The Improved Refrigerator

Assignment: 6.3 | ✳ Group Assignment: Final Recommendations

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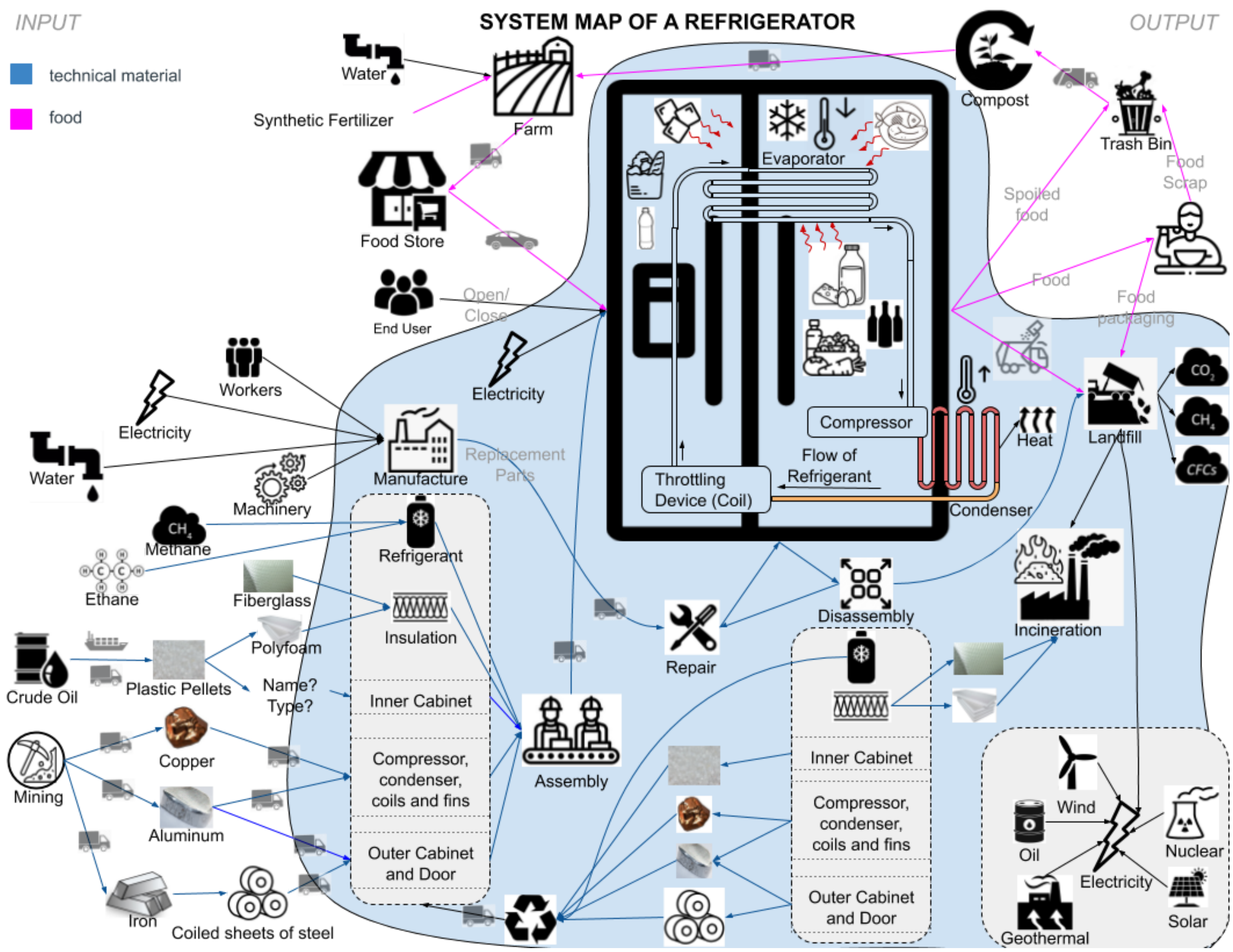
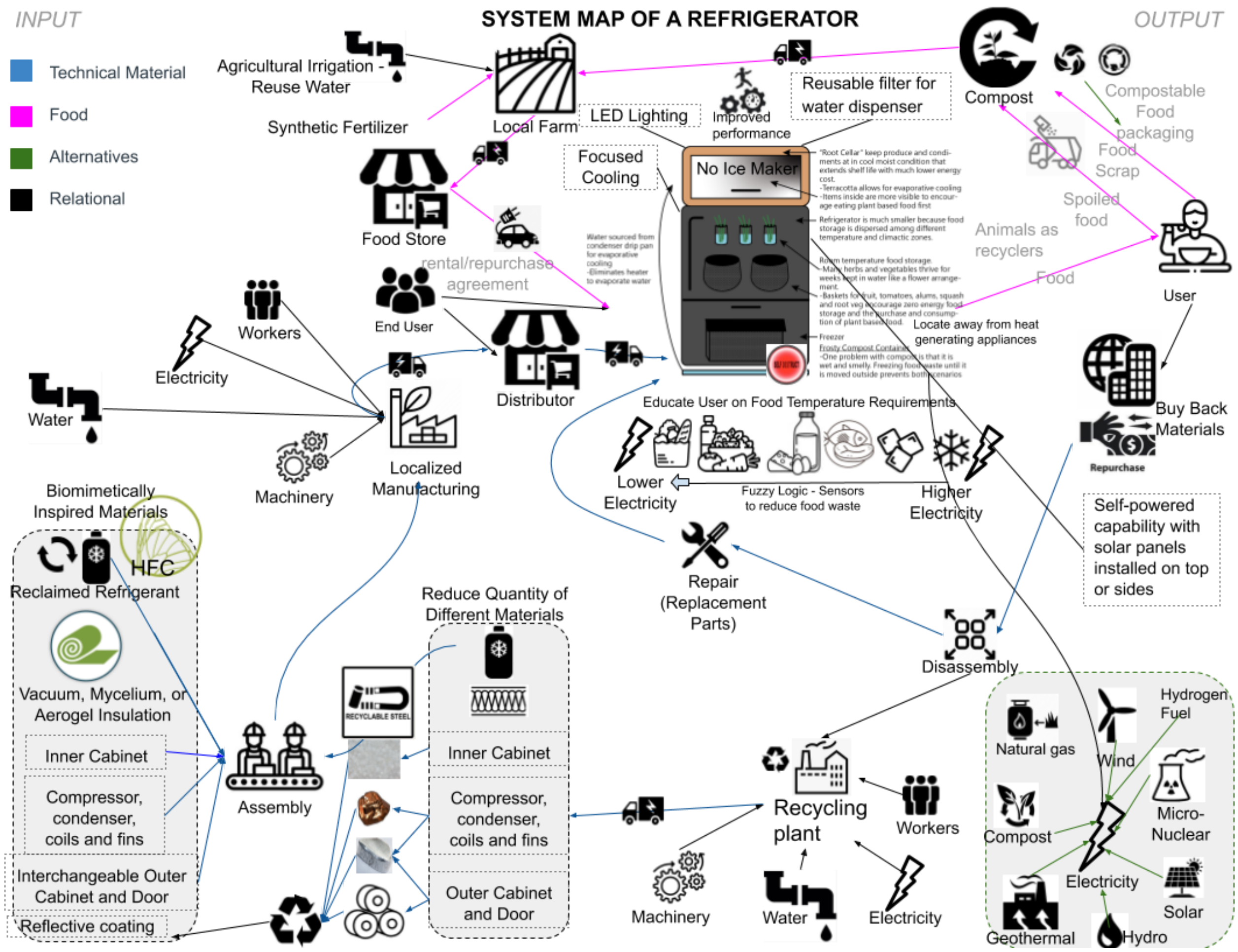
SYSTEM MAP

System Map of the Original Refrigerator



System Map of the Improved Refrigerator



DESIGN BRIEF’S PRIORITIES AND METRICS

Top Priorities for Redesign - In order of importance

Priority #1: Recycling: Use of recycled materials in unit and reclaiming materials at end of use cycle

Metric: Unit is made of 80% recyclable materials, and implements a circular system to make new units out of 80% reclaimed material.

Reasoning: Replacing virgin materials with recycled materials and incorporating reclamation of materials to be reintegrated into future units reduces waste and environmental impacts.

Priority #2: Electricity: US low voltage compared to Euro low voltage ratio to calculator US footprint

Metric: Lower overall electricity consumption and ensure that electricity usage during manufacturing is from 50% renewable energy sources.

Reasoning: Using renewable/more efficient electricity sources lowers the unit's environmental impact.

Priority #3: Plastic: Reclaiming plastic and incorporating compostable plastics into design

Metric: The use of bioplastics provide an 80% lower carbon footprint from the plastic components of the unit when compared to traditional plastics.

Reasoning: Using Recyclable/Biodegradable plastics reduces the impact in manufacturing and end of life.

Priority #4: Insulation: Explore the potential for Aerogel as an alternative material for insulation versus traditional insulation materials (i.e. polyurethane foam)

Metric: Alternative insulation methods (aerogel) can improve efficiency from energy usage by 14x

Reasoning: Lower thermal conductivity directly relates to amount of electricity consumed during use.

Priority #5: Shipping: Oceanic Shipping is most impactful by a factor of 10-20 versus truck

Metric: 10% reduction on weight even if the material is recycled or reclaimed the weight is consistent.

Reasoning: Moving the location of manufacturing and/or decreasing the weight of the unit makes shipping much more efficient and drastically lowers the environmental impact of the unit’s transportation.

Scope and Functional Units of LCAs

Scope/Boundaries:

- Cradle to Gate (Lifespan), Typical Lifespan in an average of 15 years.
- Focus on Manufacturing > Use > Disassembly.

Functional Units:

- Material Impact Per Unit Of Service (MIPS) - Ecological Rucksack

THE WINNING OPTION

Description

To reduce the number of materials we would use **mycelium** as a sustainable alternative to energy intensive synthetic materials such as plastic when possible and steel.

Ecological Impacts

Steel production has a number of impacts on the environment, including air emissions (CO, SOx, NOx, PM2), wastewater contaminants, hazardous wastes, and solid wastes. The major environmental impacts from integrated steel mills are from coking and iron-making which would decrease if we replace steel panels with mycelium. Mycelium is 100% organic, compostable, and biodegradable and it uses less energy in production, when it is dried, it becomes incredibly durable and resistant to water, mold, and fire making it ideal to replace steel refrigerator panels.

Mycelium composites have customizable material properties based on their composition and manufacturing process and can replace some of the plastics used in a unit.

Meeting Other Business Objectives

Lifespan of the refrigerator
Ease of use, complexity

SKETCH OF THE WINNING DESIGN

In the winning design, there were no changes to the appearance of the refrigerator. The mycelium panel is used as the insulation and the frame of the refrigerator.

LCA COMPARISON

The Redesign #1

The Redesign #1 improves the insulation of the refrigerator by replacing the existing polyurethane foam with aerogel.

Silica Aerogel has the lowest thermal conductivity of any solid, with an R-value of 20. Polyurethane, by comparison, has an R-value of 7.14 when it is brand new, however, within the first year of use it can degrade effectiveness down to an R-value of 5.0. That means Aerogel could be 300% more efficient. 7% of the unit's total energy use comes from opening the unit, which means that the remaining 93% of energy consumption is used to keep the unit cold while totally sealed. I'm going to round this to 90% to account for the added loss from the gasket. This means that 63 watts of the 70 watts used can be attributed to the polyurethane insulation. To maintain the same tempera-tures with aerogel insulation only 15.75 watts is required, bringing the total energy usage to 22.75 watts, less than a third of the energy consumption.

The manufacturing CO2 emissions are higher, but according to LCAs conducted by a team out of Brunel University, London, the CO2 emissions can be recovered in under two years of use. This was too complicated to have captured in the ecolizer tool.

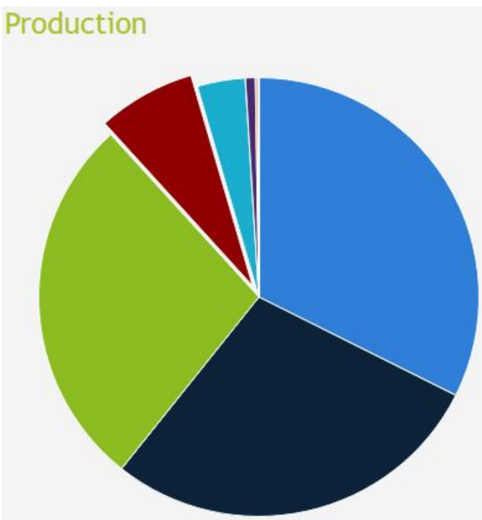
There are a handful of silica aerogel manufacturing methods, each with their own density. In general, Silica aerogel is 97% air and only 3% silica. It would be lovely to have the volume of insulator listed in the BOM, but without that, I'm choosing to take 3% of the 5.6 kg of polyurethane and calculating the .2kg as silicate (water glass). Silicate (water glass) is the unprocessed initial form the silica aerogel starts as and Ecolizer actually has that in the catalog.

The Redesign #2

The Redesign #2 improves the insulation of the refrigerator by replacing the existing polyurethane foam with on-the-market Vacuum Panel Technology.

The vacuum panel used in the LCA is the Panasonic Standard U-Vacua TZB7840E panel. A copy of the datasheet is shown below. The panel consists of a unique glass fiber core and an adsorbent surrounded by laminate film. The adsorbent is not included in the LCA. The laminated film is assumed to be entirely made of PET. By replacing polyurethane foam insulation with vacuum insulation, the environmental impact of insulation in the production phase decreases by 74.5%, from 3259.2 mPt to 834.55 mPt.

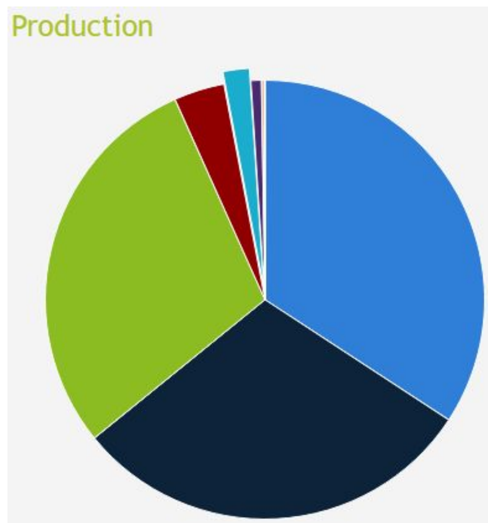
Original Design



6. Insulation

Material or process	Amount	Indicator	Result
PUR - polyurethane: PUR, rigid foam	5.6 kg	452	2531.2
PUR - polyurethane: Injection moulding	5.6 kg	130	728
		Total:	3259.2

The Redesign #2

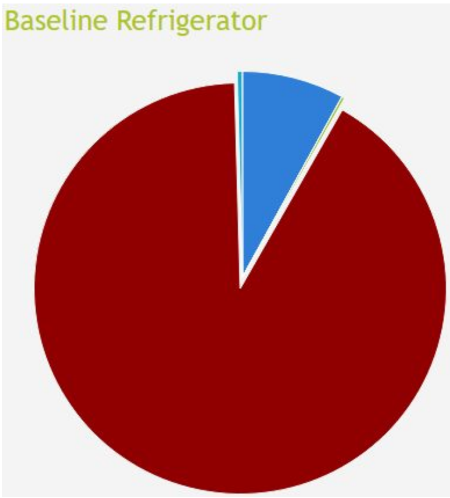


6. Insulation

Material or process	Amount	Indicator	Result
PET - polyethylene terephtalate: PET, recycled	1 kg	80	80
PET - polyethylene terephtalate: Vacuum forming	1 kg	20	20
glass: glass fibre	2.49 kg	273	679.77
glass: tempering	2.49 kg	22	54.78
		Total:	834.55

The vacuum panel from Panasonic has an R-value of 66 °F·sq.ft.·hr/Btu while the polyurethane foam has an R-value of 6.25 °F·sq.ft.·hr/Btu. The R-value of both materials degrade over time; since the rate of degradation is unknown, both materials are assumed to degrade at a rate such that the ratio of their R-values remains constant. And since the ratio between the vacuum panel's R-value and the polyurethane foam's R-value is 10.56, the energy consumption during usage is said to decrease by the same factor. By replacing polyurethane foam insulation with vacuum insulation, the environmental impact of insulation in the production phase decreases by 90.5%, from 515,088.2 mPt to 48,786.19 mPt.

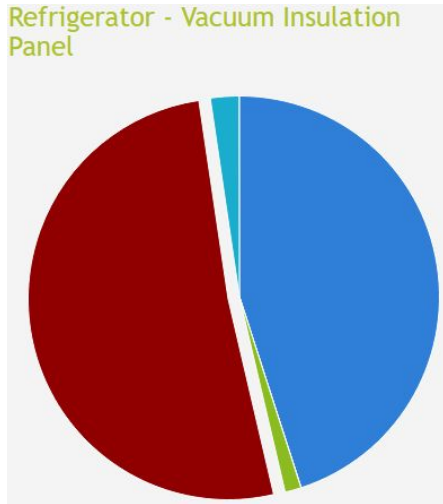
Original Design



Usage

Component	Amount	Result
Energy	-	515088
	Total:	**515088**

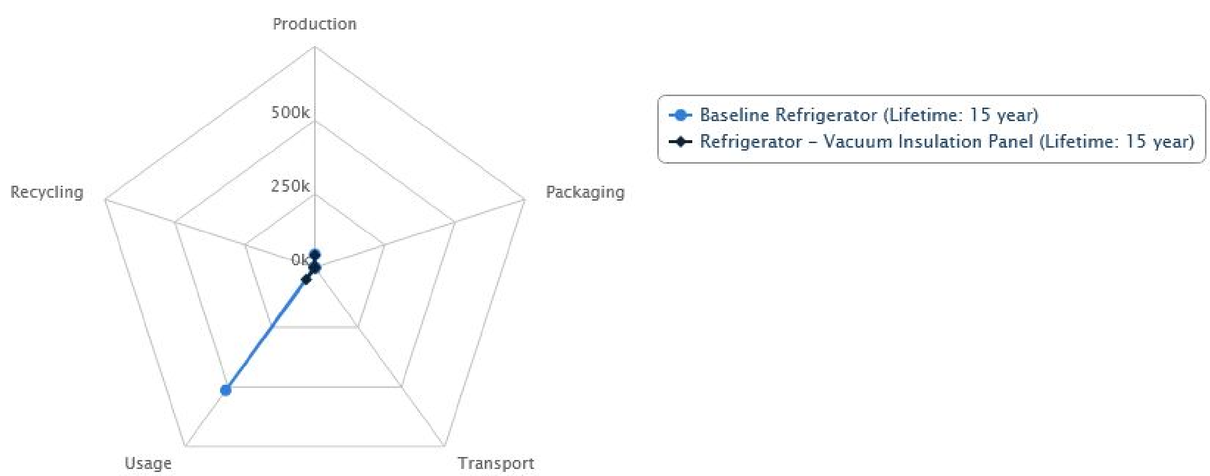
The Redesign #2



Usage

Component	Amount	Result
Energy	-	48786.19
	Total:	**48786.19**

By replacing polyurethane foam insulation with vacuum insulation, the environmental impact of the overall design decreases by 83.1%, from 563,959.75 mPt to 95,048.55 mPt.



Design	Production	Packaging	Transport	Processing	Recycling	Total
Baseline Refrigerator	45217.9	0	1284.75	515088	2369.1	563959.75
Refrigerator - Vacuum Insulation Panel	42793.25	0	1249.81	48786.19	2219.3	95048.55

The Redesign #3

The Redesign #3 improves the insulation of the refrigerator by replacing the existing polyurethane foam with mycelium insulation panel.

A mycelium insulation panel has a thermal conductivity between 0.04 W/(m K) to 0.08 W/(m K). A polyurethane foam insulation has a thermal conductivity between 0.022 W/(m K) to 0.035 W/(m K). In order to match the insulation capability of the two materials, the thickness of a mycelium insulation panel must be doubled.

There was not enough information to complete an LCA for the mycelium panel. However, the following information was used to conclude that the mycelium panel is highly likely to have a much lower environmental impact compared to the polyurethane foam panel:

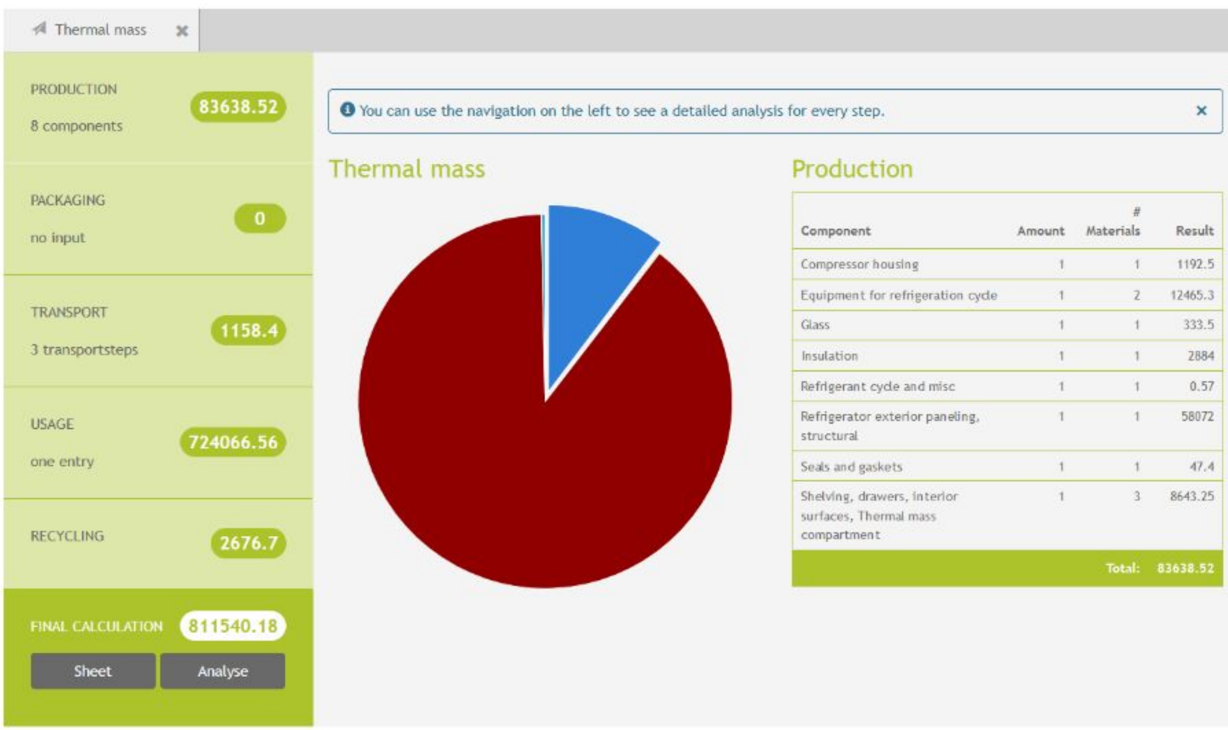
1. The mycelium panel is 100% organic hence is 100% compostable.
2. The mycelium panel is made from waste materials such as coffee grounds, wood dust, etc. hence virgin materials are hardly used.
3. The mycelium panel only requires heat but no special processes such as sheet rolling or blowing in the production phase which means that its production process is likely to consume less energy than the production process of polyurethane foam.
4. The substrate of the mycelium is soaked in water for a period of time in which grey water can be used.

The Redesign #4

The Redesign #4 introduces thermal mass to cool the lining of the refrigerator.

Thermal MassThermal mass is sometimes referred to as having a thermal flywheel effect because it provides"inertia" against temperature fluctuations. Rather than cooling the air in a refrigerator, the unit could contain an internally cooled thermal mass (like a heated tile floor) in the form of a shelf or as a lining. This thermal momentum would ward against energy loss due to frequent or prolonged opening of the door. The immediate problem with this concept is that it has the possibility of adding substantial weight to the unit. To give this idea merit, I propose that the unit is manufactured in a more centralized location then distributors or installers can fill the thermal mass compartment with an appropriate localized material, even water is a serviceably dense material for this purpose. This will not require more material or weight, just a reallocation of materials. Opening the door accounts for 7% of the appliance's total energy use, according to Home Energy Magazine. 7% of 70 watts comes to 4.9 watts. Let’s say that the thermal mass reduces this energy loss from 7% to 3%. That brings the overall energy consumption down to 67.2 watts.

Boundary: Cradle to Gate (Lifespan), Typical Lifespan in an average of 15 years. Focus on Manufacturing > Use > Disassembly.



Component	Amount	# Materials	Result
Compressor housing	1	1	1192.5
Equipment for refrigeration cycle	1	2	12465.3
Glass	1	1	333.5
Insulation	1	1	2884
Refrigerant cycle and misc	1	1	0.57
Refrigerator exterior paneling, structural	1	1	58072
Seals and gaskets	1	1	47.4
Shelving, drawers, interior surfaces, Thermal mass compartment	1	3	8643.25
		Total:	83638.52

The Redesign #5

The Redesign #5 introduces the compost section integrated into unit design.

The idea is to add a section to the refrigerator that would make composting easier for everyone.Greenhouse gases generated from food rotting in landfills could be reduced to help mitigate climate change.

A box-like compartment with a pull-out drawer can be added to the freezer section. To reduce the number of materials we would use mycelium as a sustainable alternative to energy intensive synthetic materials such as plastic. Mycelium composites have customizable material properties based on their composition and manufacturing process and can replace some of the plastics used in a unit.

The Redesign #6

The Redesign #6 introduces modular compartments to build and change the shape of the interior of the refrigerator as needed.

The following LCA uses the above assessment of recycled material integration and reclamation and adds in a modular segmented design. Taking a page from Mitsubishi Electric Corp.'s refrigerator unit of segmented compartments to reduce energy loss when opening and closing the fridge, we are adding material demand up front by increasing the material required to manufacture the unit and comprise the individual compartments. The energy savings from increased efficiency of the unit through the use of a modular/segmented design provides long-term gains. The Mitsubishi Electric refrigerator is an example of the proposed changes in the Redesign #6..

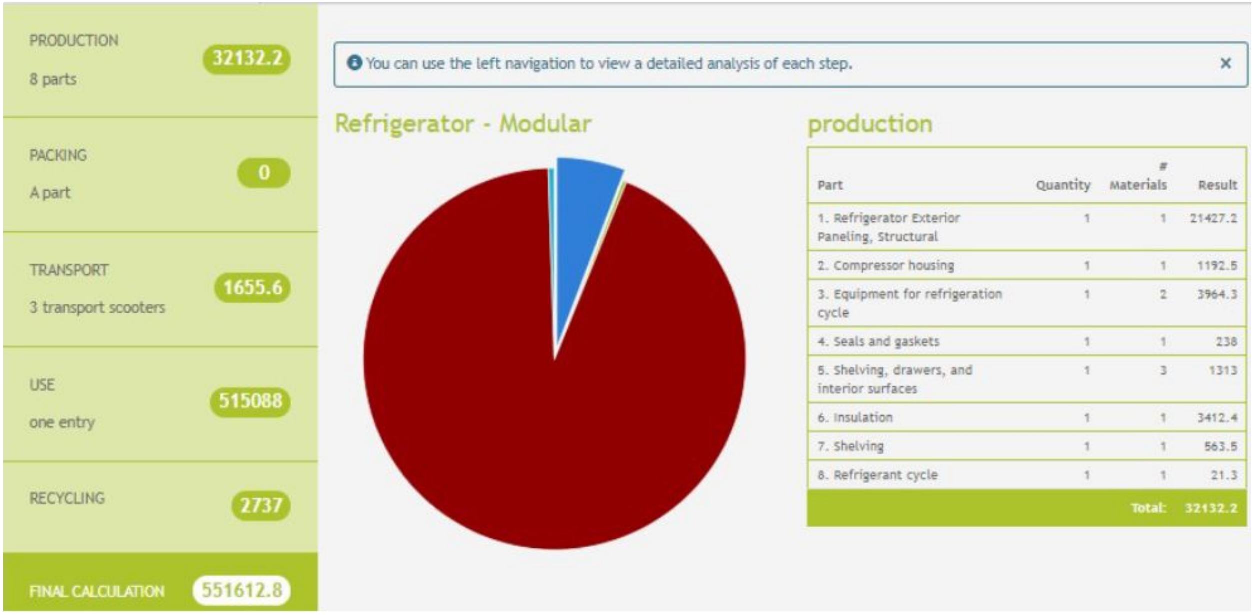
Mitsubishi Electric cutting-edge refrigerators answer call for energy efficiency

One of the world's leading suppliers in electrical products, Mitsubishi Electric, has launched two new fridge models with 4.0 star, energy rating.

The launches arrive in Australian stores following reports that the average Australian is paying $807 more for their power than they need to, more than half of the average weekly wage. Reports also show a rising trend in energy efficiency among Australians*.

The Mitsubishi Electric LX630 and WX500 are set to be in high demand in the Australian market and showcase how the manufacturer is leading the way for energy efficiency in today's current climate, with the new fridge models possessing stand-out features such as a power saving mode and ECO mode.

Mitsubishi Electric WX500 multi drawer refrigerator



Part	Quantity	# Materials	Result
1. Refrigerator Exterior Paneling, Structural	1	1	21427.2
2. Compressor housing	1	1	1192.5
3. Equipment for refrigeration cycle	1	2	3964.3
4. Seals and gaskets	1	1	238
5. Shelving, drawers, and interior surfaces	1	3	1313
6. Insulation	1	1	3412.4
7. Shelving	1	1	563.5
8. Refrigerant cycle	1	1	21.3
		Total:	32132.2

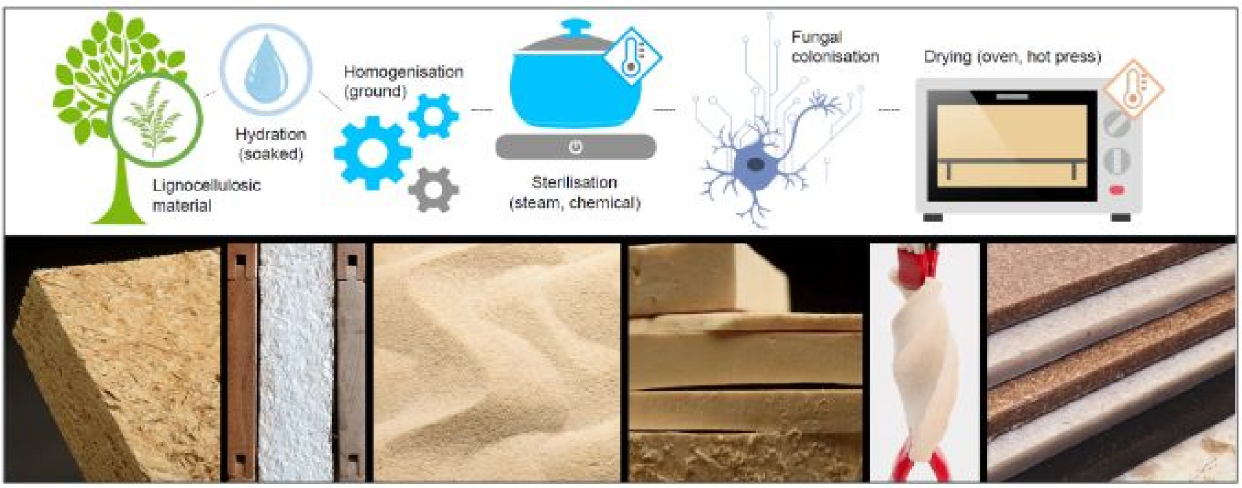
The Redesign #7

The Redesign #7 removes steel from the original design which makes the refrigerator lighter. The insulation material is made of mycelium panel which is sufficient in providing structural support to the refrigerator.

Two materials have the potential to be replaced.

We can reduce plastics by replacing it with mycelium when possible.• Steel panelling can be replaced with mycelium which can have the same strength. When it is dried, it becomes incredibly durable and resistant to water, mold, and fire making it ideal for a refrigerator.

Steel has a high environmental impact, and it could be an easy replacementMycelium is 100% organic, compostable, and biodegradable and it uses less energy in production. Boundary: Cradle to Gate (Lifespan), Typical Lifespan in an average of 15 years.

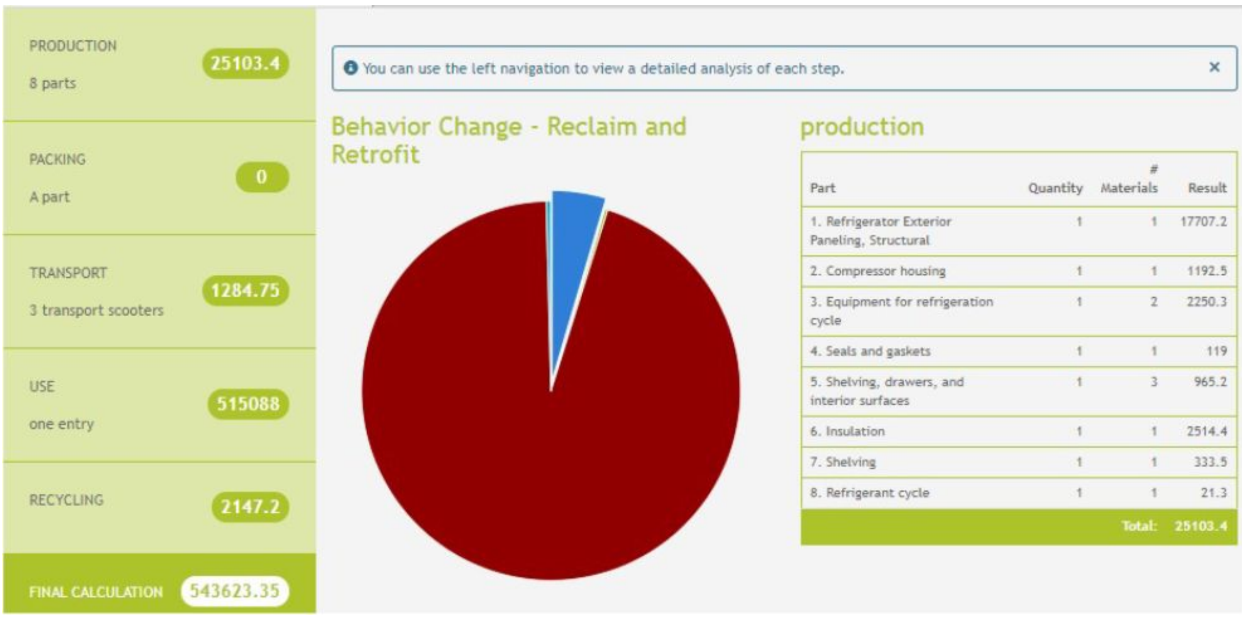



PRODUCTION
5 components
14534.7
PACKAGING
one component
0
TRANSPORT
3 transportsteps
403.54
USAGE
one entry
450702
RECYCLING
912.5
FINAL CALCULATION
466552.74
Sheet
Analyse
You can use the navigation on the left to see a detailed analysis for every step.
Refrigerator1032020
Production
Component Amount # Materials Result
glass 1 1 319
Metals 1 3 10516.8
plastics 1 3 3589.3
Refrigerant 1 2 23.2
rubber 1 1 86.4
Total: 14534.7

The Redesign #8

The Redesign #8 retrofits existing units, reuses shelves and replaces broken components, and buys back parts.

The following LCA uses the base refrigerator BOM but implements a behavior change and encourages the reuse and recycling of all materials. A circular economy for the refrigerator units requires that all materials be reclaimed and recycled and that existing units be retrofitted upon end-of -life to be reintegrated into the system of reclamation instead of waste generation



Part	Quantity	# Materials	Result
1. Refrigerator Exterior Paneling, Structural	1	1	17707.2
2. Compressor housing	1	1	1192.5
3. Equipment for refrigeration cycle	1	2	2250.3
4. Seals and gaskets	1	1	119
5. Shelving, drawers, and interior surfaces	1	3	965.2
6. Insulation	1	1	2514.4
7. Shelving	1	1	333.5
8. Refrigerant cycle	1	1	21.3
		Total:	25103.4

THE DECISION MATRIX

Adjustment in Priority

Due to overlapping contents, some of the original priorities were adjusted. The original priorities, the new priorities, and the reasons for the adjustment are shown below:

#	Original Priority	Modified Priority	Reasons
1	Recycling	Circularity	-Cover materials that are compostable and/or reusable. -Cover the original priority #3.
2	Electricity	Energy Consumption in Production	-Electricity is split into energy consumption in production and in usage to clearly show the performance of each redesign. -See reasons for priority #4.
3	Plastic	Low Impact Material	-Cover the impact of a material on the environment regardless of how much the material is used.
4	Insulation	Energy Consumption in Usage	-See reasons for priority #2. -The environmental impact of energy consumption in usage mainly depends on two factors: how energy is generated (unsustainable or sustainable energy sources) and how much energy is lost during usage which solely depends on the insulation.
5	Shipping	Shipping	None.

Explanations for the Weight of Priorities

The priorities are weighed based cradle to cradle concepts and the four system conditions in the Natural Step. The highest weight (most important) is 5, and the lowest weight (least important) is 1. Here are the explanations for the weight score:

- Priority #1 receives a weight of 5 because no parts of the refrigerator should become waste or be sent to landfills.
- Priority #2 receives a weight of 3 because if materials/components are designed such that they can be recovered and reused, the energy consumption in production will automatically decrease.
- Priority #3 receives a weight of 5 because materials that are obtained by means of blowing up mountain tops or clearing forests are not as sustainable as materials that are obtained without those means.
- Priority #4 receives a weight of 4 because the energy consumption in usage can be well controlled by the redesign of the refrigerator. This parameter also fluctuates with the size of the refrigerator and the number of times the users open/close the refrigerator's door per day.
- Priority #5 receives a weight of 1 because shipping had the least impact in the original design.

The Decision Matrix Calculation and Result

The decision matrix for The Redesigns is shown below. The winning design is the Redesign #7 with 72 points (highlighted in orange) in which the use of steel is eliminated and mycelium panel is used for insulation and frame of the refrigerator. In second place is the Redesign #3 with 67 points in which mycelium panel is used for insulation. Redesign #1 takes third place with 62 points in which aerogel is used for insulation.

		Options									
Objective	**Weight**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**
Priority 1 - Circularity	5	5	5	5	1	3	1	5	4		
Priority 2 - Energy Consumption in Production	3	1	1	4	1	1	1	5	4		
Priority 3 - Low Impact Material	5	3	2	5	1	1	1	5	1		
Priority 4 - Energy Consumption in Usage	4	4	5	1	3	2	3	1	1		
Priority 5 - Shipping	1	3	3	1	1	1	1	3	1		
	Total Score:	**62**	**61**	**67**	**26**	**32**	**26**	**72**	**42**	**0**	**0**

Scoring Key: 5 = Best in the market. Significant improvement over existing design. Paradigm shifting.
4 = Great but no paradigm shift.
3 = Statistically significant. Measurable impact.
2 = Slightly better than existing design.
1 = Lateral change.

Option and Description

1. Aerogel Insulation.
2. Vacuum Panel Technology - Highly efficient for cooling/insulating.
3. Superinsulating: increased efficiency but increases material, and encouraged material reclamation. Mycelium.
4. Thermal Mass to cool lining of fridge.
5. Compost section integrated into unit design.
6. Fridge modules to build and change unit shape as needed.
7. Make units lighter. Reduce number of different materials. Eliminate steel.
8. Behaviour change. Retrofit existing units, reuse shell and replace broken components, and buy back parts. Circular Economy/System. Design for Disassembly.
9. Focused cooling into specific sections for reduced energy use while away (temperature-controlled compartments).
10. Viewing panels or small openings to reduce cool air loss while searching for food.