INDUSTRIAL WASTE SIMULATIONS AND ANALYTICS

PROCESS FLOW DIAGRAM

- A PFD is a graphical representation of a process to show the primary process flow path.
- It focuses on the equipment used, control valves, and other instruments that are present.
- Illustrates how the major components of a process plant interact with each other to bring about the desired effect.
- Trace the primary flow of chemicals through the unit.

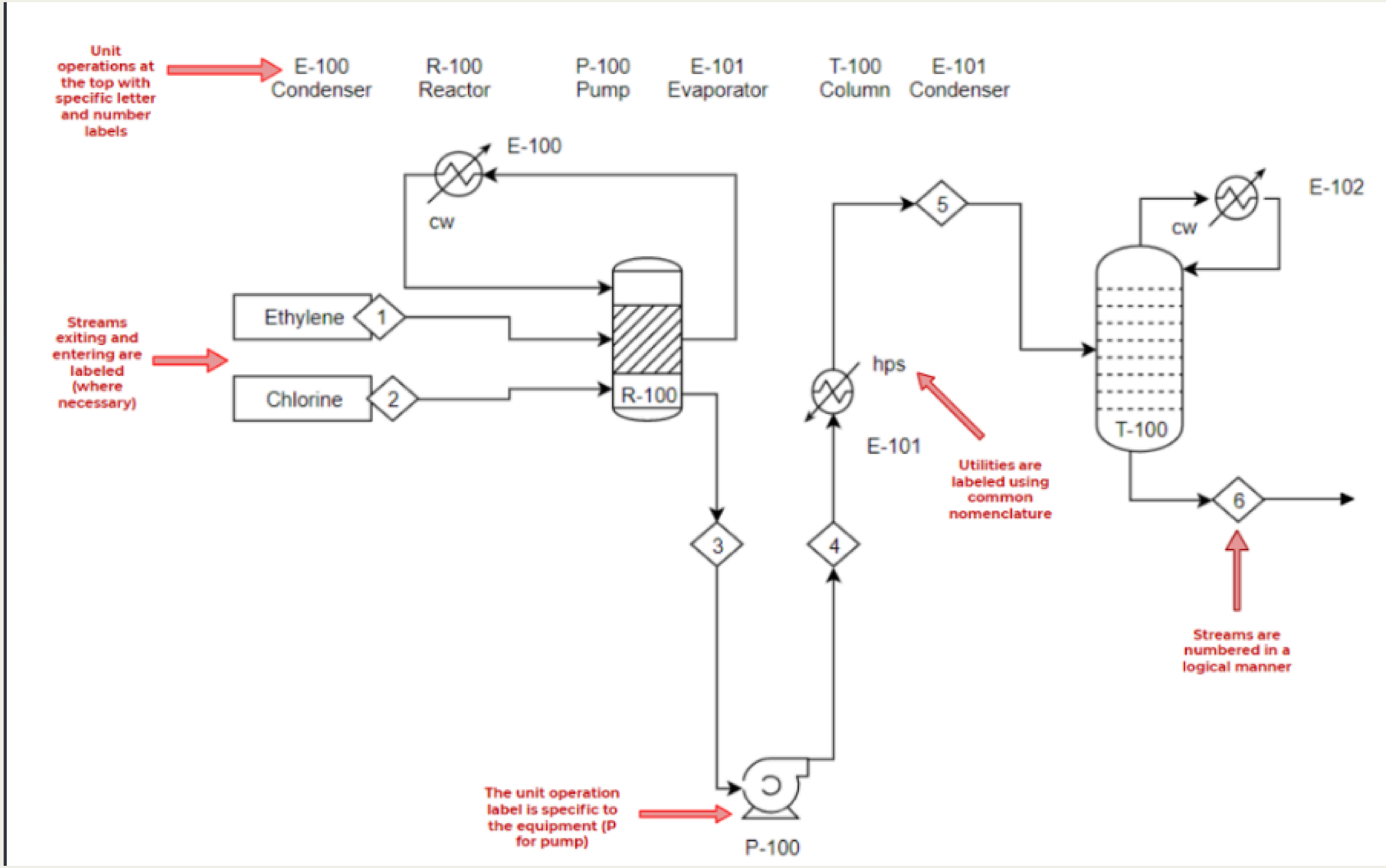
WHAT INFORMATION DOES PFD PROVIDE?

- All major equipment
- Process flow stream and direction of the process
- Control valves and connections with other systems
- Operational data such as temperature, pressure and mass flow rates.

WHAT INFORMATION DOES PFD NOT PROVIDE?

- Process control instruments
- Relief and safety valves
- Pipe line numbers
- Minor bypass values

CONSIDER CHLORINATION OF ETHYLENE:



CLASS 2

WHAT IS OPTIMISATION ?

- Definition: Selecting the best solution among many possible choices using efficient quantitative methods.
- Goal: Maximize performance criteria (e.g., minimum cost, maximum yield).
- Key Elements: Process models, performance criteria, trade-offs.
- Role of Computers: Use of software and engineering judgment to make informed decisions.

WHY OPTIMISATION ?

- Improves efficiency: Enhances production, reduces costs, and minimizes energy use.
- Benefits operations: Increases yields, reduces downtime, and optimizes resources.
- Predictive Analysis: Helps in decision-making by systematically identifying constraints and objectives.
- Economic Impact: Small efficiency improvements can lead to significant cost savings.

HOW ITS DONE?

- Define the problem: Identify the system, objectives, and constraints.
- Use predictive models: Mathematical equations describe system behavior.
- Adjust key variables: Find the best combination while satisfying constraints.
- Optimization tools: Algorithms and software (e.g., MATLAB, ASPEN, HySyS).

APPLICATIONS IN CHEMICAL ENGINEERING

- Process Design: Heat exchanger networks, equipment sizing.
- Plant Operations: Distillation column optimization, predictive control.
- Scheduling & Planning: Maintenance scheduling, operations planning.
- Industry Tools: Optimization in software like ASPEN, CHEMCAD, Pro/II.

CLASS 3

REAL-WORLD CONTEXT

Industrial Waste & Environmental Impact

- Industries generate large amounts of solid, liquid, and gaseous waste.
- Improper waste disposal leads to pollution, resource depletion, and climate change.
- Regulatory frameworks (e.g., PCF, LCA) help assess and reduce environmental impact.

PRODUCT CARBON FOOTPRINT

A Product Carbon Footprint (PCF) measures the total greenhouse gas (GHG) emissions produced throughout a product's life cycle. This includes all five stages:

- **Raw Material Extraction:** Sources include activities like logging and mining.
- **Manufacturing:** Sources include factory operations like energy consumption.
- **Transportation:** This includes transportation at all stages like raw materials to manufacturing, manufacturing to storage and distribution centers, and distribution centers to retail stores and consumers.
- **Usage:** Related to product usage like energy consumption during operation.
- **End-Of-Life Disposal:** Emissions from composting, recycling, or landfilling.

HOW ARE GREENHOUSE GAS EMISSIONS MEASURED

It is measured as Global Warming Potential (GWP), and it normalizes multiple GHGs, such as methane and nitrous oxide, to understand the impact compared to carbon dioxide (CO2). GWP takes into account three important factors:

- **Time Horizon:** The time horizon includes several different ranges, often 20, 100, and 500 years because gasses remain in the atmosphere for different lengths of time.
- **Heat-trapping ability**: Gasses like methane trap more heat than carbon dioxide, making it more potent. This must be considered or the impact will be miscalculated.
- **Atmospheric Lifetime:** Some gasses stay in the atmosphere for longer periods of time than others which varies the impact gasses.

LIFE CYCLE ASSESSMENT (LCA)

- A Life Cycle Assessment or Life Cycle Analysis (LCA) evaluates a product's environmental impact throughout its life cycle.
- Unlike PCF, which focuses exclusively on GHG emissions, an LCA provides a multi-dimensional analysis of a product's environmental footprint, offering businesses a broader view of potential environmental impact areas.
- This includes GHG emissions, but it also incorporates other metrics such as eutrophication, acidification, ozone depletion, water usage, and more.
- This provides a more comprehensive understanding of the full environmental impact of a product beyond GHG emissions.
- It analyzes a product's environmental impact across multiple areas throughout its entire life cycle.

HOW TO CHOOSE BETWEEN PCF AND LCA

- Choosing between a PCF and an LCA will be dependent on what your company's goals are. If your company only needs to know GWP or GHG emissions, then a PCF may be sufficient. This may be the case for a company whose only goal is to reduce GHG emissions and communicate these efforts to stakeholders.

- However, if your company needs a more comprehensive understanding of a product's environmental impact, an LCA will include GHG emissions along with other environmental metrics.

- Companies with goals to reduce environmental impact across multiple areas, or those seeking opportunities for improvement beyond GHG emissions, may find an LCA more suitable.

CLASS 4

LIFE CYCLE ASSESSMENT (LCA)

- **Definition:** A systematic, quantitative method to evaluate environmental impacts of a product or service throughout its entire life cycle.
- **Key Focus:** Assesses environmental loads (e.g., CO_2, BOD, solid waste, resource use) and their impacts on:
  - Ecosystems
  - Human health
  - Natural resources
- **LCA Phases:**
  - Goal & Scope Definition
  - Life Cycle Inventory Analysis
  - Life Cycle Impact Assessment
  - Life Cycle Interpretation
- **Standards**: Guided by ISO 14040 series, which standardizes LCA methodology across all four phases.

GOAL AND SCOPE DEFINITION

- **Goal**
  - Why LCA?
    - To identify environmental weak points
    - To improve product environmental performance
    - To compare environmental impacts of disposal scenarios
  - Applications of LCA Results:
    - Design, development, and management improvements
  - Audience:
    - Product designers, developers, managers
- **Scope**
  - Product System: Includes the product and all upstream/downstream processes: manufacturing, distribution, use, disposal, transportation, energy
  - Function: Defines the use (e.g., drying hair)
  - Functional Unit (FU): A measurable output (e.g., drying hair in 5 minutes)
  - Reference Flow: Quantity of product required to fulfill the FU (e.g., 1 hair drier)

SYSTEM BOUNDARIES & DATA CATEGORIES

- **System Boundaries**
  - Include Processes Based on:
    - Mass Contribution Rule: Include processes up to 80% of total weight
    - Environmental Significance: Include even low-mass processes if they involve toxic or significant environmental effects
  - Example (Hair Drier):
    - Components included: Body, Power Cord, Packaging, Motor
    - Iterative definition with LCI and impact categories
- **Process Tree & Data Category**
  - Process Tree:
    - Visual map of unit processes and their interrelations
  - Data Categories:
    - Inputs: Raw/ancillary materials, energy
    - Outputs: Product, co-/by-products, emissions (air, water, land)

CASE STUDY – HAIR DRIER (MODEL A)

- **Goal:**
  - Identify environmental weak points for improvement.
  - Compare impacts under two disposal scenarios.
  - Support eco-friendly product design.
- **Audience & Application:**
  - Internal stakeholders: product designers, developers, and managers.
  - LCA results guide design and decision-making.
- **Scope Overview:**
  - Product: Hair Dryer (Model A)
  - Function: Drying hair in 5 minutes
  - Functional Unit: One 5-minute hair drying session
  - Reference Flow: One hair dryer
- **Product System Includes:**
  - Manufacturing (components & materials)
  - Distribution, Use, and End-of-Life
  - Energy and transportation at each stage
- **System Boundaries (Decision Rule):**
  - Include processes contributing up to 80% cumulative weight
    → Body, Power cord (PVC), Packaging, Motor (steel)
  - Include any environmentally significant processes (e.g., toxic chemicals)

CASE STUDY – HAIR DRIER (MODEL A)

Table E2.1 Product composition

Components	Material	Weight (g)	Weight (%)
Body	PP	130.00	27.37%
Power cord (PVC)	PVC	116.00	24.42%
Packaging	Cardboard	75.00	15.79%
Motor (steel)	Steel	60.00	12.63%
Motor (Cu)	Cu	31.00	6.53%
Power cord (Cu)	Cu	25.00	5.26%
Heater	(Galvanized) steel	21.00	4.42%
Fan	ABS	10.00	2.11%
Switch (steel)	Steel	5.00	1.05%
Switch (ABS)	ABS	2.00	0.42%
	Total	475.00	100%

LIFE CYCLE INVENTORY ANALYSIS

Life cycle inventory analysis (LCI) involves data collection and calculation to quantify inputs and outputs of materials and energy associated with a product system under study.

A product system consists of the manufacturing process of a product under study, plus the up and down stream processes of the product.

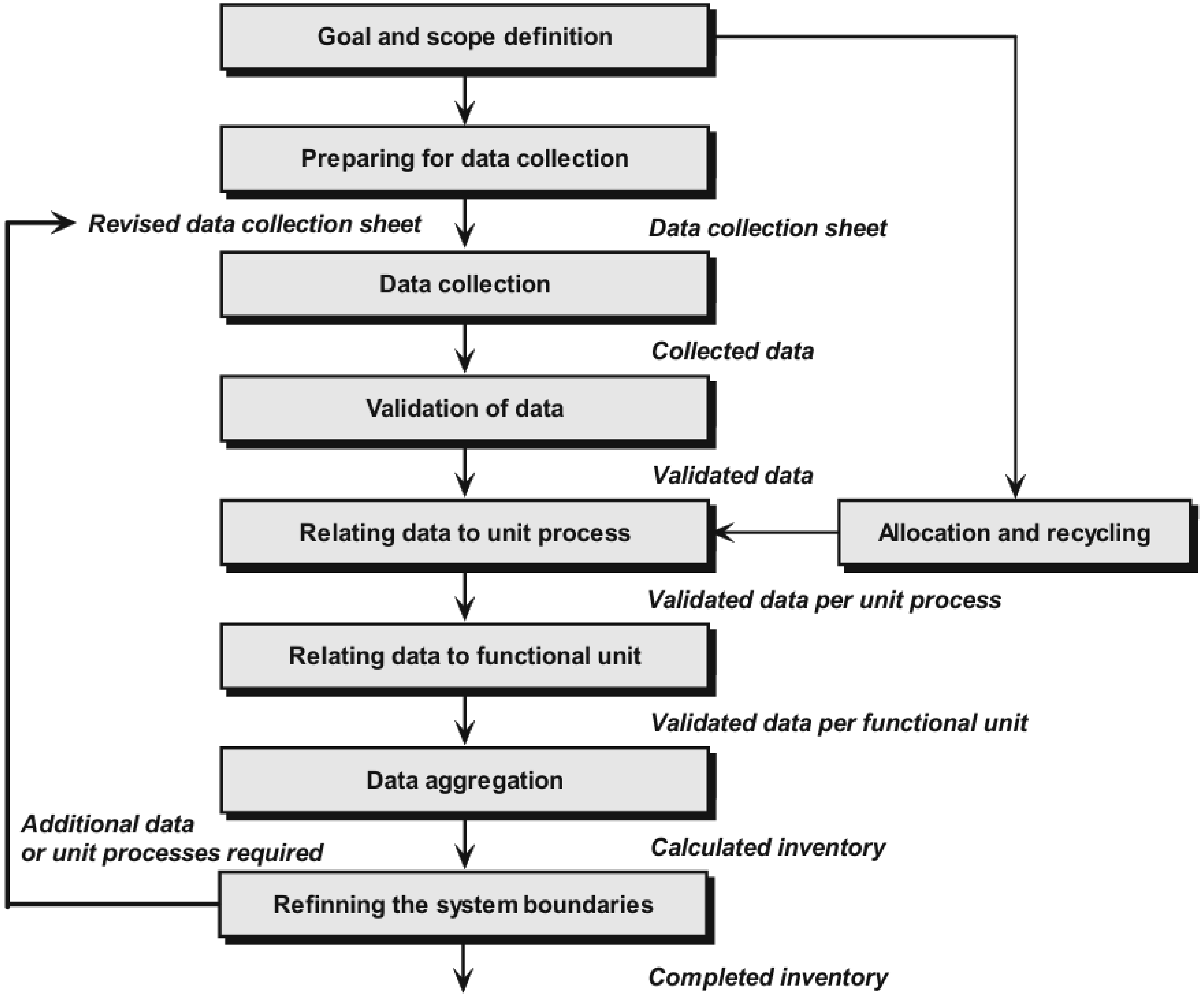


Figure 3.1 Operational procedures for LCI (ISO 14041, 1998)

CASE STUDY – HAIR DRIER (MODEL A)

Refer to -

https://drive.google.com/file/d/1noCb43jgoqdQ4bzj52GsWlNX5YznyYGn/view?usp=sharing

CLASS 5

INTRO TO LIFE CYCLE IMPACT ASSESSMENT

- The significance of potential environmental impacts of a product system based on life cycle inventory results is evaluated by using LCIA.
- Part of the Life Cycle Assessment (LCA) framework.
- Goal: Evaluate the significance of potential environmental impacts of a product system.
- Follows Life Cycle Inventory (LCI).
- Translate resource use and emissions into environmental consequences.

KEY STEPS IN LCIA

1. Selection of Impact Categories
- Decide which environmental issues to evaluate.
- Climate change, human toxicity, eutrophication, etc.

2. Classification
- Assign LCI results to relevant impact categories.

3. Characterization
- Quantify impact using equivalency factors (e.g., CO_2 equivalents for GHGs).

4. (Optional) Normalization, Grouping, and Weighting
- Make results more interpretable and decision-useful.

COMMON IMPACT CATEGORIES (EXAMPLES)

- Global Warming Potential (GWP) – kg CO_2-eq
- Ozone Depletion Potential (ODP) – kg CFC-11-eq
- Acidification Potential (AP) – kg SO_2-eq
- Eutrophication Potential (EP) – kg PO_4^{3-}-eq
- Photochemical Ozone Creation Potential (POCP) – kg ethene-eq

OPTIONAL LCIA PHASES

1. Normalization:
   - Compares impacts to a reference (e.g., per capita emissions in a region).

2. Grouping:
   - Cluster impact categories (e.g., by ecosystem, human health).

3. Weighting:
   - Apply value-based preferences to rank categories.
   - Note: Subjective, not recommended for comparative assertions

LIFE CYCLE INTERPRETATION

- Results of life cycle inventory analysis and life cycle assessments are analyzed with respect to various aspects such as completeness, sensitivity , and consistency.
- In addition, key issues that contribute significantly to the environmental impact of the product system are also identified.
- From these assessments, conclusions are drawn and recommendations made as to the environmental aspects of the product, possible areas of improvement or key environmental information that can be communicated to consumer.

COST-BENEFIT ANALYSIS FOR WASTE MANAGEMENT IN FOOD PRODUCTION

COST BENEFIT ANALYSIS

- Goals:
  - Reduce environmental impact
  - Optimize resource use
  - Achieve long-term financial savings
- Focus: Waste segregation (recyclables, compostable food, non-compostables)
- Current Challenges
  - Improper waste segregation
  - Inefficient disposal methods
  - Inadequate infrastructure
  - Example:
    - 3,000 bento meals/day → large packaging waste
    - Includes cartons, plastics, styrofoam, metals
  - Incineration cost: $77/ton (NEA waste-to-energy plants)

COST BENEFIT ANALYSIS

- Assumptions on waste data in a Food Production Factory
  - Recyclables (Cartons): 39,000kg / month
  - Recyclables (Metal): 2,000kg / month
  - Divertible waste (Food waste): 20,000kg / month
  - General waste: 11,000kg / month
  - Total Waste = 72,000kg / month
- **Scenario A (Worst Case): No Waste Segregation at Source and No On-Site Digester**
  - Number of General Waste Truck Trips per week = 5
  - Cost of Truck Use per trip = $220
  - Cost of Waste Truck Usage per month (4 weeks) = $220 x 5 x 4 = $4,400
  - Cost of Incineration per month: (39 + 2 + 20 + 11) x $77 = $5,544
  - *Total Cost of Waste Disposal per month (4 weeks) = $4,400 + $5,544 = $9,944*

COST BENEFIT ANALYSIS

- **Scenario B: No Waste Segregation at Source and Inclusive of a On-Site Food Waste Digester**
  - Cost of Digester Machine (1 ton/day) = $120,000
  - Cost of Operating Digester (1 ton/day) per month = $500
  - Expected Shelf Life = 10 years
  - Monthly Depreciation Cost = $1,000
  - Monthly Cost (Depreciation + Operations) = $1,500
  - Number of Waste Truck Trips per week = 3
  - Cost of Waste Truck per trip = $220
  - Cost of Waste Disposal per month (4 weeks) = $220 x 3 x 4 = $2,640
  - Cost of incinerating = (39 + 2 + 11) x $77 = $4,004
  - *Total Cost of Waste Disposal (4 weeks) = $1,500 + $2,640 + $4,004 = $8,144*

COST BENEFIT ANALYSIS

- **Scenario C (Ideal Case): 100% Waste Segregation at Source Recycled with On-site Food Waste Digester**
  - *Assume no charges incurred to off-take well-segregated recyclables
  - Cost of Digester Machine (1 ton/day) = $120,000
  - Cost of Operating Digester (1 ton/day) per month = $500
  - Expected Shelf Life = 10 years
  - Monthly Depreciation Cost = $1,000
  - Monthly Cost (Depreciation + Operations) = $1,500
  - Number of Waste Truck Trips per week = 1
  - Cost of Waste Truck per trip = $220
  - Cost of Waste Disposal per month (4 weeks) = $220 x 4 = $880
  - Cost of incinerating = 11 x $77 = $847
  - Total Cost of Waste Disposal (4 weeks) = $1,500 + $880 + $847 = $3,227

COST BENEFIT ANALYSIS

Scenario	Waste Management System	Total Cost of Waste Disposal
A.	No Recyclables Segregation at Source + No Food Waste Digester	S$9,944
B.	No Recyclables Segregation at Source + 100% Food Waste Segregation with On-Site Digester	S$8,144
C.	100% Recyclables Segregation at Source + 100% Food Waste Segregation with On-Site Digester	S$3,227

Comparing the different waste management systems, we can see that segregating food waste and employing digesters would allow cost savings to be achieved.