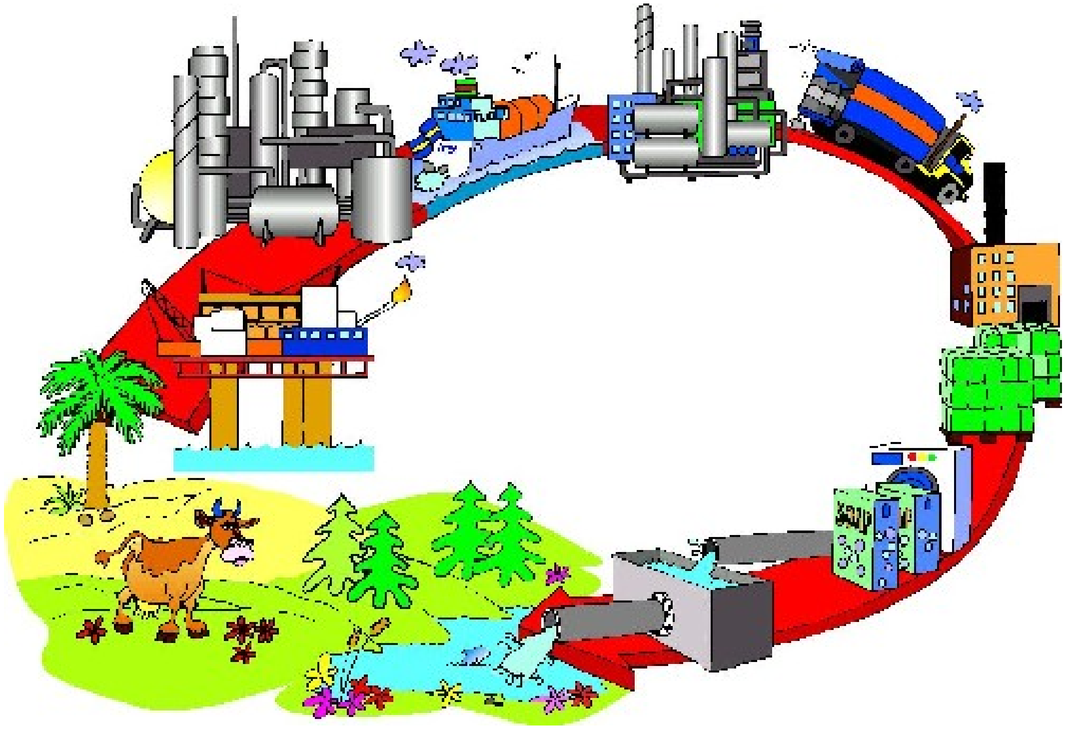
Environmental Life Cycle Assessment
PSE 476/WPS 576
Lecture 6: Life Cycle Inventory



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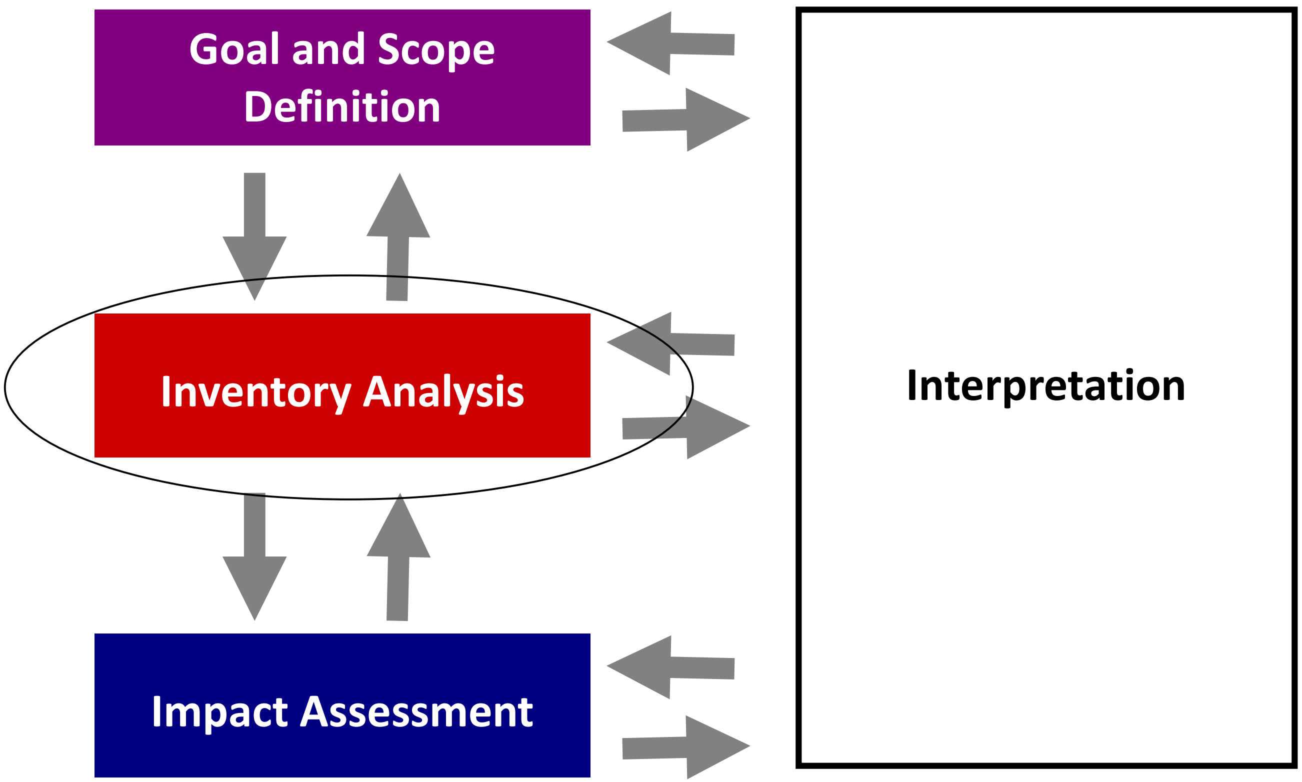
Major Parts of a Life Cycle Assessment



Life Cycle Inventory Analysis(LCI):

- **Life cycle inventory analysis**: Phase of the life cycle assessment involving the compilation and the quantification of inputs and outputs for a product throughout its life cycle [ISO 14044:2006(E)]
- “an inventory analysis means to construct a flow model of a technical system.”
- “the model is an incomplete mass and energy balance over the system”
- “environmentally indifferent flows such as diffuse heat and emissions of water vapour as a combustion product are not modelled” HHGLCA, 2004.

Life Cycle Inventory Analysis(LCI):

- Three major activities:
  - Construction of the flowsheet
  - Data collection and documentation
  - Calculation of the environmental loads in terms of the functional unit (i.e., the reference flow)
    - Resource use
    - Pollutant emissions

HHGLCA, 2004.

Construction of the flowsheet

- Should have all of the processes as in accordance with the Goal and Scope section
- Should show the system boundary
- Should clearly show significant interchanges between processes
- IF the entire system is extremely complicated then two flowsheets are suggested:
  - A simplified flowsheet showing the major life cycle “lumped” parts of the system, suitable for communicating the major concepts of the system
  - A detailed flowsheet that provides finer documentation of the system

HHGLCA, 2004.

Construction of the flowsheet

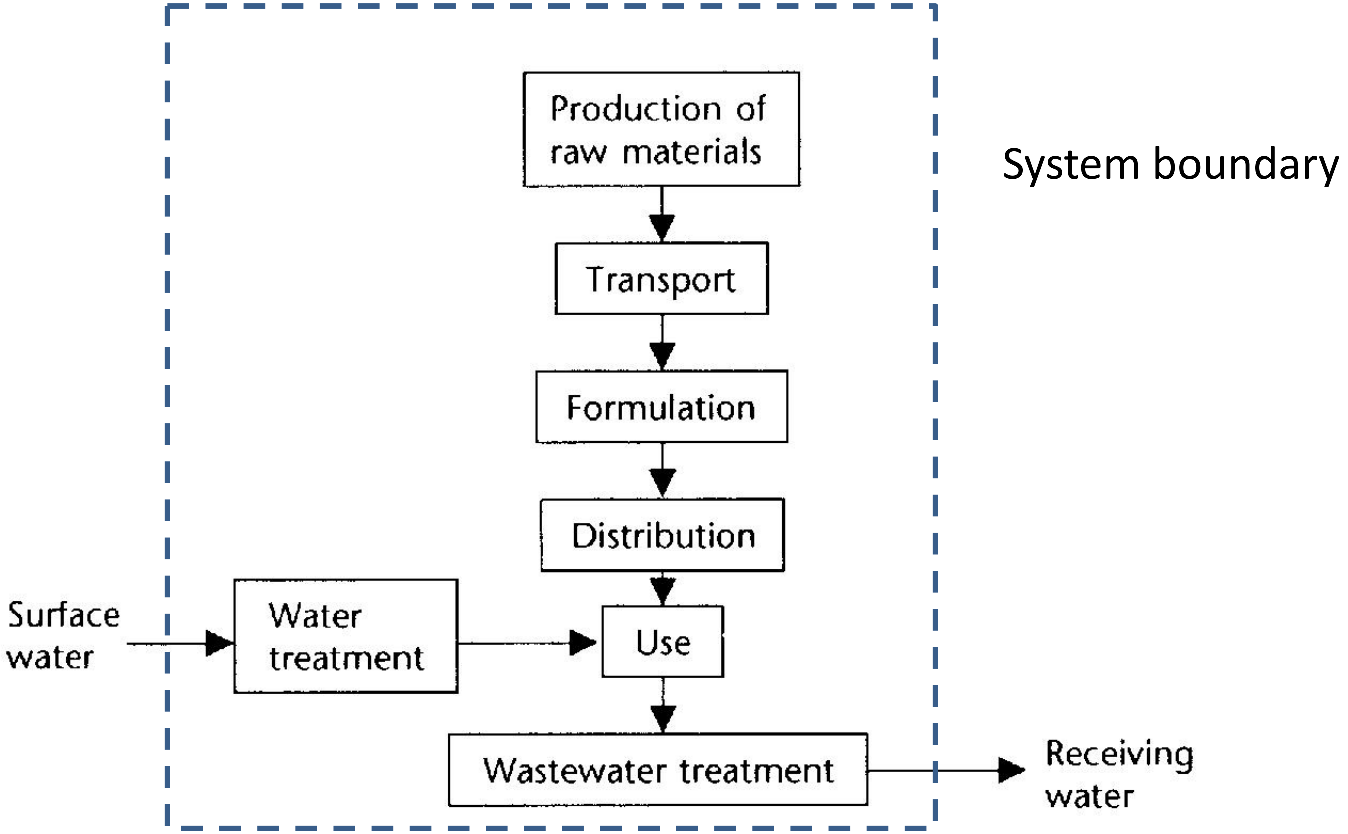
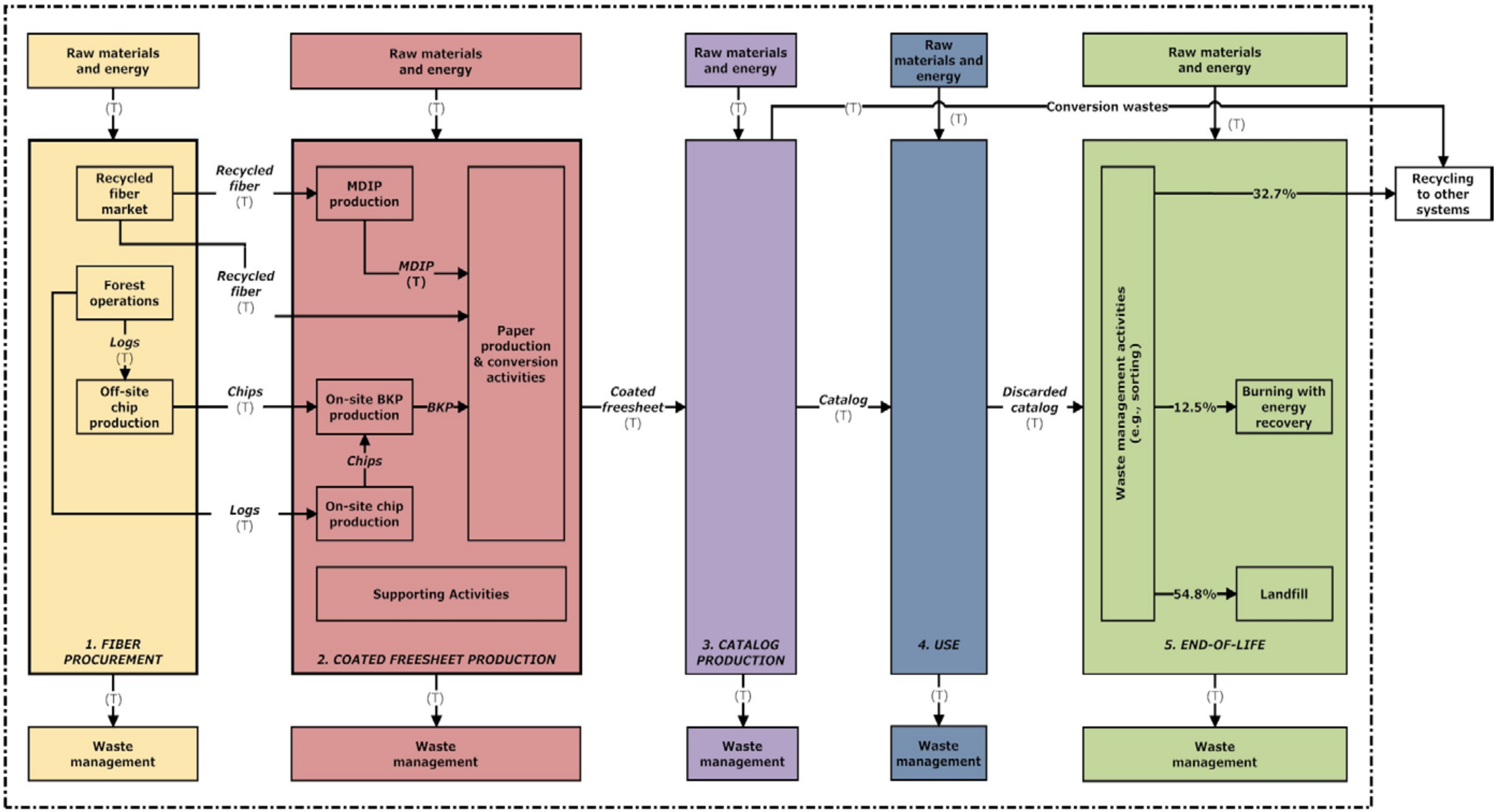


Figure 3.1 General and initial flowchart showing the life cycle of laundry detergents.

HHGLCA, 2004.

Construction of the flowsheet



System boundary

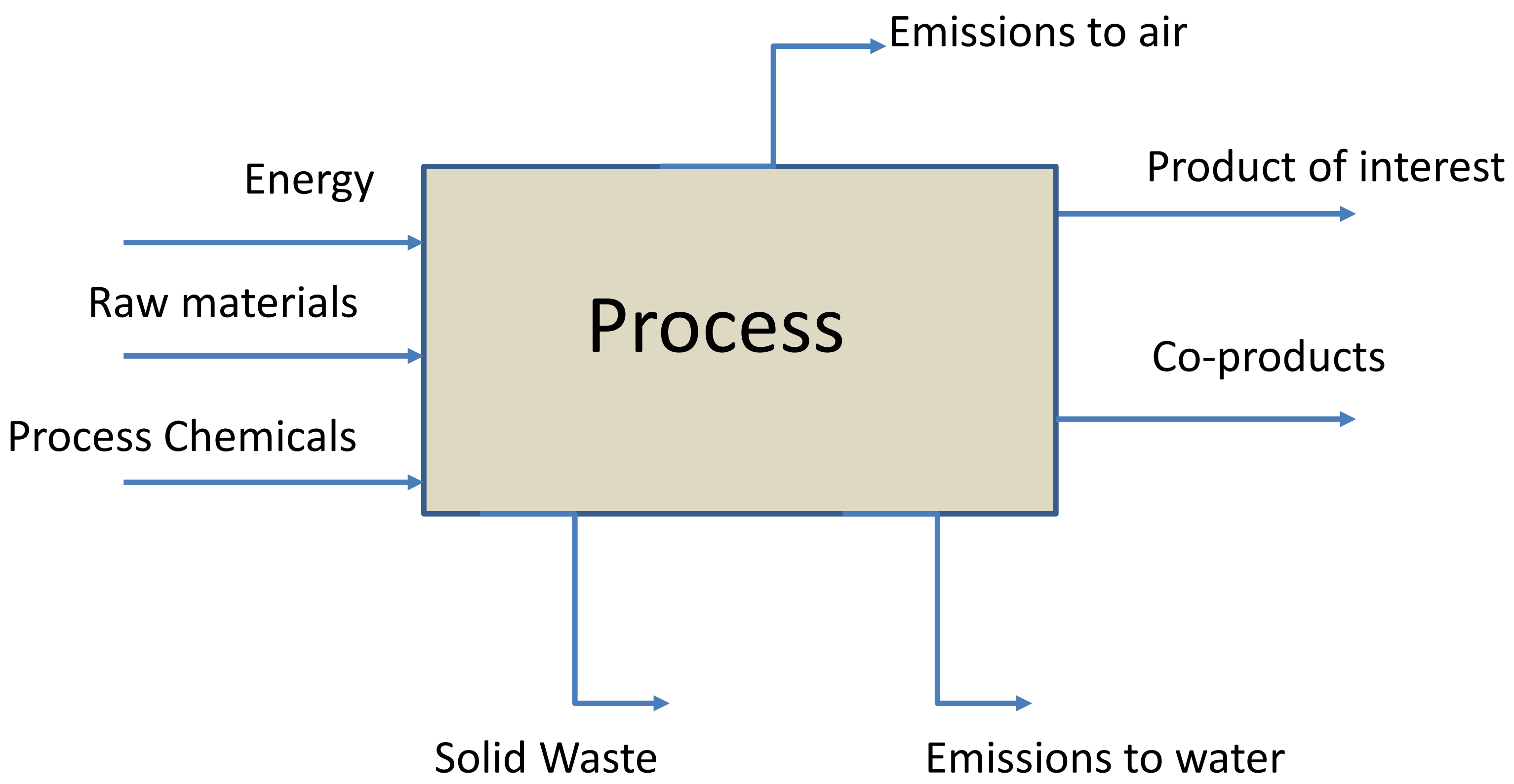
Data Collection

- One of the most time consuming activities in a LCA
- Garbage in, garbage out
- Main data:
  - Input flows of raw materials and energy
  - Other “inputs” such as land use
  - Product output flows
  - Emissions to air, water and land and other environmental impacts (eg., noise)
  - Data to describe processes
    - Example: production efficiencies, equipment, useful lifetimes of products, travel distances…
- Should also have data to guide allocation

HHGLCA, 2004.

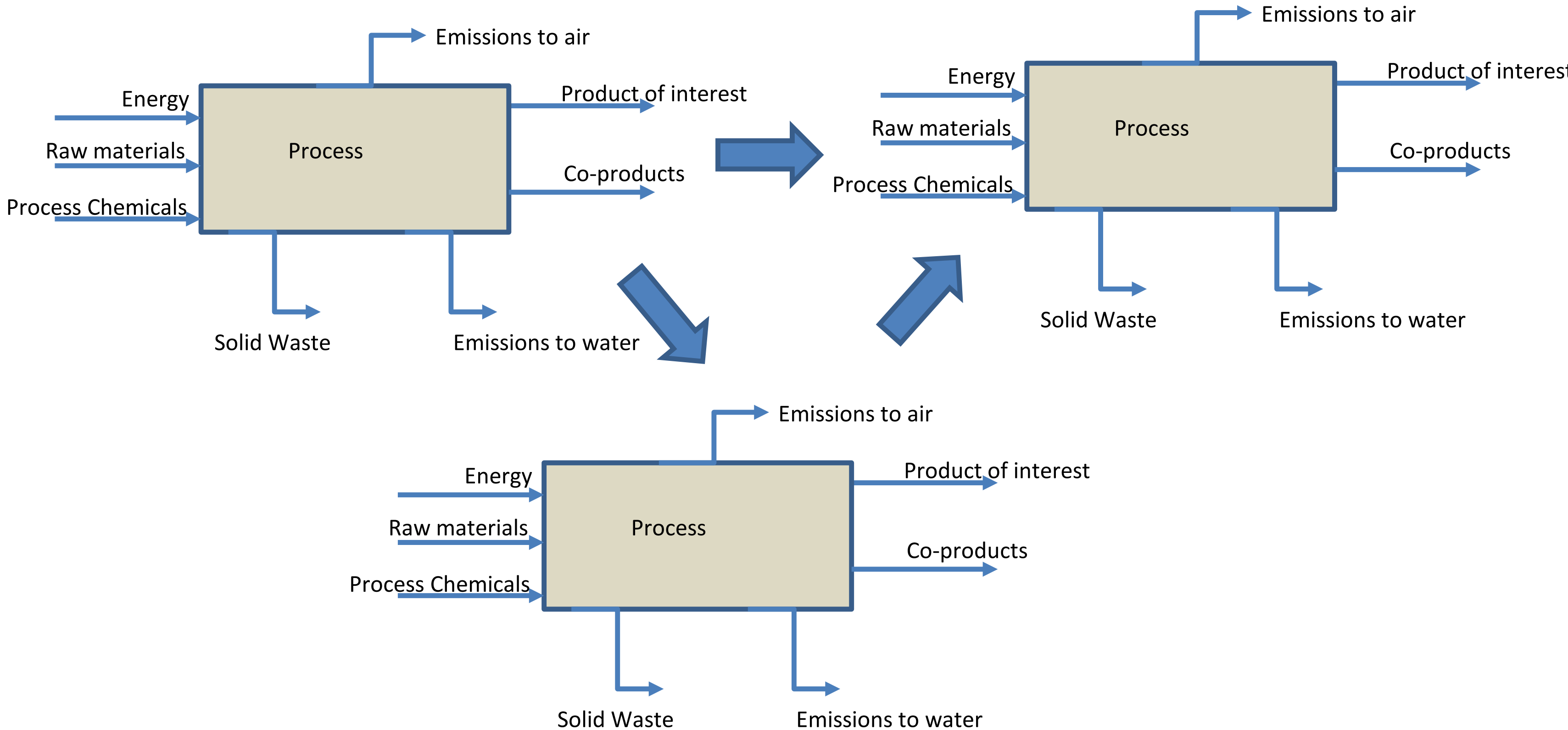
Data Collection

- For each process in the flowsheet:



HHGLCA, 2004.

Data Collection

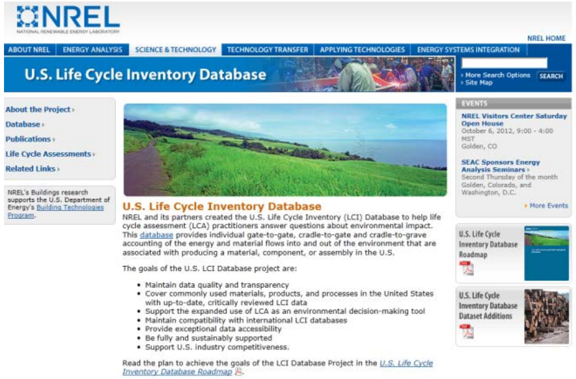


Large solid arrows signify ***link flows*** between processes, could be any type of flow. Link flows leave one process and enter another process.

HHGLCA, 2004.

Data Sources

- Direct measurements
- Literature
- Internet
- Life cycle inventory databases
- Interviews



HHGLCA, 2004.

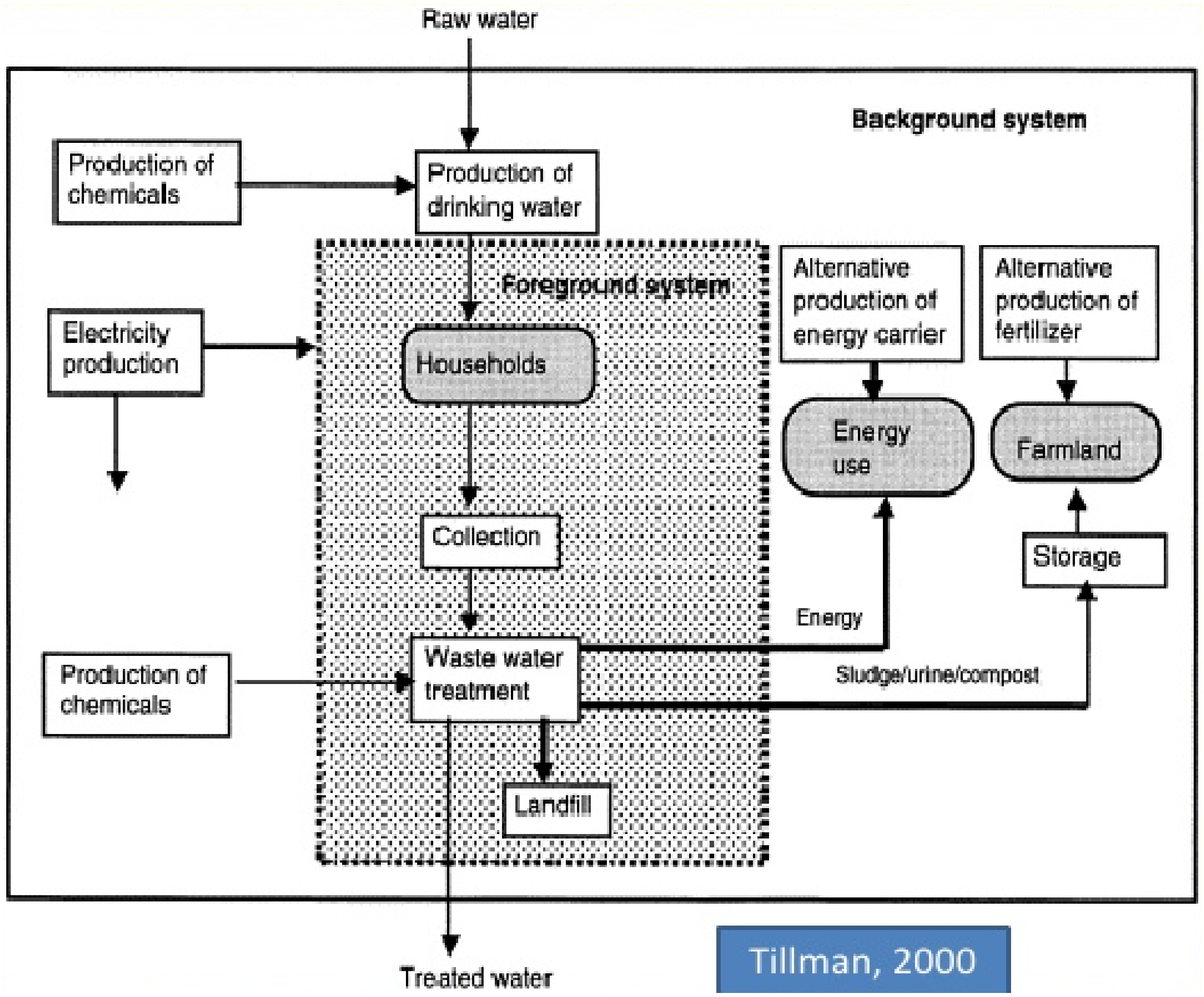
Data Sources

- **Foreground system:** processes that actions can be directly taken with respect to the results of the LCA, direct measurements can often be taken
- **Background system:** processes that actions can not be directly taken wrt the results of the LCA, often, external secondary data used

- **Primary Data:** direct measurement/description of variables
- **Secondary Data:** data sources from published or unpublished data articles, reports or studies
- **Assumptions:** used when primary or secondary data is not available.

HHGLCA, 2004.

Foreground and background data:
Municipality study on waste water treatment



Tillman, 2000

What type of data are these?

- **A food factory collects the energy usage on their food extrusion process.**
- **The emissions from the electricity generation process for the electricity that the food factory uses.**
- **The food factory finds from an internet source that 40% of food in the US gets uneaten. ***
- **The extrusion equipment will run at the same efficiency for the next 20 years.**
- **The emissions of the trucks that transport the food to the distributors.**

* http://www.nrdc.org/food/files/wasted-food-ip.pdfHHGLCA, 2004.

LCI Calculation Procedure:

Calculation of all flows relative to the Functional Unit (reference flows)

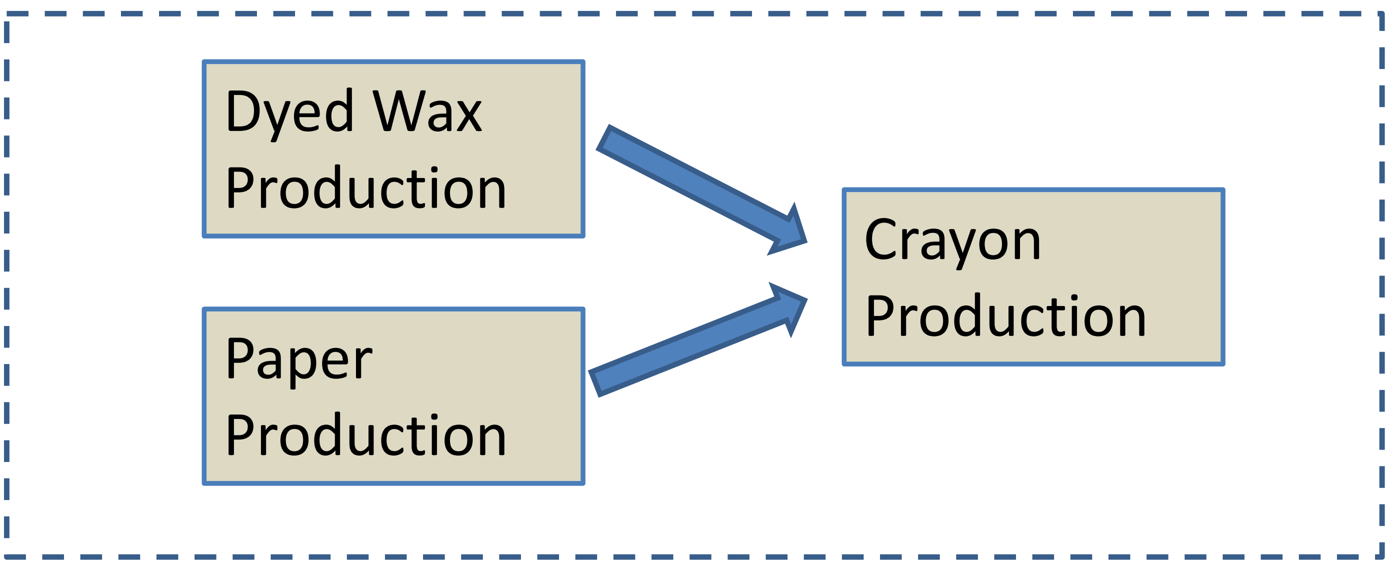
1. Have a good flowsheet and collect data.
2. Normalize data for each process, scale each flow to a product or input of the process.
3. Calculate the flows that link the processes together, **link flows**. These flows should be based on the “reference flow(s)” that are determined to fulfill the functional unit.
4. Calculate the flows that pass the system boundary. These flows should be based on the “reference flow(s)” that are determined to fulfill the functional unit. Make sure to identify the **elementary flows**

   * **Elementary flows are** flows from/to the environment not previously/further modified by man.
5. Sum up the elementary flows (raw resource use and emissions to the environment) for the whole system
6. Document the calculations.

HHGLCA, 2004.

LCI: Calculation Procedure Example:

- It is of interest to do a partial life cycle inventory analysis on crayons (major raw materials, CO2 process emissions from burning heating oils, wastes and electricity use).
- **Goal**: find hot spots amongst paper production, wax production and crayon production (waste, CO2, resource use)
- **Scope**: The functional unit of the study is one box of crayons, a set of 20 crayons (also the reference flow, RF)
- **Scope**: Three manufacturing processes will be in the study and within the system boundary (all others are not within the scope of this study):



Calculation Procedure Example: Data Collection

- **Product specification.** It is known that 1 crayon has 6 g of wax and 0.5 g of paper wrapper

- **Crayon Production.** It is reported from the factory that 10,000 crayons can be successfully produced in 24 hours. The electricity consumption is 100 kW-hr for a 24 hr period. CO_2 is emitted at a rate of 10 kg/hr from combustion processes used in the crayon production. There is a defective/disposed stream of crayons that is thrown away; the crayon reject flowrate is 5% of the total successful crayon production flowrate.
- **Dyed Wax Production.** It is reported that the flow of wax produced in the dyeing process is 6,000 grams per hour. Electricity consumption is 20 kW-hr per day. CO_2 is emitted is at a rate of 5 kg/hr from combustion processes. 10% of the feed wax is wasted/disposed in the process.
- **Paper Production.** 200 metric tonne of usable paper are produced per day. The amount of electricity consumed is 4000 kW-hr per day. The amount of wood consumed per day is 600 metric tonne of wood. CO_2 is emitted at a rate of 12 kg/hr from combustion processes. Waste is produced at 10 metric tonnes per day rate.

Calculation Procedure Example: Normalization

- **Crayon Production.** It is determined that 10,000 crayons can be successfully wrapped in 24 hours. The electricity consumption is 100 kW-hr for a 24 hr period. CO_2 is emitted at a rate of 10 kg/hr from combustion processes used in the crayon production. There is a defective/disposed stream of crayons that is thrown away; it is 5% of the total successful crayon production.
- Normalize process with respect to one crayon produced:

Calculation Procedure Example: Normalization

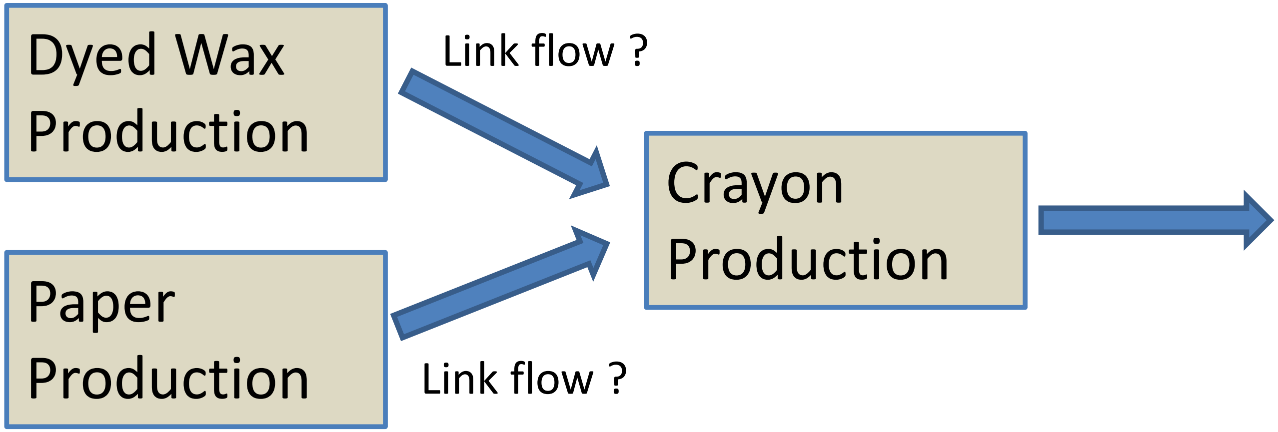
- **Dyed Wax Production.** It is reported that the flow of wax produced in the dyeing process is 6,000 grams per hour. Electricity consumption is 20 kW-hr per day. CO_2 is emitted at a rate of 5 kg/hr from combustion processes. 10% of the feed is wasted material that is disposed.
- Normalize process with respect to a gram of wax produced:

Calculation Procedure Example: Normalization

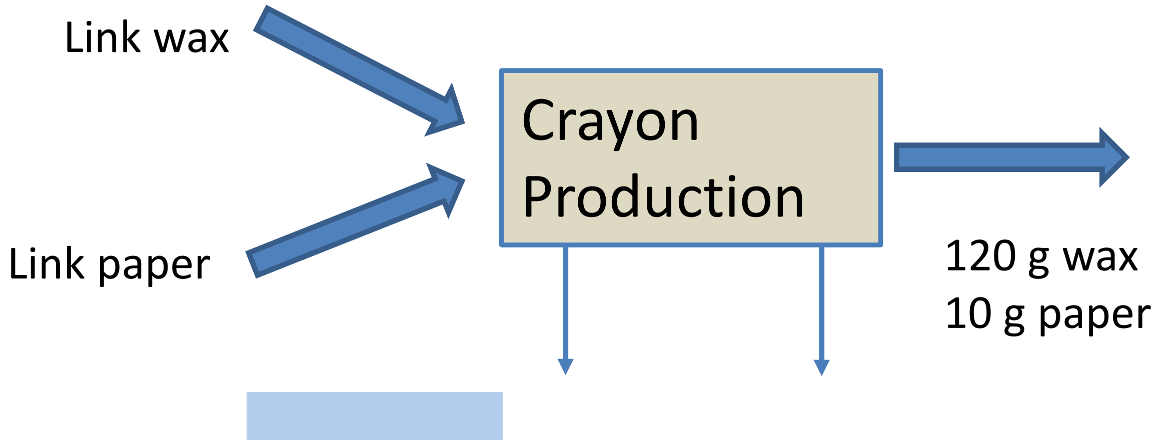
- **Paper Production.** 200 metric tonne of paper are produced per day. The amount of electricity consumed is 4000 kW-hr per day. The amount of wood consumed per day is 600 metric tonne of wood per day. CO_2 is emitted at a rate of 12 kg/hr from combustion processes. Waste is produced at 10 metric tonnes per day rate.
- Normalize process with respect to a metric tonne of paper produced:

Calculation Procedure: link flows

- Step 2. Calculate the flows that link the processes together. These flows should be based on the “reference flow(s)” that are determined to fulfill the functional unit.
- Reference flow based on the functional unit of one box of crayons: 20 crayons, each with 6 g wax, 0.5 g paper



Calculation Procedure: link flows



Calculation Procedure:

STEP 3: Calculate the flows that pass the system boundary. These flows should ultimately be in terms of the

“reference flow(s)” that are determined to fulfill the functional unit.

Crayon Production:

HHGLCA, 2004.

Calculation Procedure:

STEP 3: Calculate the flows that pass the system boundary. These flows should be based on the “reference flow(s)” that are determined to fulfill the functional unit.

Dyed Wax Production:

HHGLCA, 2004.

Calculation Procedure:

STEP 3: Calculate the flows that pass the system boundary. These flows should be based on the “reference flow(s)” that are determined to fulfill the functional unit.

Paper Production:

HHGLCA, 2004.

Calculation Procedure:

Step 4. Sum up the resource use and emissions to the environment for the whole system

	Paper Prod.	Wax Dyeing	Crayon Prod.	Total
Waste (g/RF)	.5	13.9	6.5	20.9
Waste % of total				
CO2 (kg/RF)				
CO2 % of total				
Wood (g/RF)	31.5	0	0	31.5
Raw Wax (g/RF)	0	140	0	140
Electricity (kWhr/RF)				
Elect % of total				

(RF= reference flow, 20 crayons, containing 120 g dyed wax and 10 g paper)

Calculation Procedure:

Step 5. Document the calculations (for others). Show example calculations and data used. Explain boundary, allocation, and calculation methods.

What were the hotspots for waste, CO_2 and electricity?

HHGLCA, 2004.

Summary

- **Life cycle inventory (LCI) analysis**
- **3 Major Activities in LCI**
  - **Flowsheet, collect data, calculations**
- **System Boundary**
- **Foreground data**
- **Background data**
- **Primary data**
- **Secondary data**
- **Assumptions**
- **Functional unit**
- **Reference flows**
- **Elementary flows**
- **Normalized Process Data**
- **Link flows**
- **Hot spots**