Recycling Homeworks #1, 2, 3, 4
Solutions

Recycling Homework # 1 *Solution*
2.83/2.813 Environmentally Benign Manufacturing

Curbside Recycling Questions

Review this calculation and Porter's Ch 9, then answer the following questions:
1. Is this right?
2. Add the quantity of waste per household as a variable and explore options to improve on the situation.
3. What does this development leave out?

Curbside Recycling Solutions

1) This calculation is an artifact of how waste and recycling costs are often charged. There are however, other ways to charge for these costs.

2) Concerning a) We add the quantity per house, W. See below.

Concerning b) If recycling grows to a large amount, you could stagger pick ups, say one week recycling and one week waste. This may lead to a smell issue. It might be partly abated by picking up compost (including food stuff) w/ recycled. In effect you are asking the homeowners to store the trash for a week.

Another strategy is to charge for the quantity of waste *W,* say at rate *k*. Then the cost of waste is $kW + WZ/C$. This in effect makes a fixed cost into a variable cost. This is the so called "Pay per throw" pricing system. Now the costs are: $kW(1 - r) + W(1 - r) Z/C$ and $k_rW_r + W_rZ/\alpha C$. Now the total cost can be written as

$$W[(k + \frac{Z}{C})(1 - r) + (k_r + \frac{Z_r}{\alpha C})r]$$

Now everything scales with "*W*". So the most effective way to reduce costs is to reduce *W*. The recycling constants k_r and Z_r are written with a subscript to differentiate them from the waste values of *k* and *Z*. In general $k_r < k$ because the recycler will obtain revenues from the materials recycled, however k_r could grow if you attempt to recycle too many materials (diseconomies of scope). It is likely that $Z_r > Z$ because hauling distances for some of the recycled materials may be quite large, however this depends upon local conditions.

Concerning c) There is a complex trade-off between sorting, compaction and material value. Highly sorted materials are more homogeneous and hence can get higher values. This also off-loads the sorting costs to the customer. Given current truck configurations however, highly sorted recyclables usually guarantees that the trucks will only be part full. Flexible, reconfigurable trucks with some on-site (on the truck, or at the customer) compaction could help with the problem. Unsorted material is usually not fully compacted to ease sorting later.

3) There are two things wrong with this calculation. A) The households are not directly charged for the amount of trash they throw out. This leads to a market failure. Trash is not properly valued, this stifles recycling which now requires mandates and incentives to make it work. B) It does not look at social costs of landfilling, recycling, and the production of virgin materials.

Recycling Homework # 2 *SOLUTION*
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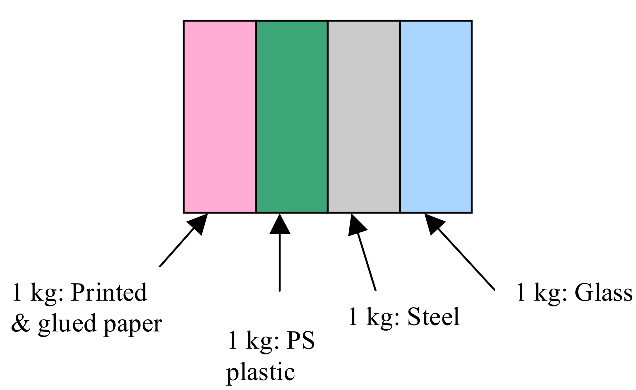
Recycling Questions #2

- Consider a product made up of four parts as in the example, but in this case the materials are: 1) printed and glued paper, 2) PS plastic, 3) glass, and 4) steel.
- Using similar scenarios as above, which one has the lowest cost?
- What modifications would you suggest to the scenarios, if any?

Solution

The product is made up of 4 materials like the example in class except in this case they are: 1) printed & glued paper, 2) PS plastic, 3) glass and 4) steel



Case #1: Landfill Everything

Costs:

Transport (200 km, 4 kg)	$0.80
4 kg x 12.5 cents/kg	$0.50
Total	$1.30

Net Cost = $1.30

Case #2: Recycle Steel & PS Plastic. Landfill Paper & Glass

Costs:

Shred and Sort (4 kg)	$0.80
Transport (200 km, 3 kg)	$0.80
Landfill (glass & paper)	$0.25
Total	$1.85

Revenues:

PS Plastic (1 kg)	$0.10
Steel (1 kg)	$0.10
Total	$0.20

Net Cost = $1.85 – $0.20 = $1.65

Case #3: Redesign with only recycled materials – Plastic & Steel (still 4 kg total)

Costs:

Shred and Sort (4 kg)	$0.80
Transport (200 km, 4 kg)	$0.80
Total	$1.60

Revenues:

PS Plastic (2 kg)	$0.20
Steel (2 kg)	$0.20
Total	$0.40

Net Cost = $1.60 – $0.40 = $1.20

Summary:

1. Landfill All $1.30
2. Recycle & Landfill $1.65
3. Redesign $1.20

The reason that there is no net revenue in any of these cases is the cost of transport as compared to the relative worth of the materials. It this product used materials that have a higher recycled value like aluminum then recycling might have given a net revenue.

Recycling Homework # 3 *Solution*
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Questions

- Please plot the 4 material example given in class on the $ value Vs mixing plot (in the Dahmus paper). Also plot the 3 material redesign.
- Also plot the 4 material example in homework #2 (above) on the value Vs mixing plot.
- Suggest how to redesign these "products" to enhance the possibility they are recycled.

Solutions

In order to plot the products on the $ value vs. mixing plot, you have to find the H value for each of them and the $ value of the recycled materials. We have already found the $ value of the recycled materials, but will review here.

The mixing value is found through the following equation:

$$H = -\sum c_i \log_2 c_i = -M\frac{1}{M}\log_2\left(\frac{1}{M}\right) = -\log_2\left(\frac{1}{M}\right) = \log_2 M$$

For a 4 material product:

$$H = \log_2 4 = \frac{\log_{10} 4}{\log_{10} 2} = 2$$

For a 3 material product:

$$H = \log_2 3 = \frac{\log_{10} 3}{\log_{10} 2} = 1.58$$

There are 3 examples products to plot: 1) the 4 material product from the class lecture. 2) the 3 material redesign from the lecture, and 3) the 4 material product from Recycling HW #2

Value Calculations:

1)

Pb	\$0.70
Al	\$0.80
ABS	\$0.50
Glass	\$0
Total	\$2.00

2)

Al	\$0.80
ABS	\$0.50
Glass	\$0
Total	\$1.30

3)

P&G Paper	\$0
PS	\$0.10
Steel	\$0.10
Glass	\$0
Total	\$0.20

As can be seen on the plot, both of the 4-material product designs are not near the apparent recycling boundary and would therefore be landfilled. Only the 3-material product appears to be recyclable. Redesign for products to move them above the apparent recycling boundary would either change the materials to ones that are more valuable when recycled or reduce the number of materials used in order to reduce *H*.