Tools to Measure Sustainability:

Life Cycle Assessment

May 25, 2011

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New York State Pollution Prevention Institute at RIT

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Life Cycle Assessment (LCA) is a technique used to quantify the environmental impact of a product from raw material acquisition through end of life disposition. (cradle-to-grave)
LCA Methodology

- A Life Cycle Assessment is carried out in four distinct phases: (ISO 14040, 14044)
  - Step 1: Goal definition and scoping. Identify the LCA's purpose, the products of the study, and determine the boundaries. (what is and is not included in the study)
  - Step 2: Life-cycle inventory. Quantify the energy and raw material inputs and environmental releases associated with each life cycle phase.
  - Step 4: Report results. Evaluate opportunities to reduce energy, material inputs, or environmental impacts at each stage of the product life-cycle.
Benefits of LCA

- **Quantify environmental benefits** of products
- Provide **credible evidence** for marketing claims
- Identify opportunities to **improve the environmental performance** of products at various points in their life cycle
- Inform **decision-makers** in industry, government or non-governmental organizations
- Select **relevant indicators** of environmental performance, including measurement techniques
- Validate product **marketing claims**
- Instill **life cycle thinking** within businesses
Methods of Conducting LCA

(1) Manual
(2) Software
(3) Consultant

- Advantages of product/process analysis over life-cycle vs. analysis of 1 stage of LCA (ie – manufacturing)
Step 1: Goal Definition and Scoping

Define the **goal:**
- Intended application of the study
- Intended audience

Define the **scope:**
- Identify the product system to be studied
- Define the functional unit
- Define the boundaries of the product system
- Identify assumptions and limitations of the study
- Select impact categories to be included
Step 2: Life cycle inventory

Inventory collected from multiple sources

Energy

Raw Materials

ecoinvent data

Inputs

Materials

Manufacturing

Distribution

Customer use

End of use processing

Outputs

Products

Air, Water and Solid Emissions

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Step 3: Impact Assessment

- Converts the inventory into impact categories or end points which explain the environmental effect.
- Impact categories include: carcinogens, respiratory organics and inorganics, climate change, radiation, ozone layer, ecotoxicity, acidification/eutrophication, land use, minerals, fossil fuels.
- Can apply weights to impact categories.
Impact Assessment

Life Cycle Inventory
- NOx
- SOx
- Pesticides
- Heavy metals
- CO2
- VOCs
- Particulates
- Chemicals

Impact Categories
- Concentration in air, water, food
- Concentration greenhouse gases
- Changed pH and nutrient availability
- Change in habitat
- Fossil fuel availability

Category Indicators
- Local effects on species
- Climate change
- Ozone layer depletion
- Radiation
- Respiratory effects
- Cancer cases and types
- Surplus energy

Damage Categories
- Human Health
- Ecosystem Quality
- Mineral & Fossil Resources

Single Score Indicator

Fate analysis
Exposure & effect analysis
Damage analysis
Normalization & weighting

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Impact Assessment Results

- Impact assessment converts the inventory into impact categories or end points which details the human health and environmental effects.
Step 4: Report Results

- Life cycle interpretation: findings of the inventory analysis or impact assessment are evaluated in relation to the goal and scope of the study to reach conclusions and recommendations
  1. Identify significant issues
  2. Evaluate results for completeness, consistency, and sensitivity of the data
  3. Draw conclusions & make recommendations consistent with the goal & scope of the study
Manual Calculations
Manual Calculations

- Example of Life Cycle Inventory (LCI): Toner
  - Published in Journal of Cleaner Production, 2003
- Highly data intensive
- Detailed mass & energy balances performed over life-cycle
- Advantages: measure data & define baseline metrics of manufacturing process
- Challenges: Assumptions made when data unavailable
Xerography

1. Charging
2. Exposure
3. Development
4. Transfer
5. Fusing
6. Cleaning

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Defining the Boundaries


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Toner Manufacturing Process

Functional Unit = 1 metric tonne of toner produced
Two Key Recycling Loops: Internal/External

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The System

Post-production Processing

- Post production processes begin once the toner is sent to the customer and include:
  - Use of the toner in the xerographic machines
  - Destination of waste toner left in the machines
  - Final destination of the toner that is transferred to the paper

From Toner Manufacturing

Customer Use

To Indefinite Storage

Toner on Paper

To Solid Waste Management

Deinking of Recycled Paper

To Toner Manufacturing

Toner Recycling

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## Results

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<td>Toner on Paper to Landfill</td>
<td>min</td>
<td>min</td>
<td>min</td>
<td>min</td>
<td>min</td>
<td>min</td>
<td>min</td>
<td>min</td>
<td>min</td>
<td>320</td>
</tr>
<tr>
<td>Transportation</td>
<td>7.6</td>
<td>7.6</td>
<td>min</td>
<td>0.60</td>
<td>2.3</td>
<td>0.1</td>
<td>0.68</td>
<td>0.33</td>
<td>min</td>
<td>min</td>
</tr>
<tr>
<td>Raw Materials to T. Man.</td>
<td>3.4</td>
<td>3.4</td>
<td>min</td>
<td>0.27</td>
<td>1.0</td>
<td>0.0</td>
<td>0.31</td>
<td>0.15</td>
<td>min</td>
<td>min</td>
</tr>
<tr>
<td>Toner to Customer</td>
<td>2.6</td>
<td>2.6</td>
<td>min</td>
<td>0.19</td>
<td>0.73</td>
<td>0.0</td>
<td>0.22</td>
<td>0.11</td>
<td>min</td>
<td>min</td>
</tr>
<tr>
<td>Toner Waste Recycle</td>
<td>1.6</td>
<td>1.6</td>
<td>min</td>
<td>0.13</td>
<td>0.49</td>
<td>0.0</td>
<td>0.15</td>
<td>0.07</td>
<td>min</td>
<td>min</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>260</td>
<td>21</td>
<td>240</td>
<td>16</td>
<td>73</td>
<td>130</td>
<td>37</td>
<td>51</td>
<td>140</td>
<td>780</td>
</tr>
</tbody>
</table>
Toner Life-cycle Inventory

## Toner Life-cycle Inventory

<table>
<thead>
<tr>
<th>Waste/Materials</th>
<th>Without Recycling (kg/mton)</th>
<th>With Recycling (kg/mton)</th>
<th>Percent Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid Waste Produced in the Life-cycle</td>
<td>1020</td>
<td>780</td>
<td>24%</td>
</tr>
<tr>
<td>Virgin Materials Used in Toner Life-cycle</td>
<td>2530</td>
<td>1790</td>
<td>29%</td>
</tr>
</tbody>
</table>

Software Calculations
Software Calculations

- Ability to translate the inventory data to environmental impact
- Used to facilitate life cycle assessments
- Useful for relatively quick comparisons or complex studies
- Process
  - User collects input and output data
  - Imbedded inventories populate the associate energy, materials, and wastes associated with materials and processes
  - Impact assessment translates the inventory to environmental damage
- Two ways to input data:
  1. Actual data can be input
  2. Select data from the imbedded database
- SimaPro commercially available software - [http://www.pre.nl/](http://www.pre.nl/) for more info
Today’s Example

• Goal:
  – Determine which grocery bag – *single use paper, single use plastic, reusable plastic, or reusable cotton* – has the lowest environmental impact

• Assumptions:
  – All bags are manufactured 100km from the customer
  – All bags travel 10km from the customer to the end of life
  – Half of paper bags are recycled at end of life, half go to landfill
  – Plastic & cotton bags go to landfill at end of life
# Functional Unit

<table>
<thead>
<tr>
<th>Bag Type</th>
<th>Single use plastic</th>
<th>Single use paper</th>
<th>Reusable plastic</th>
<th>Reusable cotton</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Material</strong></td>
<td>HDPE</td>
<td>Unbleached Kraft paper</td>
<td>Polypropylene</td>
<td>Cotton</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>7g</td>
<td>42.6g</td>
<td>95g</td>
<td>85g</td>
</tr>
<tr>
<td><strong>Relative Capacity</strong></td>
<td>1</td>
<td>0.9</td>
<td>1.1</td>
<td>1.1</td>
</tr>
<tr>
<td><strong>Bags per Year</strong></td>
<td>520</td>
<td>578</td>
<td>4.55</td>
<td>4.55</td>
</tr>
<tr>
<td><strong>Mass bags per year</strong></td>
<td>3640g</td>
<td>24622.8g</td>
<td>432.25g</td>
<td>386.75g</td>
</tr>
</tbody>
</table>

Sustainability Victoria, Comparison of existing life cycle analysis of shopping bag alternatives, Apr07.
Single Use Plastic Bag

**Input materials & resources to make 520 bags**
- Populated by the user

**Known emissions & outputs from production of 520 bags**
- Populated by the user

What happens at the end of life?
You decide and input where the product goes

<table>
<thead>
<tr>
<th>Name</th>
<th>Sub-compartment</th>
<th>Amount</th>
<th>Unit</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyethylene, HDPE, granulate, at plant/RER U</td>
<td></td>
<td>3640 g</td>
<td>g</td>
<td></td>
</tr>
<tr>
<td>Stretch blow moulding/RER U</td>
<td></td>
<td>3640 g</td>
<td>g</td>
<td></td>
</tr>
<tr>
<td>Transport, lorry 3.5-7.5, EURO4/RER U</td>
<td>(3640/1000000)*100 = 0.364</td>
<td>8km</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transport, municipal waste collection, lorry 212/CHU</td>
<td>(3640/1000000)*10 = 0.364</td>
<td>101km from manufacturing to customer</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Emissions to air</th>
<th>Sub-compartment</th>
<th>Amount</th>
<th>Unit</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emissions to water</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emissions to soil</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Final waste flows</th>
<th>Sub-compartment</th>
<th>Amount</th>
<th>Unit</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non material emissions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Social issues</th>
<th>Sub-compartment</th>
<th>Amount</th>
<th>Unit</th>
<th>Distribution</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Economic issues</th>
<th>Sub-compartment</th>
<th>Amount</th>
<th>Unit</th>
<th>Distribution</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Known outputs to technosphere: Waste and emissions to treatment</th>
<th>Amount</th>
<th>Unit</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disposal, polyethylene, 0.4% water, to sanitary landfill/CHU</td>
<td>3640 g</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
HDPE

Peer reviewed datasets imbedded in software
data
Data has been collected by others and
represents actual operations

Include:
• Known inputs
• Emissions to air
• Emissions to water
• Emissions to soil
• Wastes and emissions sent to treatment

Ability to modify datasets based on your own
data
LCA Results - Improvement Opportunities

- Quantify contribution of individual materials and processes to the life cycle impact
- Understand relative contribution of processes and products
LCA Results - Product Comparisons

Results comparing environmental impacts of multiple products

- Used to support marketing claims
- Identify impact categories which products differ

![Average Environmental Impact](image)

New York State Pollution Prevention Institute
LCA Results – Paper Bags

Paper Manufacturing process contributes 90% of the LC impact

End of Life Impact of recycling 50% of the bags does not offset landfilling the other 50%
Company Examples
Comparing Multiple Blood Pressure Cuff Designs using LCA

- Objective was to compare three designs and explore multiple end of life scenarios to determine which is ideal for each cuff
- Results were used to
  - Validate the dematerialization and material choices that were made by the product designers
  - Identify operations throughout the life cycle which contribute significant environmental impact which allowed the design team to focus on those processes to further reduce the environmental impact of future designs
  - Validate environmental claims made by the manufacturer
  - Assist customers in making more informed purchasing and end of life management decisions

![Normalized Average Impact and Cuff B Contribution to Life Cycle Impact charts]
Comparing Remanufacturing & Recycling Toner Cartridges using LCA

- Objective was to determine the optimal end of life scenario (recycling or remanufacturing) and pinpoint opportunities to further improve the environmental footprint of the cartridges
- Results highlight processes that contribute significantly to energy and environmental impact which the company was unaware
  - Present a design roadmap for product designers and supply chain managers which pinpoint those processes which contribute significantly to the total environmental impact to further advance environmental performance
  - The company has used the results to communicate the environmental footprint of their products to customers, in order for customers to make more informed purchasing decisions.
LCA Results - Product Comparisons

Results comparing life cycle stages impact of multiple products
- Pinpoint contribution of stages to the life cycle impact
- Visualize differences between products

![Graph showing contribution to Life Cycle Environmental Impact]

New York State Pollution Prevention Institute
LCA & Material Reuse

• Quantify the environmental benefits of
  – Recycling materials at the end of life
  – Reusing or using recycled content materials
  – Multiple remanufacturing cycles

• Identify improvement opportunities to further reduce the environmental impact
LCA Challenges

- **Data collection**
  - Complex supply chains
  - How far back in the life cycle is data collected?
  - Analysis can be time consuming, if data not readily available
  - Engaging suppliers & end-of-use processors in data analysis
  - Is data representative of the time? Geography? Production processes?

- Accuracy of results dependent on **quality of inventory data**
- **Communicating** results can be tricky
- **Comparative LCA results** are representative of one specific case and do not represent population of a product
LCA Recommendations

• **Educate and rally** team to understand LCA as a tool and reasons for its use
• Clearly **define the goal & scope** of the LCA
• Ensure the **functional unit** is clearly defined
• **Build the LCA model** with best data physically available
• Complete **sensitivity analysis**
• Use **experienced and trained** LCA practitioners
• Follow the **ISO 14040 process** to validate marketing claims and bring recognition to the study
• **Stay up to date on LCA** research, data sources, and modeling techniques
Benefits of LCA

- **Quantify environmental benefits** of products
- Provide **credible evidence** for marketing claims
- Identify opportunities to **improve the environmental performance** of products at various points in their life cycle
- **Inform decision-makers** in industry, government or non-governmental organizations
- Select **relevant indicators** of environmental performance, including measurement techniques
- Validate product **marketing claims**
- **Instill life cycle thinking** within businesses
Thank you

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