Energy and CO$_2$ analysis of drinking cups

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Outline

• Objective
• Analysis by Phase
  – Production
  – Manufacturing
  – Use
  – Disposal
• Life Cycle Assessments
• Comparison (energy and CO2)
• Conclusion
Objective

• Compare Energy and CO2 footprints for coffee drinking cups
• Studied:
  – Polystyrene
  – Paper
  – Stainless steel
  – Glass
  – Polyethylene
• Coffee hour- is it best to bring your own dishes?
Embedded Energy and CO2

• Assumptions-
  – CES embedded energy and CO₂ for all materials
  – 10 oz cup weights (experimentally determined)
    • Paper 7 g
    • Polystyrene 2 g
    • Stainless Steel 120 g
    • Glass 370 g
    • Polyethylene 40 g
Manufacturing

- Polystyrene- Expanded foam molding
- Paper- from source
- Stainless Steel- cast (*calculated*)
- Polyethylene- *Melting energy, negligible CO₂*
- Glass- cast/blown

Use

• Average Dishwasher
  – Reusable cups washed after every use
  – Energy use: ~80% water, 20% Drying¹
  – Model uses average household water consumption and drying energy per load²
    – 0.06 gCO₂ / kJ (electric)³
      *assume all energy consumed is electrical*
  – Assume 50 dishes / load

• Average Wash by hand
  – Heat 1/5 gallon of water and air dry

³. source: http://cdiac.ornl.gov/pns/faq.html
Disposal

• Two Options:
  – 100% to landfill
  – 50% incinerated (\(\eta = 30\%\)), 50% to landfill

• Sources of energy loss and \(\text{CO}_2\) emission
  – Transport to landfill/incinerator
  – Energy/\(\text{CO}_2\) extracted by incineration\(^1\)
  – \(\text{CO}_2\) released by decomposition (based on molecular formulas)

Life Cycle Assessment

Disposal  
Use  
Manufacturing  
Production

- Styrofoam  
- Paper

0 200 400 600  
energy (kJ/cup)

Disposal  
Use  
Manufacturing  
Production

- Styrofoam  
- Paper

-20 0 20 40  
CO2 (g/cup)

Disposal  
Use  
Manufacturing  
Production

- Polyethylene  
- Glass  
- Stainless Steel

0 200000  
energy (kJ/cup)

Disposal  
Use  
Manufacturing  
Production

- Polyethylene  
- Glass  
- Stainless Steel

0 5000 10000  
CO2 (g/cup)
Life Cycle Assessment

Disposables:

- Styrofoam
- Paper

Energy Use (kJ/cup)

- Landfill Styrofoam
- Burning Styrofoam
- Landfill Paper
- Burning Paper

CO2 Emissions (g/cup)

- Landfill Styrofoam
- Burning Styrofoam
- Landfill Paper
- Burning Paper

Manufacturing:

- Paper
- Glass
- Stainless Steel

Use:

- Paper
- Glass
- Stainless Steel

Disposal:

- Paper
- Glass
- Stainless Steel

Energy (kJ/cup)

CO2 (g/cup)
Life Cycle Assessment

Disposables:

Take home message for Disposables

Incinerating has LITTLE effect on energy/cup and LARGE effect on CO2/cup
Life Cycle Assessment

Reusables:

- Styrofoam
- Paper

Energy Use (kJ/cup)
- Dishwashing
- Hand Washing

CO2 Emissions (g/cup)
- Dishwashing
- Hand Washing
Life Cycle Assessment

Take home message for Reusables

Washing has large effect on energy/cup and LARGE effect on CO2/cup
Break-Even Energy

Dishwasher

Literature break even: glass = 15 for paper, 390 for PS
Break-Even Energy

Hand-washing

Take home message for Energy

If using disposable, use PS
IF using mug, use PE

Much better to wash by hand (20 uses)

Literature break even: glass = 15 for paper, 390 for PS
Break-Even CO2

Dishwashing, no incineration

<table>
<thead>
<tr>
<th>Number of Cups</th>
<th>Paper</th>
<th>PS</th>
<th>S.S. Wash</th>
<th>Glass Wash</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>50</td>
<td>250</td>
<td>500</td>
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<tr>
<td>100</td>
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<tr>
<td>150</td>
<td>750</td>
<td>1500</td>
<td>750</td>
<td>1500</td>
</tr>
<tr>
<td>200</td>
<td>1000</td>
<td>2000</td>
<td>1000</td>
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</tbody>
</table>

Total CO2 g
**Break-Even CO2**

**Dishwashing, w/ 50% incineration**

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<th>Total CO2 g</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>50</td>
<td>500</td>
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<td>1000</td>
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<tr>
<td>150</td>
<td>1500</td>
</tr>
<tr>
<td>200</td>
<td>2000</td>
</tr>
</tbody>
</table>

- paper inc
- ps inc
- S.S. wash
- glass wash
- PE wash
Break-Even CO2

Dishwashing, no incineration

Break Even CO2

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Graph showing the relationship between number of cups and total CO2 g for different materials:
- Paper: dotted blue line
- PS: dashed red line
- Glass wash: solid green line
- PE wash: solid yellow line
Break-Even CO2

Hand-washing, no incineration

Take home message for CO2
Use hand washing to make it worth it
We should not incinerate disposables for energy

number of cups
Model Sensitivity to Assumptions

• Model is very sensitive to assumptions
• Validity:
  – Total energy in paper: 700 kJ/cup
    • Compared with 550 kJ/cup\textsuperscript{1}
  – Total energy in PS: 400 kJ/cup
    • Compared with 200 kJ/cup\textsuperscript{1}
  – From earlier, the number of cups required by reusables made sense with literature values
• We believe we were able to get reasonable quantitative data
Conclusions

- Incineration of materials does not save much energy while producing a lot of CO2
  - Don’t do it
- Washing mugs more economically drastically reduces the number of uses to save energy, CO2

- What types of dishes should be used for coffee hour dishes?
  - First choice- bring your own mug (if use it more than 20 times)
  - Second Choice- PS
Life Cycle Assessment

- Polyethylene
  - Disposal: 0.57%
  - Use: 7.80%
  - Manufacturing: 91.63%
- Glass
  - Disposal: 0.23%
  - Use: 9.72%
  - Manufacturing: 81.05%
- Stainless Steel
  - Disposal: 0.85%
  - Use: 16.34%
  - Manufacturing: 82.81%
- Styrofoam
  - Disposal: 0.17%
  - Use: 46.65%
  - Manufacturing: 53.18%
- Paper
  - Disposal: 0.35%
  - Use: 36.26%
  - Manufacturing: 63.39%
Life Cycle Assessment

Polyethylene
- Disposal: 0.25%
- Use: 96.36%
- Manufacturing: 3.39%
- Production: 0.00%

Glass
- Disposal: 0.00%
- Use: 91.18%
- Manufacturing: 4.30%
- Production: 4.52%

Stainless Steel
- Disposal: 0.39%
- Use: 92.09%
- Manufacturing: 7.52%
- Production: 0.00%

Styrofoam
- Disposal: 0.00%
- Use: 53.18%
- Manufacturing: 46.65%
- Production: 0.00%

Paper
- Disposal: 0.35%
- Use: 63.39%
- Manufacturing: 16.26%
- Production: 0.00%
Processing Methods- Paper
Processing Method - Polystyrene

- Expanded Foam molding

Source: CES Edupack 2005
Processing- others
Use

• Average Dishwasher
  – Reusable cups washed after every use
  – Energy use: ~80% water, 20% Drying\(^1\)
  – Model uses average household water consumption and drying energy per load\(^2\)
  – 0.06 gCO\(_2\) / kJ (electric)\(^3\)
    \(\text{assume all energy consumed is electrical}\)
  – Assume 50 dishes / load

• Average Wash by hand
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• Break even calculation
  \[ \#uses_{\text{Break even}} = \frac{E_{\text{reusable}}}{E_{\text{disposable}} - E_{\text{wash}}} \]