprefrigerator.aspx; hMp://www.thedailygreen.com/goinggreen/7ps/refrigeratordoorwastesenergy

REDESIGNED REFRIGERATOR:

Business Objectives

The primary business objective of the redesigned refrigerator is to reduce the Beyond the environmental impacts associated with energy use and materials captured in the LCA, the winning design addressed other business metrics as well.

Reducing the weight of the unit from 186 to 97 pounds not only reduces the environmental impacts associated with shipping, but it also allows the user more freedom to place the unit where it is needed. The smaller size and kitchen-island-like form change the top of the fridge from a dust collector to useful food preparation surface.

By greatly improving the use-phase energy consumption, the cost savings on energy help to offset the increased purchase price associated with the vacuum-insulated panels when compared to the Concept model. It is expected that the purchase price of this unit would still be comparable to the Baseline model. The cost of the unit will play a significant role in the adoption rate of this innovative refrigerator.

The modular nature of the drawer system allows for direct reuse of components through a product take-back program, and while the extra transportation adds some environmental impacts, the savings associated with avoiding the landfill outweigh the costs. The end of product life is further improved by using less-toxic materials than the Baseline model.

A smaller unit will require a change in user behavior. To help encourage that change, the winning design incorporates a welcoming aesthetic, which combined with the lower sticker price and extreme long-term energy savings should encourage new users to try the product.

By identifying opportunities for improvement in a traditional model, a user-friendly, streamlined, and energy efficient model was identified. Design for function as opposed for form creates a more sustainable, common-sense model rooted in the benefits of the triple bottom line.