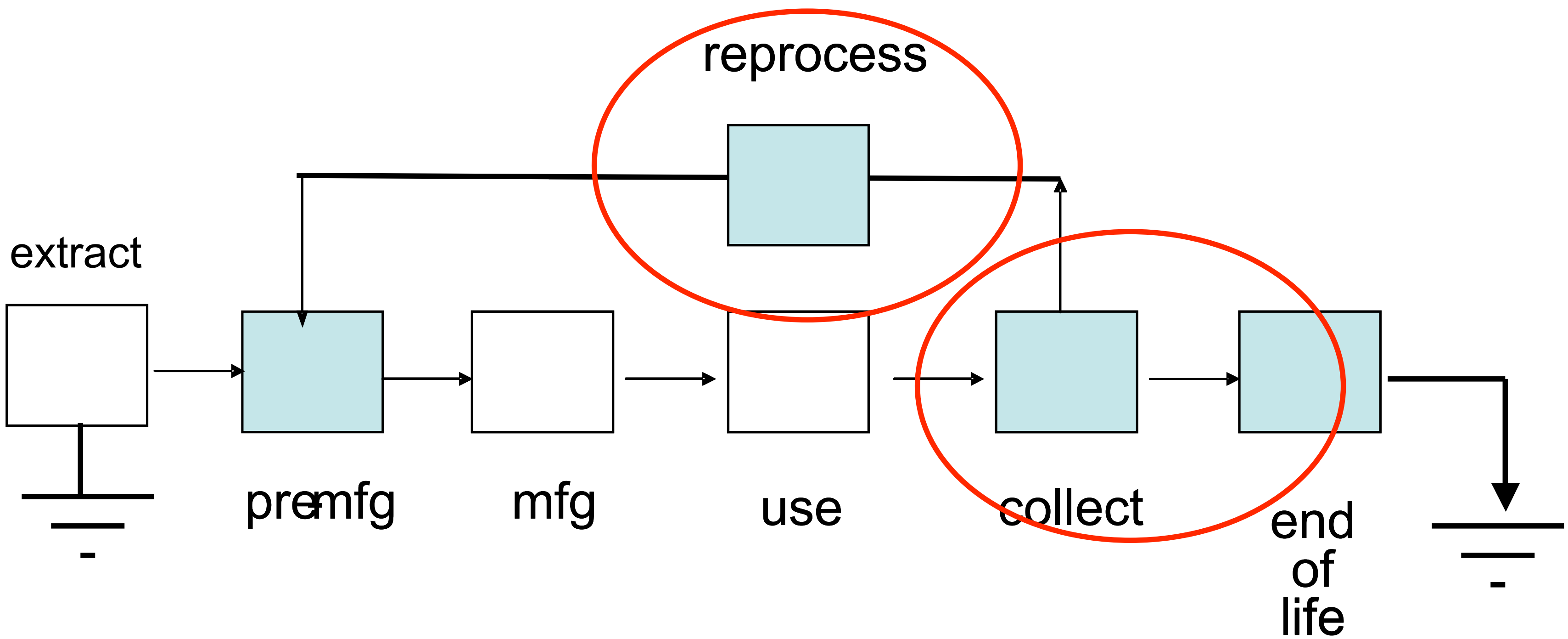
# Recycling Homework #1

Review the curbside recycling calculation and Porter's Ch 9, then answer the following questions:

1. Recycling looks uneconomical. Is this calculation right?
2. Explore options on how to improve on this situation. Express them as cost equations. The basic issues here are: a) scaling the costs with the amount, b) two pick-ups instead of one, and c) compacting and sorting.
3. What does this development leave out?

# *Recycler's Point of View*




Costs must not exceed revenues

# *Estimating Costs at the Recycler*

- Recycling Profits = Revenues – Costs

  $= R_{fees} + R_{materials} + R_{components}$

  $- \ C_{collection} - C_{\ processing} - C_{disposal}$

- Some illustrative numbers for recycling costs and materials values are given on the next three slides. These will vary with time.

# Market Values for Recovered Materials (~2004)

| | |
|---|---|
| **Paper (clean)** | \$100/ton = 10¢/kg |
| **Other paper** | 0 |
| **Glass** | 0 |
| **PET, HDPE** | \$300/ton = 30¢/kg |
| **PP, PS, PVC, HIPS** | \$100/ton = 10¢/kg |
| **ABS, PC**<br>**Other engineering thermoplastics** | \$500/ton = 50¢/kg |
| **Steel** | \$100/ton = 10¢/kg |
| **A1** | \$800/ton = 80¢/kg |
| **Cu** | \$600/ton = 60¢/kg |
| **Mixed non -ferrous metals** | \$700/ton = 70¢/kg |

# Illustrative Numbers for Recyling Cost Estimates (U.S. East Coast ~ 2006)

| | | |
|---|---|---|
| **Landfill costs** | $ 60 to 125/ton = 6 to 12.5 cents/kg | |
| **Hazardous disposal costs** | $1000 to 2,200/ton = $1 to 2.2/kg | |
| **Disassembly labor costs** | **some skills** $12/hr = 20 cents/min = .33 cents/sec. | |
| **Disassembly labor costs** | **semiskilled** $16/hr = 26.7cents/min = .44 cents/sec. | |
| **Disassembly operator labor** | **skilled** $20/hr = 33.3 cents/min = .55 cents/sec. | |
| **Material separation costs** | **auto/metals** | 2 – 3 cents kg (large volumes) |
| | **metals only** | 6 cents/kg. |
| (data from electronics) | **plastics only** | 13 cents/kg |
| | **metals & plastic** | 20 cents/kg |

# Transportation; Energy and Cost

| Energy | Cost (including loading and unloading) |
|---|---|
| truck 4KJ/kg.km | 0.1cents/kg.km |
| | 0.01cents/kgkm (long haul 23 tons) |
| truck 7KJ/kg.km (light mat'ls) | 0.175cents/kg.km (light materials) |

Caution: the numbers on the last 3 slides are provided to enable us to do some very approximate calculations. Costs and revenues for recycling are subject to market forces and so can vary greatly by location and time. See for example Ch 9 of *The Economics of Waste* by Richard C. Porter.

# Using numbers from these tables

$$\text{Profit} = \Sigma R - C_{collection} - C_{processing} - C_{disposal}$$

$$\Sigma R - (.001 \text{ to } .01¢)/\text{kg km} - (2\text{-}6¢)/\text{kg} - (7\text{-}100¢)\text{kg}$$

$$\approx \Sigma R - (.05¢)/\text{kg km} \cdot 60\text{km} - (4¢)/\text{kg} - (7¢)\text{kg}$$

*This gives:* $\Sigma R - 14¢/kg$

*So costs are above many of the materials on the previous table, what would you do?*

# Waste Paper Price Index in Germany from 1985 to 2000

S. Baumgärtner, R. Winkler / Ecological Economics 47 (2003) 183–195

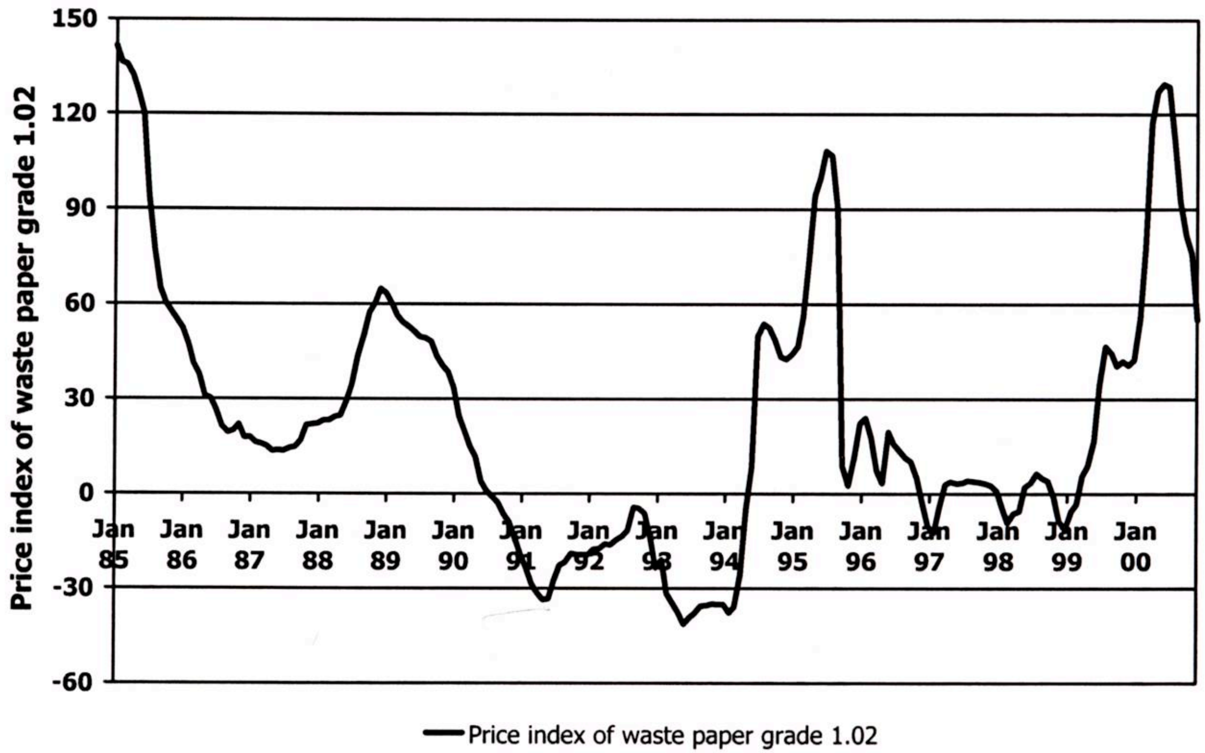
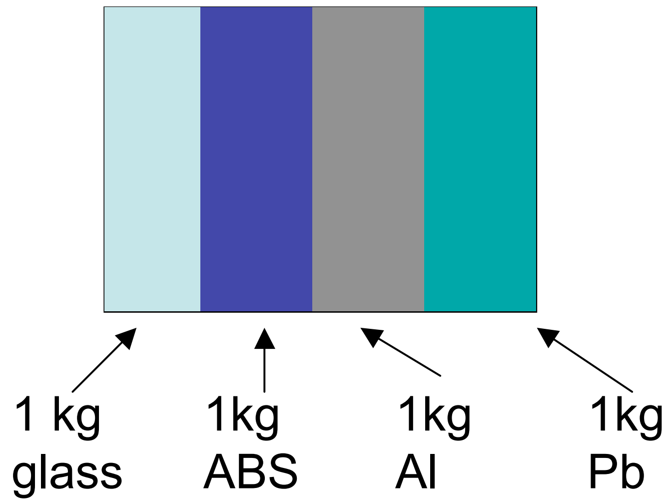



Fig. 2. Price index of waste paper grade 1.02 since January 1985 on a monthly basis. Source: StBA (2000).

Illustration of how costs for some materials can vary

# Example: End –of –Life Product Cost




## Case #1

disposal of 4 kg as hazardous waste

(shipped to special landfill in Niagra Falls)

cost 4 kg X $2.2/kg = $8.8

**TABLE 9.6** Categorization of Priority Pollutants (28)

**Volatile organics**
- acrolein
- acrylonitrile
- benzene
- bis(chloromethyl)ether
- bromoform
- carbon tetrachloride
- chlorobenzene
- chlorodibromomethane
- pentachlorophenol
- 2-chloroethyl vinyl ether
- chloroform
- dichlorobromomethane
- 1,2-dichloroethane
- 1,1-dichloroethane
- 1,1-dichloroethylene
- 1,2-dichloropropane
- 1,2-dichloropropylene
- ethylbenzene
- methyl bromide
- methyl chloride
- methylene chloride
- 1,1,2,3-tetrachloroethane
- tetrachloroethylene
- toluene
- 1,2-trans-dichloroethylene
- 1,1,1-trichloroethane
- 1,1,2-trichloroethane
- trichloroethylene
- vinyl chloride

**Acid-extractable organics**
- 2-chlorophenol
- 2,4-dichlorophenol
- 2,4-dimethylphenol
- 4,6-dinitro-o-cresol
- 2-nitrophenol
- 4-nitrophenol
- parachlorometacresol
- 1,2,4-trichlorobenzene
- phenol
- 2,4,6-trichlorophenol

**Base and neutral organics**
- acenaphthene
- acenaphtylene
- anthracene
- benzidine
- benzo(a)anthracene
- benzo(a)pyrene
- benzo(ghi)perylene
- benzo(k)fluoranthene
- 3,4-benzo-fluoranthene
- bis(2-chloroethoxy) methane
- bis(2-chloroethyl)ether
- bis(2-chloroisopropyl)ether
- bis(2-ethylhexyl)phthalate
- 4-bromophenyl phenyl ether
- butyl benzyl phthalate
- 2-chloro-naphthalene
- 4-chlorophenyl phenyl ether
- chrysene
- di-n-butyl phthalate
- di-n-octyl phthalate
- dibenzo(a,h)anthracene
- 1,2-dichlorobenzene
- 1,2-dichlorobenzene
- 4,4′-DDT
- 1,4-dichlorobenzene
- diethyl phthalate
- dimethyl phthalate
- 2,4-dinitrotoluene
- 2,6-dinitrotoluene
- 1,2-diphenylhyrazine
- fluoranthene
- fluorene
- hexachlorobenzene
- hexachlorobutadiene
- hexachlorocyclopentadiene
- hexachloroethane
- indeno(1,2,3-cd)-pyrene
- isophorone
- naphthalene
- nitrobenzene
- N-nitrosodi-n-propylamine
- N-nitrosodi-methylamine
- N-nitroso-diphenylamine
- phenathrene
- pyrene
- 2,3,7,8-tetrachloro-dibenso-p-dioxin

**Pesticides and PCBs**
- aldrin
- alpha-BHC
- beta-BHC
- gamma-BHC
- delta-BHC
- chlordane
- 4,4′-DDD
- 4,4′-DD chloroethane
- dieldrin
- alpha-endosulfan
- beta-endosulfan
- endosulfan sulfate
- endrin
- endrin aldehyde
- heptachlor
- heptachlor epoxide
- PCB-1016
- PCB-1221
- PCB-1232
- PCB-1242
- PCB-1248
- PCB-1254
- PCB-1260
- toxaphene

**Metals**
- antimony
- arsenic
- beryllium
- cadmium
- chromium
- copper
- lead
- mercury
- nickel
- selenium
- silver
- thallium
- zinc

**Cyanides**

**Asbestos**

# Case # 2 Disassemble Pb to recycle, the rest to landfill

| | | | |
|---|---|---|---|
| Costs | 1. | disassemble (1 min. unskill) | \$ 0.20 |
| | 2. | transport (1920 km to MO) | \$ 1.92 |
| | 3. | Landfill (3kg) | \$ 0.38 |
| | | Total Cost | \$ 2.50 |
| Revenues | 1. | Pb | \$0.70 |

net cost = \$2.50 - \$0.70 = \$1.80

# Case # 3 Disassemble Pb, recycle, the rest to the shredder & recycle

| | | | |
|---|---|---|---|
| Costs | 1. | disassemble (1 min. unskilled) | $0.20 |
| | 2. | transport (1920 km) | $1.92 |
| | 3. | shred and separate (3 kg) | $0.60 |
| | 4. | Transport (200 Km, 3 kg) | <u>$0.60</u> |
| | | Total Cost | $3.32 |
| Revenues | 1. | Pb | $0.70 |
| | 2. | A1 | $0.80 |
| | 3. | ABS | <u>$0.50</u> |
| | | | $2.00 |

net cost = $3.32 - $2.00 = $ 1.32

# Case # 4 Redesign Lead free; shredder & recycle

Costs

| | | |
|---|---|---|
| 1. | shred and separate (3 kg) | $0.60 |
| 4. | Transport (200 Km, 3 kg) | <u>$0.60</u> |
| | Total Cost | $1.20 |

Revenues

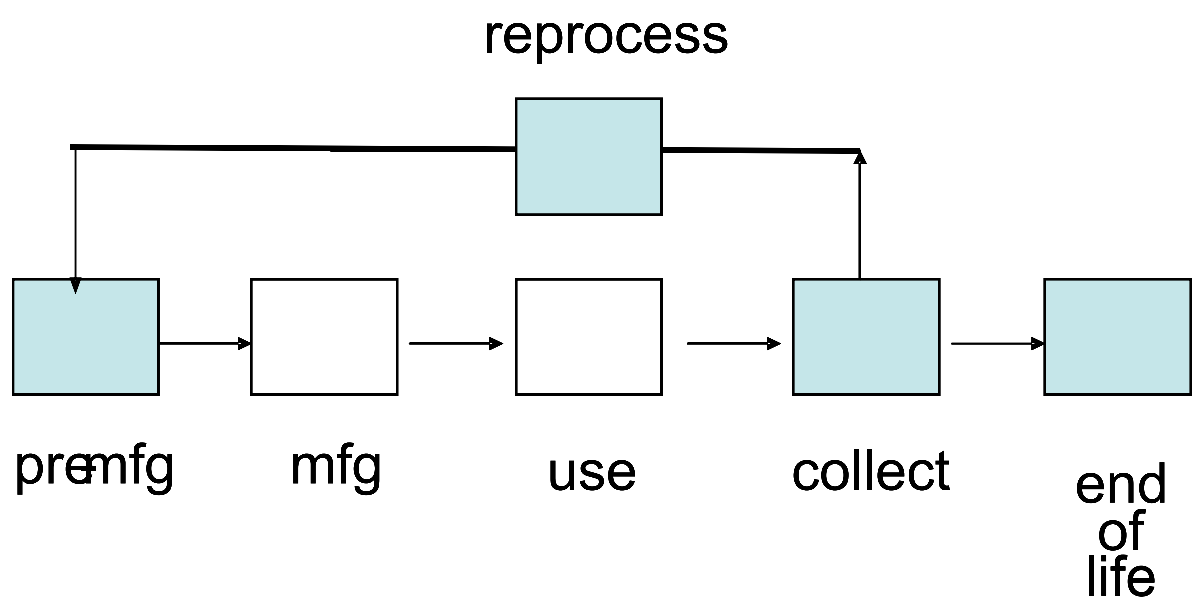
| | | |
|---|---|---|
| 1. | A1 | $0.80 |
| 2. | ABS | <u>$0.50</u> |
| | | $1.30 |

net revenue = $1.30 - $1.20 = $ 0.10

# Summary

| case | | revenue |
|---|---|---|
| 1 | Hazardous waste | $ - 8.80 |
| 2 | Recycle Pb<br>Landfill rest | $ - 1.80 |
| 3 | Recycle | $ - 1.32 |
| 4 | Lead free | $ + 0.10 |

# *Energy* Calculation, Case #3




Energy Credit = avoided primary mat'ls + avoided end of life

- reprocessing
- additional travel
- collection inefficiency

## Energy Credits for Recycling (Primary processing – Secondary)

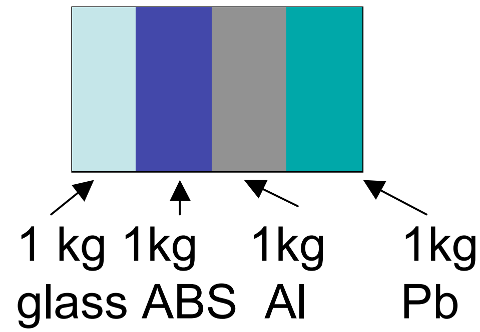
| Material | Primary | Secondary | Credit |
|---|---|---|---|
| Steel | 31 | 9 | 22MJ/kg |
| Copper | 184 | 37 | 147MJ/kg |
| Al | 270 | 16 | 254MJ/kg |
| Zn | 61 | 24 | 37 MJ/kg |
| Pb | 39 | 9 | 30MJ/kg |
| Ti | 430 | 140 | 290MJ/kg |
| Glass | ~20 | ~19 | 1MJ/kg |
| Plastics | ~100 | ~50 | 50MJ/kg |

Refs: mostly Chapman and Roberts, also see M. Ashby's book

# *Energy Account for Case # 3 (Recycling)*

Energy credits

254 MJ
30 MJ
1 MJ
50 MJ
335 MJ




Energy Costs

(transportation)

4kJ/km.kg x 1kg x 1920km =8 MJ

4kJ/km.kg x 3kg x 200km =2 MJ

10 MJ

Net Credit = 335 - 10 = 325 MJ

# Recycling Homework #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?

# Recycling Homework #3

- Please plot the 4 material example given in these slides, on the value Vs mixing plot (Dahmus & Gutowski recycling paper) (#1). Also plot the 3 material redesign (#2).
- Also plot the 4 material example in homework 2 on the value Vs mixing plot (#3).
- Suggest how to redesign these “products” to enhance the possibility they are recycled.