MINI PROJECT #10: DESIGN FOR RECYCLING

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Mini-project #10: Design for Recycling (150 points)

Recycling is essentially the reverse of manufacturing: products go in, and materials come out. It is a well-established and highly developed practice but is often misunderstood. For instance, the scale of recycling operations is routinely under-estimated, and although recycling usually has a beneficial effect on the environment, it is primarily an economic activity, done to make money.

More importantly, although products are manufactured using specific production facilities, they are generally recycled in bulk, with different types of products ending up in the same waste stream and getting processed together. It is therefore important to know in which waste stream your product is likely to end up.

The manufacturing triangle of function, cost, and quality can also be used to interpret recycling issues with products. Certain products can be easily recycled into separate high-quality materials, whereas others cannot (or only at high costs). The concept that explains this trade-off is the grade recovery curve.

i. What is a circular economy? Briefly describe with the help of a diagram. (5)

A circular economy is a sustainable system which consists of four main areas. Referring to Fig. 1, in the production phase, materials are initially taken in from the environment and manufactured into products. In the consumption phase, these finished products are bought by consumers and used until the particular product breaks/is at the end of its life expectancy. The next phase is the waste management phase in which these materials are disposed, dismantled and assorted into the types of materials they constitute. From the waste to resources stage in the below diagram, these waste resources are then cleaned, treated and used again if they are recyclable and if not, it is made sure the biodegradable materials are left to degrade through the use of bacteria and other microorganism environments. Its main principles revolve around reducing, reusing and recycling products and in today's world is something essential. This cyclical pattern encourages the use of biodegradable/re-useable materials and limits the amounts of wastage of materials. It is slowly replacing the lineal economy model and different companies have their own interpretations of the circular economy models, as can be seen in Fig.2.

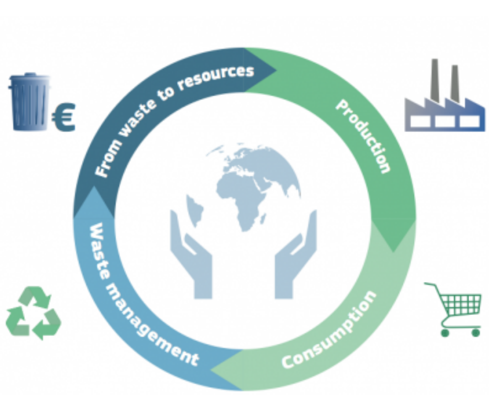

Fig.1: General Circular Economy Diagram

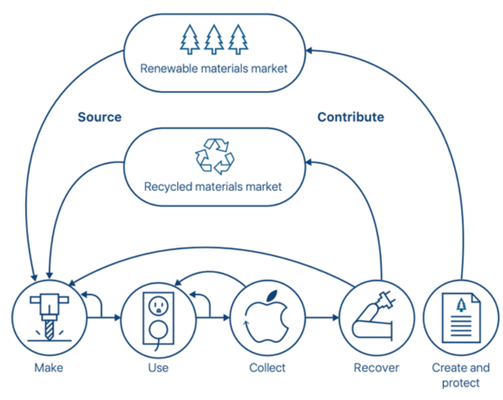

Fig.2: Apple's Circular Economy Diagram

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[1] "What Is Circular Economy?" *Sustainability for All*, www.activesustainability.com/sustainable-development/what-is-circular-econom

ii. Modern recycling processes must contend with losses in the life cycle of materials, mainly due to imperfect collection: not all products that could be recycled are collected, or if they are, they end up in the wrong waste stream. (e.g., Currently, only 5% of discarded cell phones go to the proper collection points—the rest end up in the domestic waste stream.)
Perform Internet research and briefly report on design strategies that facilitate the (separate) collection of end-of-life products, such as labels or electronic markers. Then consider the viability of laws to achieve the same objective. What is your conclusion regarding design for recycling? (10)
Hint: Considering that design can only suggest certain behavior that laws can easily make mandatory (although enforcing such laws may be another matter), you should not be surprised to conclude that when it comes to collection, design for recycling will have only limited potential.

To understand design strategies that facilitate the separate collection of end of life products,

There are multiple design strategies used by most companies today as sustainability rises to the forefront. Due to increasing costs of raw materials (in some areas), companies have started recycling not only to contribute to the sustainability initiative but to also reduce their initial costs. They usually mark their products with the sign below which indicate to not dispose the products containing these symbols in a conventional manner but to bring it back to the seller so that these products can be responsibly recycled and/or disposed off.

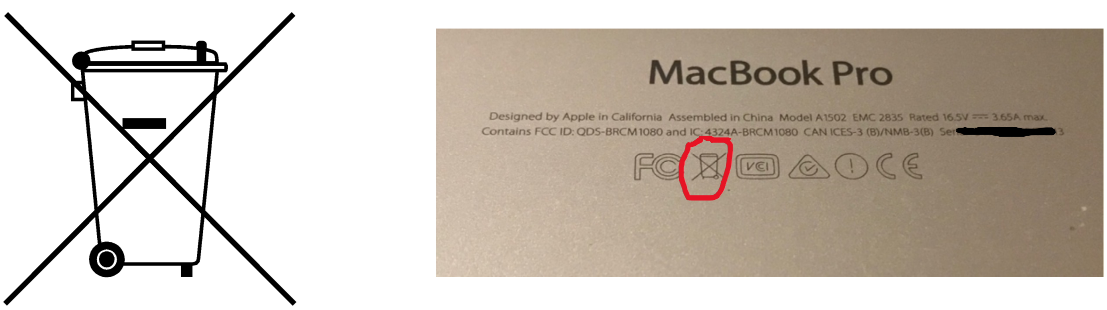

Fig.3: Markers showing that the product is unsafe to dispose off conventionally

In addition to these strategies "E-Waste Only" signs have become very omnipresent especially in/near housing complexes. In certain countries responsible disposal of recyclable components are required by law. In Singapore for example, recycling is a core part of the children's curriculum and there are multiple third-party makerspaces that teach people how to recycle and repair their broken products which leads to lesser wastage. There are also the Sustainable Development Goals Listed employed by the United Nations, of which the 12th Goal is that of Responsible Consumption and Production.

Fig. 4: Recycling Signs found on bins for Electronics Recycling

Certain design strategies employed by companies are those of reverse engineering the creation of a product when recycling them. Most of these production processes are automated and carried out by robots especially those involving segregation of multiple components. This is fairly common in the electronics industries such as Apple and Samsung and automotive manufacturers such as TESLA and are also moving towards this. However, to provide further insight it is noteworthy to look at Apple's recycling procedures.

Apple has a robot by the name of Daisy[2] which is responsible for part segregation. In addition, a percentage of the Aluminum used on an Apple product is recycled. This helps the company reduce costs of buying new raw materials and it is also extremely sustainable. Furthermore, the company salvages certain electronic components from their devices such as minute quantities of precious metals. They use these reacquired raw materials in their prototyping phases as well as in the production of new products. Furthermore, they provide users with an incentive to recycle by offering them rebates on their newer products. They also upload videos of their robots disassembling products to make recycling more appealing to the watchers.

Laws to mandate design for recycling would help to a certain extent in limiting waste. These concepts should be inculcated in academia instead so that more people feel a sense of responsibility. Furthermore, it would be difficult to enforce design for recycling laws, but it would be more helpful by providing corporations who follow design for recycling procedures with tax rebates and other such "rewards" from the government. All in all, design for recycling is an important approach which should be followed by the corporations all around the world. However, one major challenge that is faced is certain products are not economical to recycle and more research is needed to be done into methodologies to economize recycling.

iii. Grade is a measure of quality and it captures concentration levels (i.e., how pure a certain fraction is). If grade captures quality, then Recovery is a measure of quantity: it describes how much of a certain material in the input stream is made available for reprocessing.
A recovery of R% means that (100 - R)% of the material going into the process is lost, ending up either in mine tailings or as a contaminant in one or more fractions.

By weight, copper wire contains about 70% copper and 30% PVC. Suppose we process 1 ton of wire per hour into a copper fraction of 0.74 ton/hour, of which 0.69 is copper and 0.05 is PVC. What is the weight and composition of the tailing? And what are the grade and recovery of the copper? (10)
Hint: You should find that the recovery is very high (not surprising, given the value of copper) and the grade is somewhat lower, but still "quite" high.

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[2] "Environment." *Apple*, www.apple.com/environment/.

$$Amount\ of\ Copper = 0.74 \times 1 = 0.74\ tons$$

$$Copper\ Recovery = \frac{0.69}{0.70} = 98.57\%$$

$$Copper\ Grade = \frac{0.69}{0.74} = 93.243\%$$

iv. Consider the following table with the energy and price data for various primary and secondary materials.
Now, for the coffee percolator shown, determine the total potential recoverable value of the materials, and give a range for your answer. (*Note:* Instead of a coffee percolator, you are welcome to choose another widely used product which is made of plastic and steel, combined with other materials.)
The coffee percolator contains 0.20 kg of steel, 0.10 kg of wrought aluminum, 0.12 kg of copper, 0.70 kg of PP, and 0.28 kg of glass, with a total mass of 1.40 kg. (It also contains small amounts of rubber and PVC, some ceramics in the heating element, and some solder; ignore those for brevity.) (10)
Hint: Simply run the numbers. Your answer should be less than $2.

Material	$GER_{primary}$ (MJ/kg)	$GER_{secondary}$ (MJ/kg)	$Price_{primary}$ (\$/kg)	$Price_{secondary}$ (\$/kg)
Low carbon steel	29–35	8–10	0.45–0.55	0.40–0.50
Wrought aluminum	200–215	18–19	1.80–1.90	1.60–1.70
Copper	68–74	17–19	5.10–5.60	4.80–5.30
Polypropylene (PP)	85–105	36–44	1.40–1.50	0.80–1.00
Borosilicate glass	24–26	11–12	3.00–4.50	1.00–1.20

GER, gross energy requirements.

TABLE 1

MATERIAL	WEIGHT (kg)	PRICE PRIMARY ($/kg)	PRICE SECONDARY ($/kg)	PRIMARY PRICE RANGE ($)	SECONDARY PRICE RANGE ($)
Low Carbon Steel	0.20	0.45 - 0.55	0.40 - 0.50	0.090 - 0.110	0.080 - 0.100
Wrought Aluminum	0.10	1.80 - 1.90	1.60 - 1.70	0.180 - 0.190	0.160 - 0.170
Copper	0.12	5.10 - 5.60	4.80 - 5.30	0.612 - 0.672	0.576 - 0.636
Polypropylene (PP)	0.70	1.40 - 1.50	0.80 - 1.00	0.980 - 1.050	0.560 - 0.700
Borosilicate glass	0.28	3.00 - 4.50	1.00 - 1.20	0.840 - 1.260	0.280 - 0.336
TOTAL	1.40			2.702 - 3.282	1.656 - 1.942

The Total Estimated Secondary Value for the percolator is between \$1.656 and \$1.942, whereas the Total Estimated Primary Value for the percolator is between 2.702 and 3.282.

Therefore, the Total potential recoverable value is the Total Estimated Secondary Value between \$1.656 and \$1.942.

v. In countries where landfill space is scarce or expensive, municipal waste is often incinerated to reduce volume, and increasingly this is done with energy recovery, generating electricity and heat (e.g., for a regional domestic hot water system). Total energy efficiency can be up to 25%. This is much less than for regular fossil fuel power plants, mainly because waste is not a very good fuel, and because the intense waste-gas cleaning that is required uses a lot of energy. The amounts of waste are vast (in industrialized countries, typically 300 kg per person per year), and consequently the plants are large- scale, with the largest easily processing 1 million tons per year. Around 20% of the input is not burned and comes out as bottom ash: typically, just over 10% of this stream consists of metals (mainly steel, but also aluminum, copper, etc.), the bulk being a chemically inert ceramic residue enclosing the valuable metals.

To improve recovery, metals, paper, and stone can be separated from the waste prior to incineration: this is not only technologically possible but even economically feasible, and it is already done at certain locations. Some of the plastic packaging can also be recovered before incineration; however, this does require end-of-life fees to make it economically attractive.
The heat of combustion of PP is 46 MJ/kg. How does this compare to its GER? What if we also factor in the 25% efficiency? How "good" is "thermal recycling" in this case? (15)
Hint: if your answer is not in the range of 10-15% you have made an error somewhere. 'Good' is of course not very good at all in this case.

$$Heat\ of\ Combustion\ of\ PP = 46\ MJ/kg$$
$$Efficiency = 25\%$$

$$Average\ GER\ of\ PP\ (primary) = \frac{(85 + 105)}{2} = 95\ MJ/kg$$

$$Thermal\ Recycling\ Percentage = \frac{11.5}{95} \times 100 = 12.105\%$$

Based on the above calculations, a direct relationship can be seen between GER and the amount of resources being utilized for recycling which could be used elsewhere. Thus, it can be said that Thermal Recycling is not very efficient since only 12.105% of thermal energy is being recycled which is a very small percentage.