Session 3: Inventory Analysis

LCA: Methodology

- **Goal & Scope Definition**
  - What is the unit of analysis?
  - What materials, processes, or products are to be considered?

- **Inventory Analysis**
  - Identify & quantify
    - Energy inflows
    - Material inflows
    - Releases

- **Impact Analysis**
  - Relating inventory to impact on world

- **Interpretation**
Inventory Analysis

• Building a system model of the flows within your system
  - System boundaries and flow types defined in Goal & Scope
  - Typically includes only environmentally relevant flows
    • E.g., exclude waste heat, water or O₂ emissions

• Steps
  - Catalog what activities to include (draw a flowchart)
  - Data collection
  - Computation of flows per unit of analysis
    • Serious challenges around allocation

Flowchart Examples: Intl AI Inst. 2003

2.1. Goal and Scope Definition

The intended purpose of this Inventory report is to accurately characterize resource consumption and significant environmental aspects associated with the worldwide production of primary aluminium. It reflects the fact that primary aluminium is a globally traded commodity.
Figures removed due to copyright restrictions.

Inventory Analysis: Data collection

- Data collection
  - Inflows
    - Materials
    - Energy
  - Outflows
    - Primary product
    - Other products
    - Releases to land, water and air
  - Transport
    - Distance
    - Mode

- Data collection (cont.)
  - Qualitative
    - Description of activity under analysis
    - Geographic location
    - Timeframe

- Key issue:
  - Site specific vs. Industry Avg

- Data sources
  - Scientific literature, Published studies
  - Industry & government records
  - Industry associations
  - Private consultants

Calculating the Inventory

- Identify interconnection flows
- Normalize data
  - Convert all absolute flows to a quantity relative to one outflow
  - Typically reference flow serves as interconnection
    Note: Since LCAs are typically linear, choice of reference outflow is arbitrary
- Calculate magnitude of interconnection flows
  - For linear system, soluble using linear algebra
- Scale all flows relative to interconnection flows
- Sum all equivalent flows
Product Production Overview

- **Product P produced in plant C**
  - C: Metal sheets cut and pressed to make P
- **Plant B delivers metal sheets to plant C**
  - B: Ingots melted and rolled into sheets
- **Ingots come from plant A**
  - A: Mineral is extracted, turned into metal, cast into ingots

Product Production Details

- **Transport:**
  - A to B: 1000 km, by truck
  - B to C: 0 km (adjacent)
- **Scrap:**
  - Process scrap from C returned to B for remelting
- **Product P:**
  - Weight = 40 g
  - 6 m² metal sheet needed to make 1,000
  - Metal thickness = 1.0 mm
  - Metal Density = 8,000 kg/m³
### Environmental Data - Plant A

**Summary**
- **Products**: Metal ingots
- **Raw Material**: Mineral

**Inputs/Outputs**

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Units</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Annual Production</td>
<td>1200</td>
<td>tonnes/year</td>
<td>Product A</td>
</tr>
<tr>
<td>Use of raw material</td>
<td>4800</td>
<td>tonnes/year</td>
<td>Raw A</td>
</tr>
<tr>
<td>Use of energy in the process</td>
<td>6.00E+06</td>
<td>MJ/year</td>
<td>Oil Combustion</td>
</tr>
<tr>
<td>Emissions to air</td>
<td>600</td>
<td>kg/year</td>
<td>HCl</td>
</tr>
<tr>
<td>Emissions to water</td>
<td>600</td>
<td>kg/year</td>
<td>Cu</td>
</tr>
<tr>
<td>Non-hazardous solid waste</td>
<td>3800</td>
<td>tonnes/year</td>
<td>Solid Waste</td>
</tr>
</tbody>
</table>

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### Environmental Data - Plant B

**Summary**
- **Products**: Metal Sheets
- **Raw Material**: Metal ingots and process scrap

**Inputs/Outputs**

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Units</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Annual Production</td>
<td>1600</td>
<td>tonnes/year</td>
<td>Sheets</td>
</tr>
<tr>
<td>Use of raw material - ingots</td>
<td>900</td>
<td>tonnes/year</td>
<td>Ingots</td>
</tr>
<tr>
<td>Use of raw material - scrap</td>
<td>700</td>
<td>tonnes/year</td>
<td>Scrap</td>
</tr>
<tr>
<td>Use of energy - heating</td>
<td>5.63E+05</td>
<td>kWh/year</td>
<td>Electricity</td>
</tr>
<tr>
<td>Use of energy - rolling</td>
<td>3.26E+05</td>
<td>kWh/year</td>
<td>Electricity</td>
</tr>
<tr>
<td>Emissions to air</td>
<td>480</td>
<td>kg/year</td>
<td>HC</td>
</tr>
</tbody>
</table>
Environmental Data - Plant C

Summary
Products
Consumer Product P

Raw Material
Metal Sheets

Inputs/Outputs

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Units</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Annual Production</td>
<td>400</td>
<td>tonnes/year</td>
<td>Product P</td>
</tr>
<tr>
<td>Use of raw material</td>
<td>480</td>
<td>tonnes/year</td>
<td>Sheets</td>
</tr>
<tr>
<td>Use of energy - oil</td>
<td>3.00E+05</td>
<td>MJ/year</td>
<td>Oil</td>
</tr>
<tr>
<td>Use of energy - electricity</td>
<td>2.22E+05</td>
<td>kWh/year</td>
<td>Electricity</td>
</tr>
<tr>
<td>Emissions to air</td>
<td>250</td>
<td>kg/year</td>
<td>HC</td>
</tr>
<tr>
<td>Process Scrap for Recycling</td>
<td>80</td>
<td>tonnes/year</td>
<td>Scrap</td>
</tr>
</tbody>
</table>

Environmental Data - Transportation and Energy Production

Transportation – Diesel Fuel

Energy

<table>
<thead>
<tr>
<th>Driving Conditions</th>
<th>Energy Consumption</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long Haul</td>
<td>1</td>
<td>MJ/tonne-km</td>
</tr>
<tr>
<td>City Traffic</td>
<td>2.7</td>
<td>MJ/tonne-km</td>
</tr>
</tbody>
</table>

Energy Production Emissions

<table>
<thead>
<tr>
<th>Emissions (g/MJ fuel consumed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substance</td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td>HC</td>
</tr>
<tr>
<td>NOx</td>
</tr>
<tr>
<td>CO2</td>
</tr>
</tbody>
</table>
Flowchart of System Being Analyzed

Calculating the Inventory

- Identify interconnection flows
- Normalize data
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### Results - Total Inventory

[Bar chart showing various emissions and waste by category and type.]

- **HC, Cu, Solid Waste (kg)**
- **HC, NOx, CO2**

### Results - How Much Energy?

- **Totals:**
  - Oil = 230 MJ / fu
  - Diesel = 40 MJ / fu
  - Electricity = 49 kWh/fu

- **If electrical generation is 50% oil / 50 % Diesel, what is total energy carrier consumption?**
  - 24.5 kWh from Oil
  - 24.5 kWh from diesel

- **Units Conversion:**
  - 1 kWh = 3.6 MJ
Considering Energy from Electricity

• Although we are consuming 49 kWh of energy, with 50% from Oil and 50% from Diesel
• We are NOT consuming
  49 kWh x 3.6 MJ/kWh = 176 MJ of energy carriers

Why?
• Energy conversion to electricity is far from 100% efficient
Results - How Much Energy?

Total Energy Carriers Consumed

- Assuming a conversion efficiency of
  - Oil = 32%
  - Diesel = 28%

Does this matter?

IAI Inventory for 1000 kg of Primary Aluminum

<table>
<thead>
<tr>
<th>Usage</th>
<th>Unit Energy Content</th>
<th>Total Energy Consumed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>188 kg</td>
<td>32.5 MJ / kg</td>
</tr>
<tr>
<td>Diesel Oil</td>
<td>13 kg</td>
<td>48 MJ / kg</td>
</tr>
<tr>
<td>Heavy Oil</td>
<td>238 kg</td>
<td>42 MJ / kg</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>308 m3</td>
<td>41 MJ / m3</td>
</tr>
<tr>
<td>Total Thermal</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Electricity

<table>
<thead>
<tr>
<th></th>
<th>w/o efficiency (MJ)</th>
<th>w/ efficiency (MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15711 kWh</td>
<td>56,560</td>
<td>171,393</td>
</tr>
</tbody>
</table>

Total

<table>
<thead>
<tr>
<th></th>
<th>w/o efficiency (MJ)</th>
<th>w/ efficiency (MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>85,853</td>
<td>200,686</td>
</tr>
</tbody>
</table>

Ignoring efficiency of electrical conversion, drastically alters energy picture!