An Introduction to Life Cycle Assessment (LCA)

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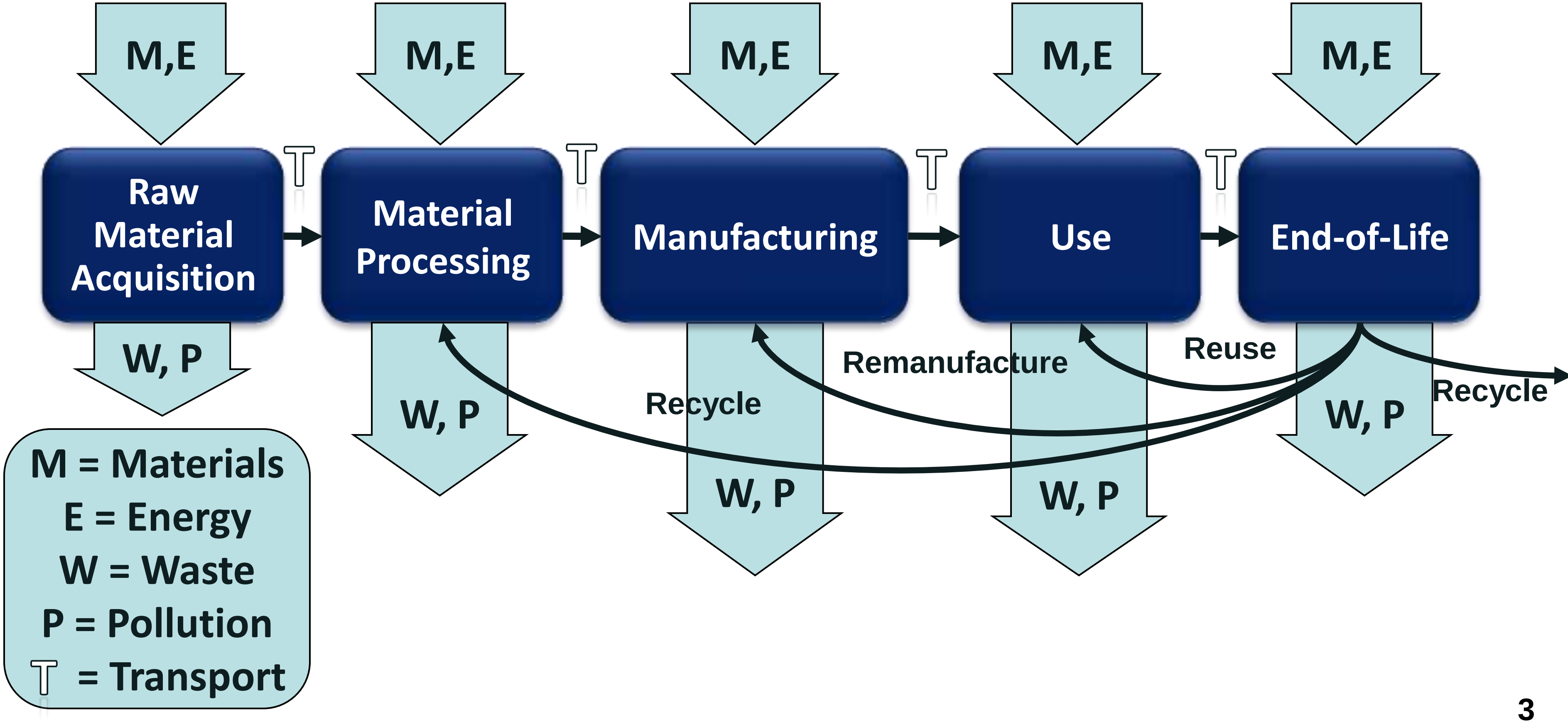
Life Cycle Assessment (LCA)

- A method for characterizing and quantifying environmental sustainability
- Applies a “cradle-to-grave” perspective when analyzing products or systems
- Measures inputs and outputs of a product or system
  - Example inputs: energy, water, materials
  - Example outputs: air emissions, waste
  - Can be categorized into *impact categories*
- General standards set by ISO 14040 series
  - Provides general LCA guidance, but lacks detailed information necessary for individual products and systems

Life cycle assessment

- Evaluates a product or system throughout its entire ***life cycle***



Let's Simply Define the Life Cycle of an Everyday Object

Three Key Elements of Life Cycle Assessment

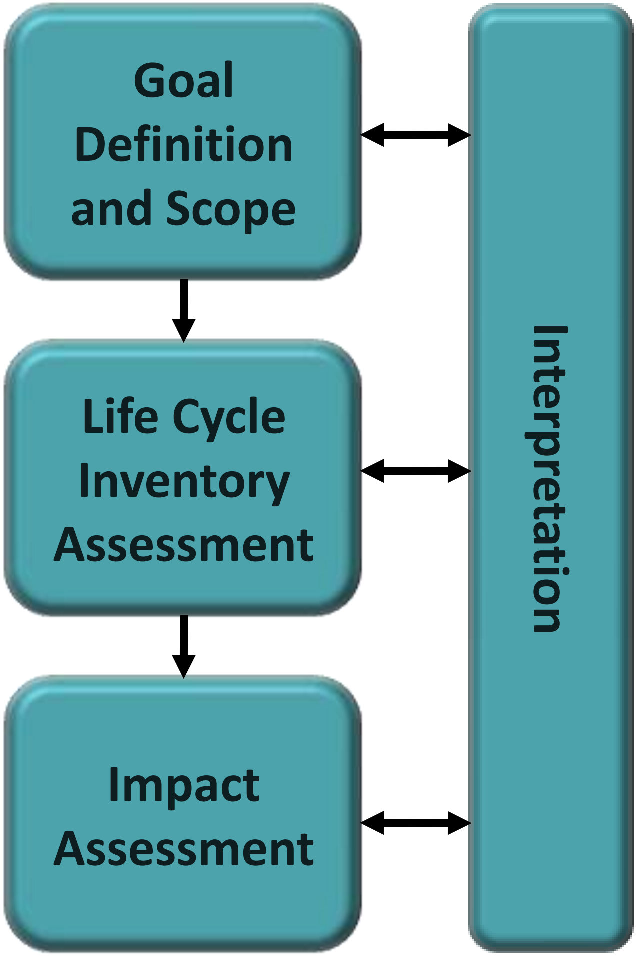


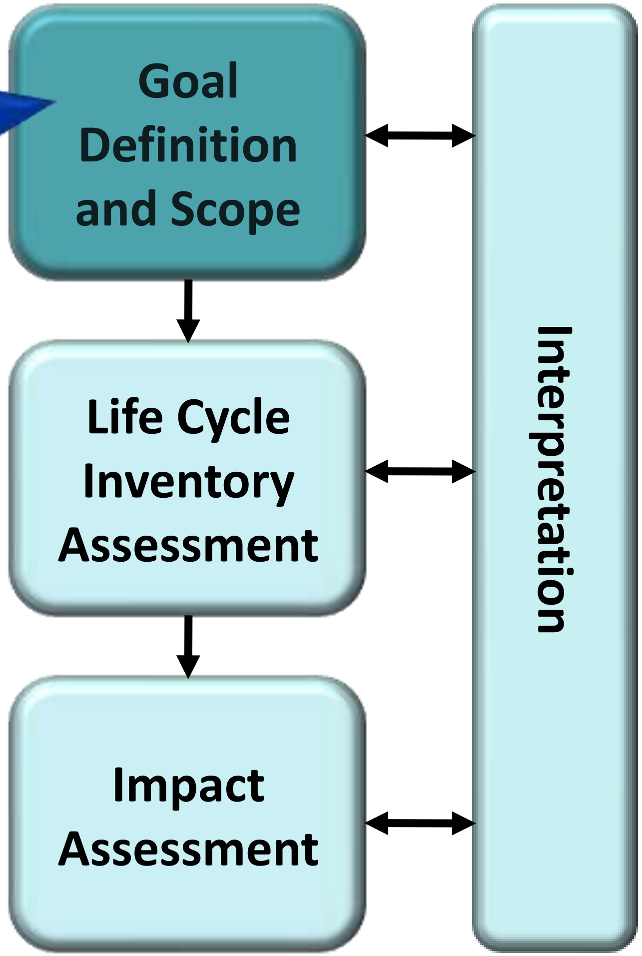
Figure based on ISO 14040

LCA Standards

- ISO = International Organization for Standardization
- ISO LCA Standards:
  - 14040 Principles and Framework
  - 14044 Requirements and Guidelines
  - 14047 Impact Assessment
- Standards are general guidelines
  - Provides general LCA guidance, but lacks detailed information necessary for individual products and systems

Three Key Elements of Life Cycle Assessment

Key steps include system boundary definition – essentially, what can be left out of the LCA?



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Scope

- Scope of the study
  - function and functional unit
  - system boundaries
  - data requirements/assumptions/limitations
- Defining the functional unit is an extremely important step
  - In comparative LCA, this will define what products and systems are comparable to one another

Defining Function & Functional Unit

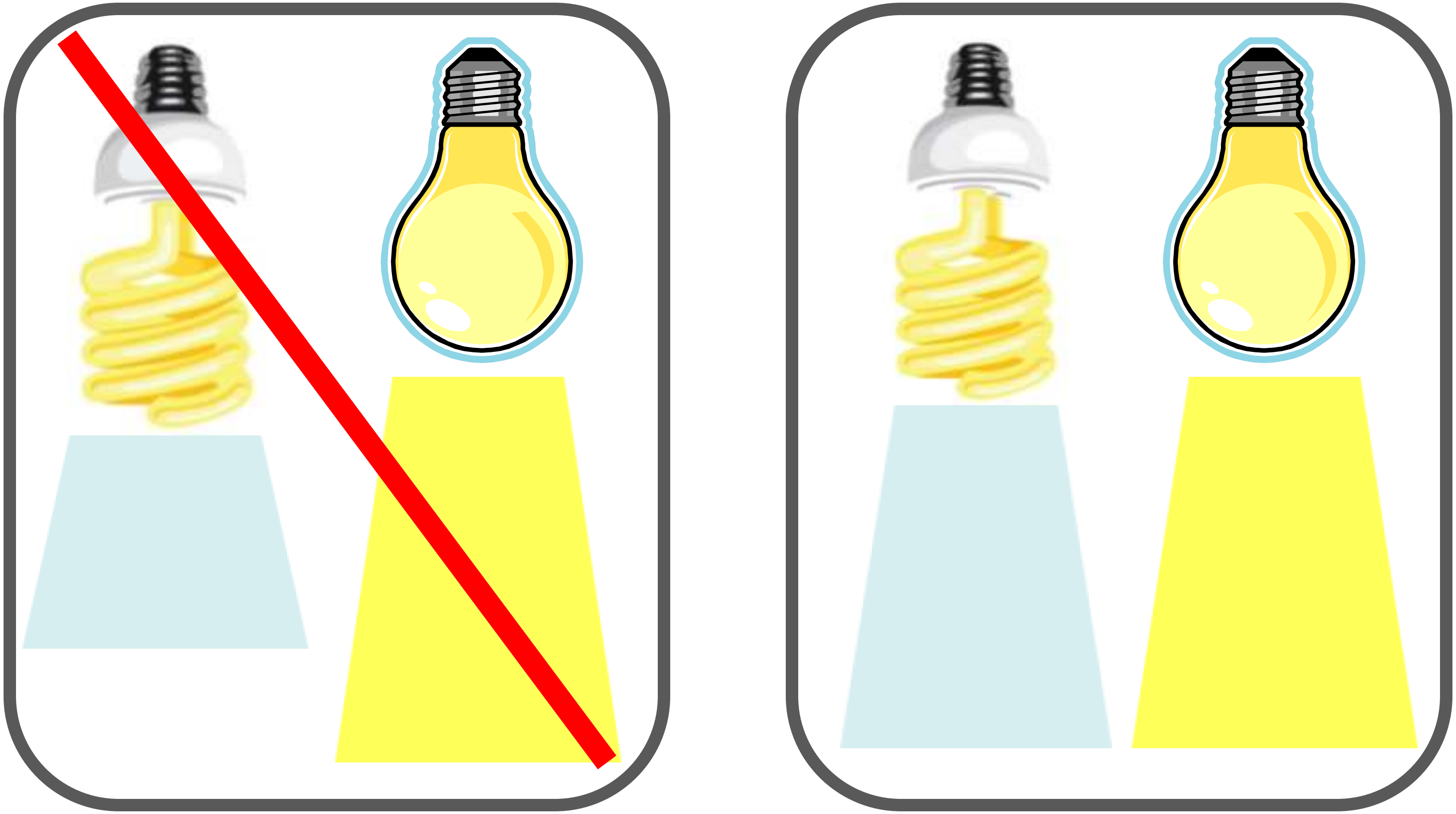
- Function
  - service provided by system; performance characteristics of the product
- Functional unit
  - means for quantifying the product function
  - basis for an LCA
  - reference for normalization of input and output data

Functional Unit

- The functional unit also needs to define a time-horizon.
- A light bulb will likely be defined by
  - the amount of light (lumens) provided (the service/function)
  - for a certain number of hours (the time horizon).
- The time-horizon is not always hours/days/years
  - A vehicle functional unit could be based on miles driven, years of use, or both

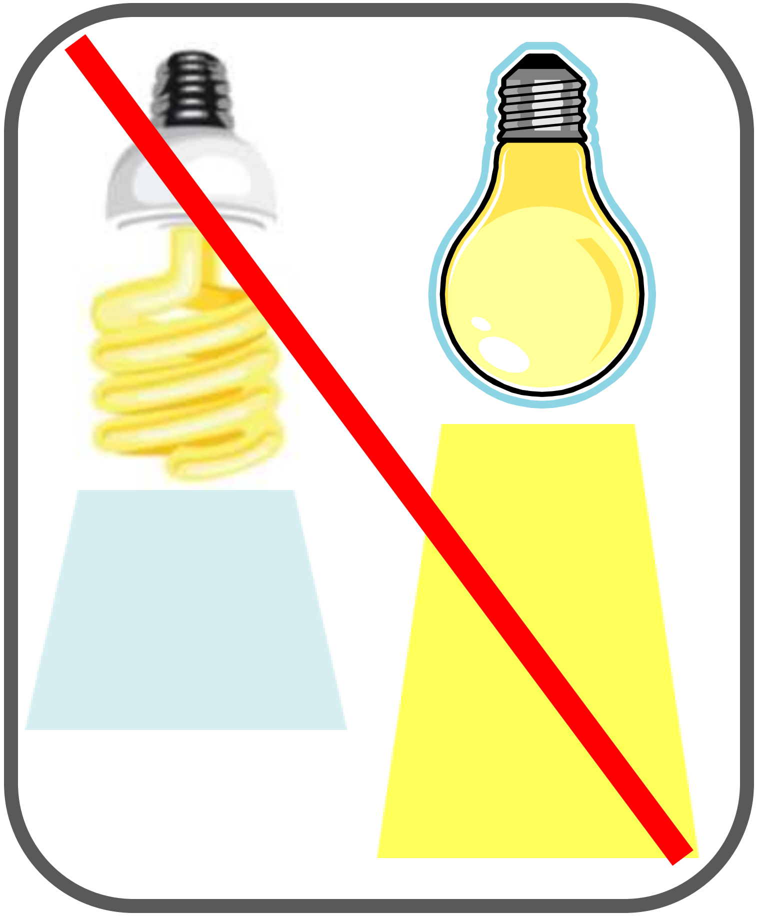
What are the consequences of a functional unit?

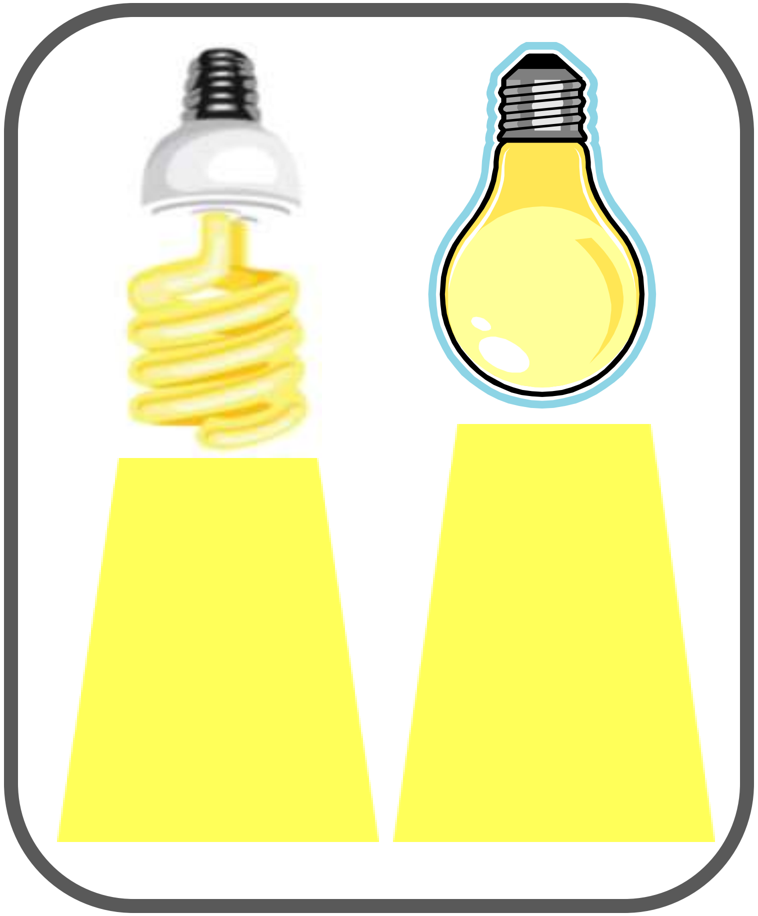
- When comparing light bulbs (e.g. compact fluorescent and incandescent) you must compare light bulbs with the *same luminescence*



What are the consequences of a functional unit?

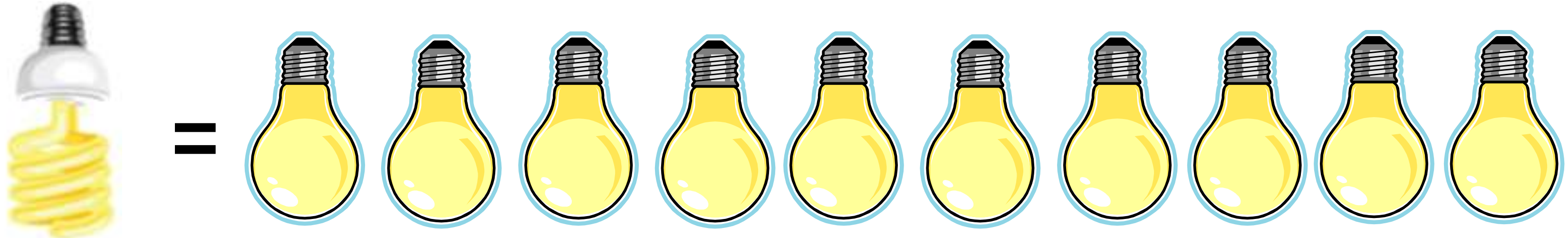
- Can you think of any other functions that are different between fluorescent and incandescent lights?





CFL vs. Incandescent

- Case Study: Compare a
  - CFL with an output of 900 lumens, and a 10,000 hour life,
  - An incandescent bulb with an output of 900 lumens and 1,000 hour life
- How many incandescent bulbs are needed to serve a study where the functional unit is 900 lumens delivered for 10,000 hours?
  - 10,000/1,000 = 10 bulbs

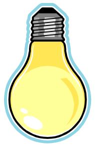


Why Time Horizon Matters

- What if we made the study time horizon 11,000 hours?
  - 11 incandescent bulb lifetimes
  - 2 CFL Bulbs (1 bulb, + 10% of the useful life of another)
  - How should we treat the remaining useful life of the CFL?
- Think about comparing pavement designs
  - One with an expected 32 year lifetime and another with 45-year lifetime?

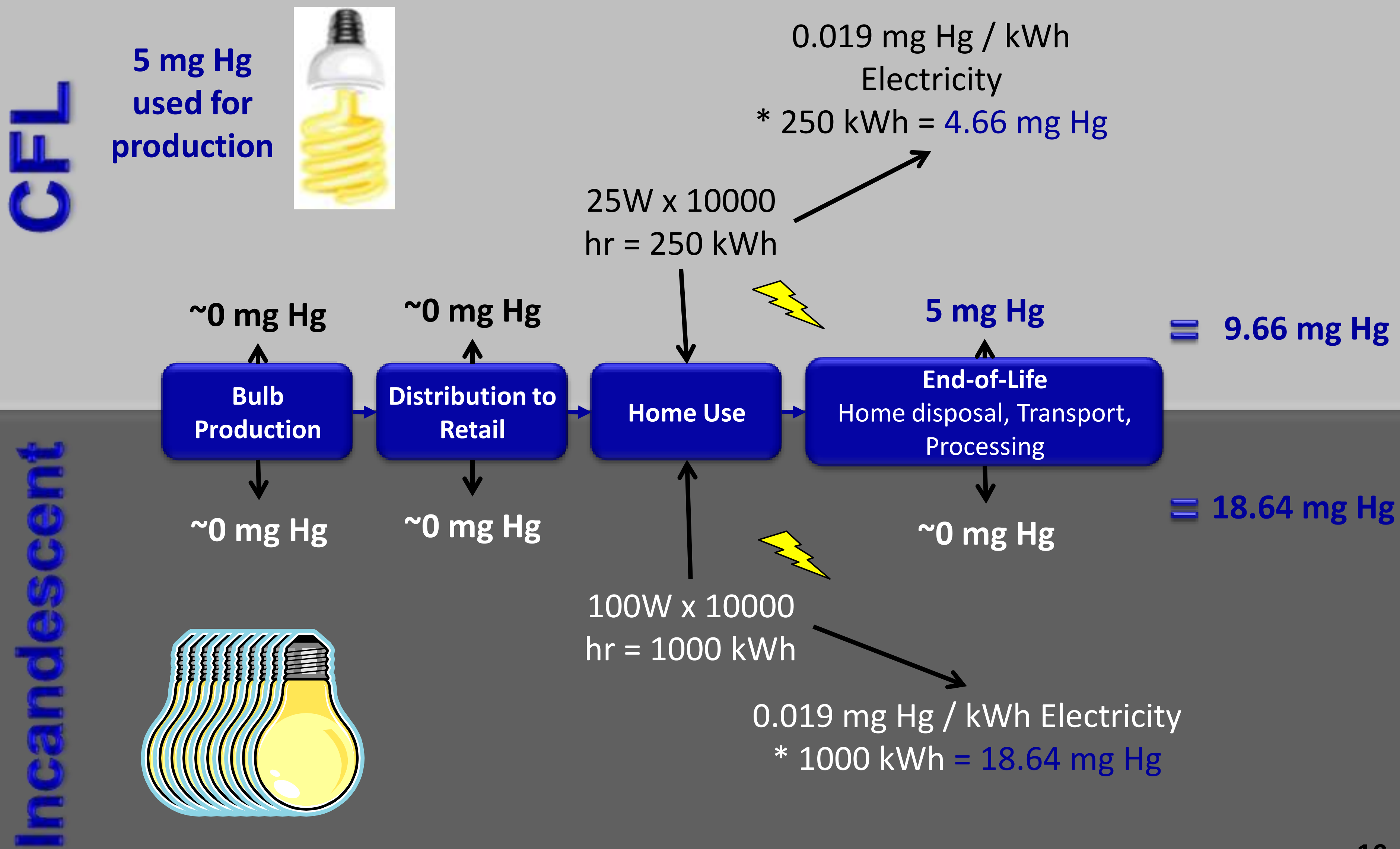
Simplified Life Cycle Hg Emissions for CFL and Incandescent Bulbs

- Why would we do this?
  - CFLs have Hg vapor in their glass tubing. When bulbs are broken, the Hg (in elemental form) is released to the environment. If disposed in a trash bin, breakage is inevitable
- Our electricity grid in the U.S. emits on average 0.0184 mg Hg/kWh
- Trade-off:


more Hg from electricity **vs.** Hg emissions at disposal


- Functional unit: 1700 lumens, 10,000 hours of light. The CFL bulb is a 25 W bulb, the Incandescent is a 100 W bulb.

Simplified Life Cycle Hg Emissions for CFL and Incandescent Bulbs



System Boundary Definition

- The system boundary defines which unit processes and which parts of the life cycle should be included in the study
- There are situations where unit processes or even life cycle phases could be excluded from an analysis
- This definition critically effects the outcome of an LCA, and determines whether outcomes of studies can be compared to one another

Three Key Elements of Life Cycle Assessment

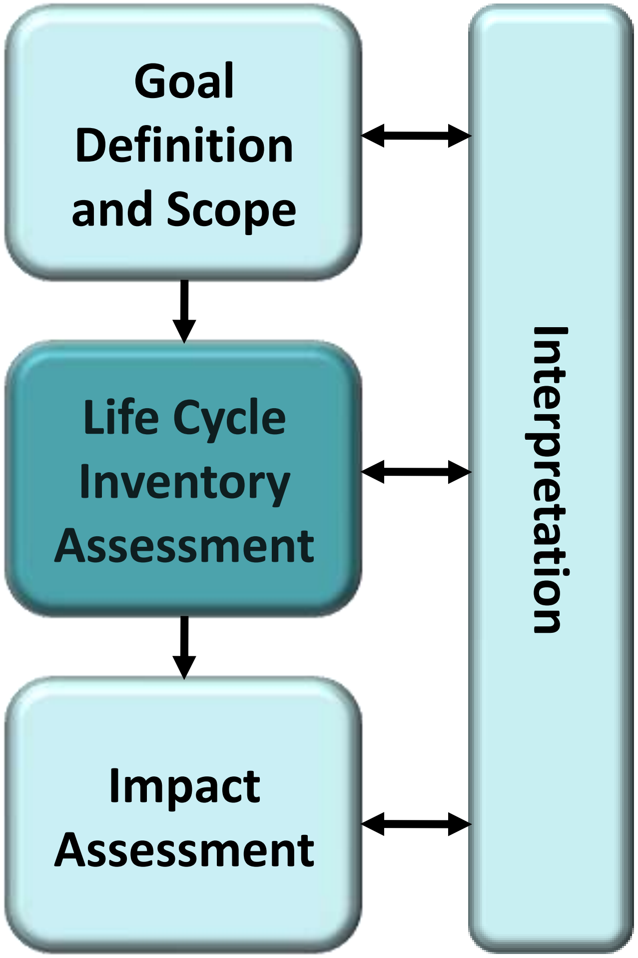
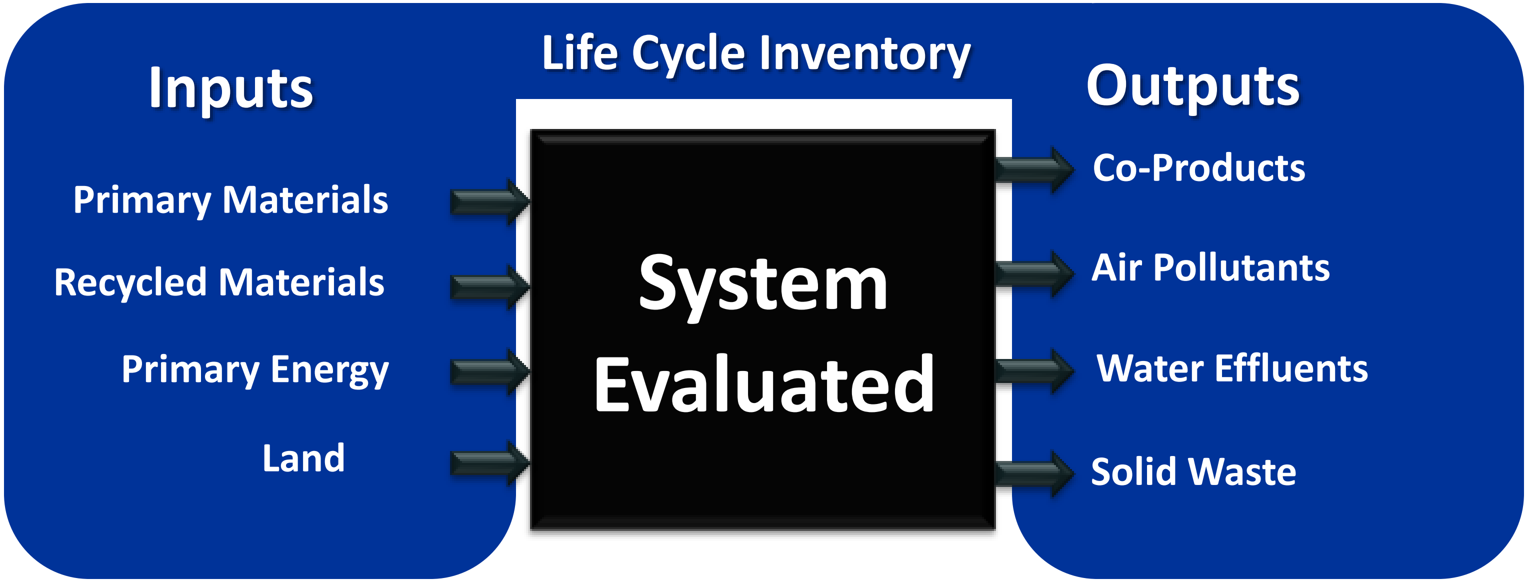


Figure based on ISO 14040

Life Cycle Inventory (LCI)

- The “accounting” **stage for LCA**



Data Quality Considerations

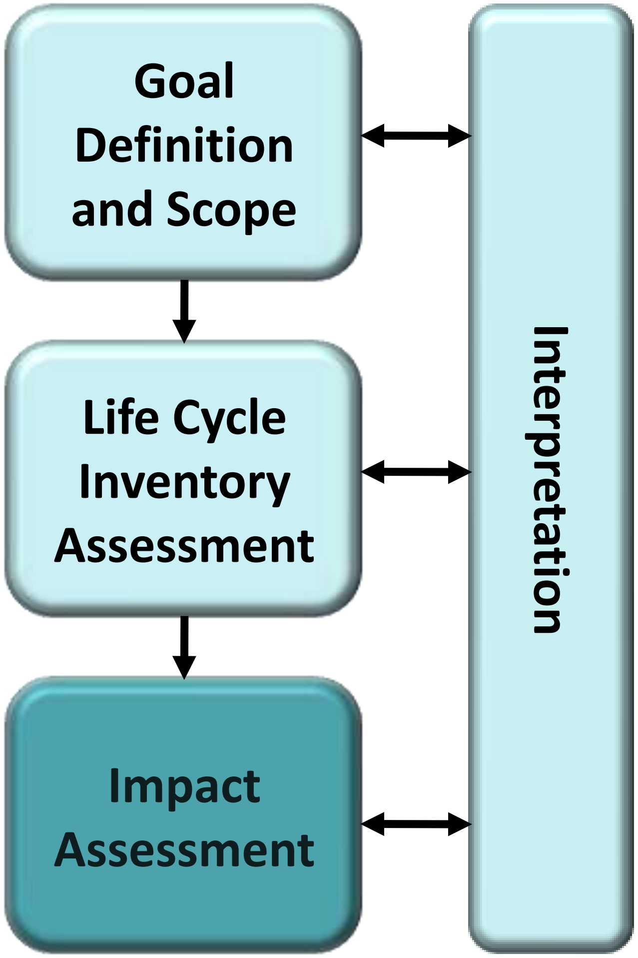
- Many times we rely on existing life cycle inventory datasets, rather than collecting new data
- Considerations include
  - Age of datasets
  - Are datasets in a study all collected and created with the same methodology?
  - Geography of study vs. geography of data
  - Uncertainty in data

Where do we get data?

- Literature
  - – Journal papers
  - – Research reports
  - – Industry data
  - – Government data

- Models
  - – General LCA models
    - e.g., Simapro, Gabi, EIO-LCA
  - – Product specific models
    - e.g., PaLATE (pavements), BEES (buildings)

Three Key Elements of Life Cycle Assessment



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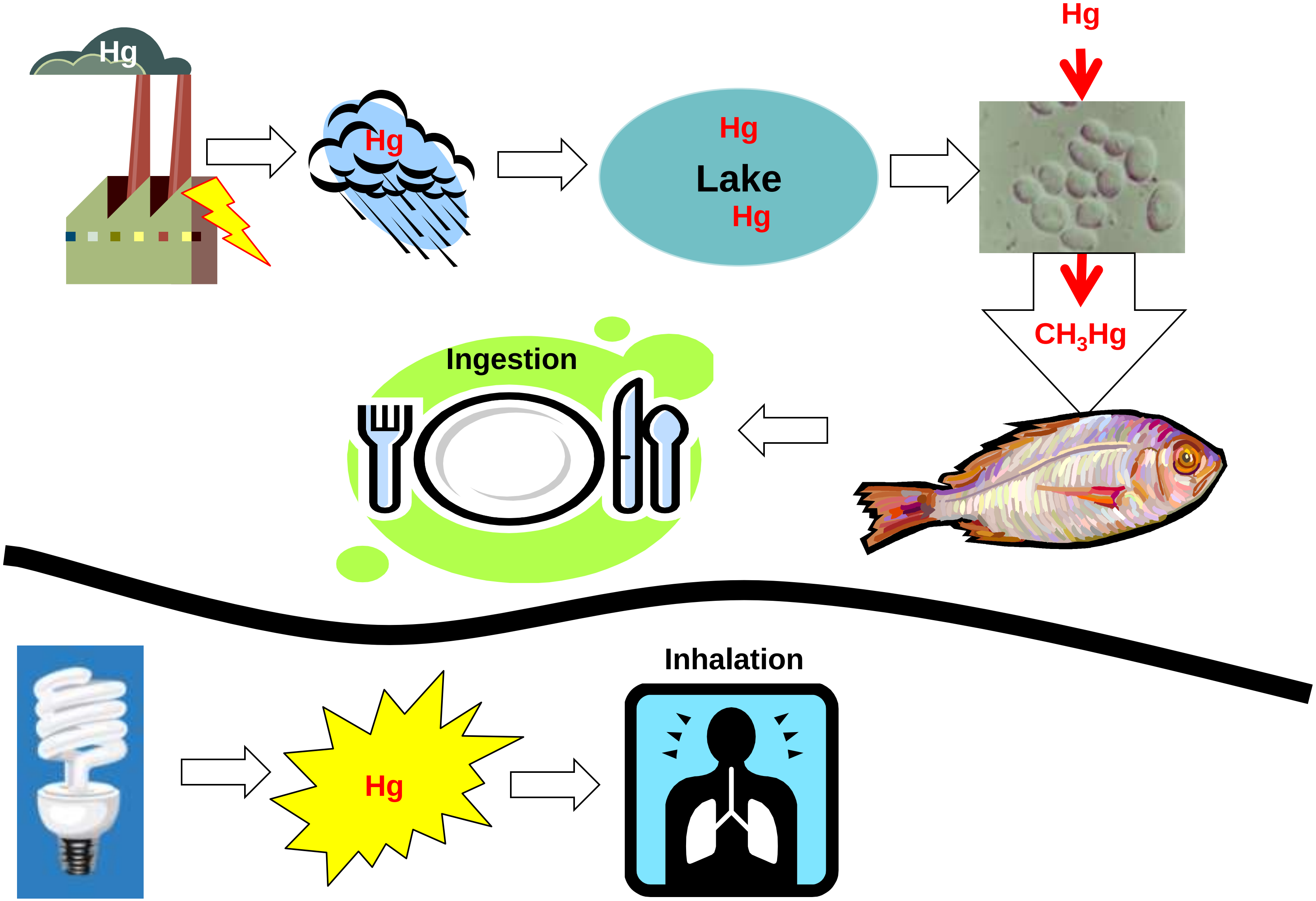
Impact Assessment

- At this stage, the LCI is translated into meaningful metrics and indicators
- Usually, we create impact categories for climate change, air pollutants, and water effluents
- Impact is dependent on the fate of pollutants and who or what environments are exposed
  - For our light bulb example, there are big differences in the way Hg is emitted and how people/environments are exposed

Impact Assessment: Hg from lighting



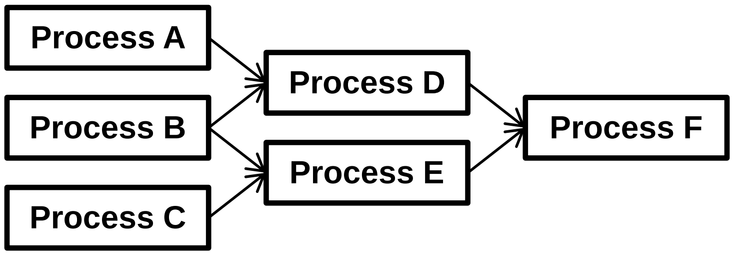
Impact assessment: Inputs

- Input related categories
  - Abiotic resource extraction
  - Biotic resource extraction
  - Fossil energy
  - Total primary energy
  - Water consumption

Impact assessment: Example Outputs

- Output related categories
  - global warming potential
    - e.g. convert LCI outputs of GHG emissions using global warming potential to CO_2e
  - human toxicity
    - e.g. convert toxic pollution recorded in the LCI into its potential or estimated toxicity to humans
  - ecotoxicity
  - photo-oxidant formation
  - acidification
  - nutrification

Approaches to LCA



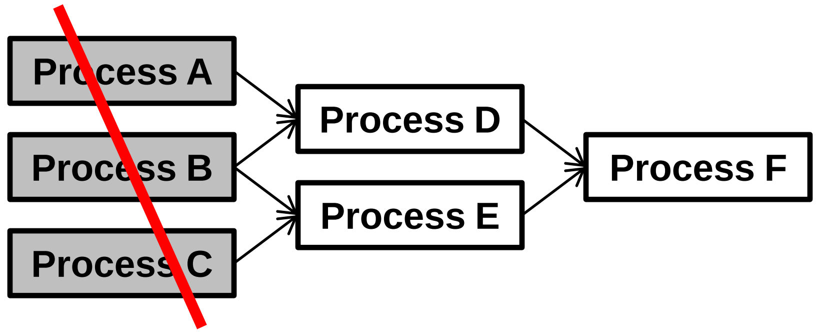
	Input to				Final Demand
Output from	1	2	3	n	
1	D_{11}	D_{12}	D_{13}	D_{1n}	F_1
2	D_{21}	D_{22}	D_{23}	D_{2n}	F_2
3	D_{31}	D_{32}	D_{33}	D_{3n}	F_3
n	D_{n1}	D_{n2}	D_{n3}	D_{nn}	F_n

- **Process-based**
  - Breaks product into individual processes
  - Allows for detailed, specific analyses
  - Necessary to truncate upstream supply chain
- **Input-Output**
  - Uses flows between sectors of economy to calculate impact
  - Integrates entire upstream supply chain
  - Uses national averages
  - Necessary to allocate within shared sectors
  - United States: www.eiolca.net

Modeling Errors

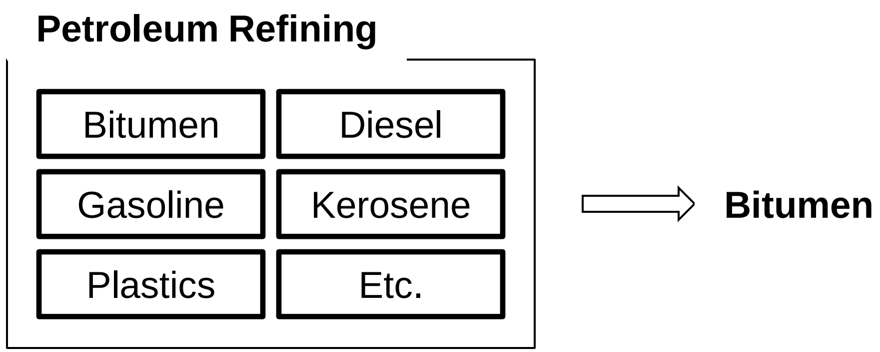
Truncation Error

Truncation of the upstream supply chain



Allocation Error

Necessary to allocate impact when multiple products share common processes



Aggregation Error

Assumption that all like products are made using identical processes (averaging)

Hybrid LCA

- Combines Process and EIO-LCA approaches
  - Process used for the most critical and unique processes
  - EIO-LCA used for commodity-type processes. Used to model upstream supply chain impacts.
- Hybrid LCA can reduce modeling errors
  - No truncation error
  - Minimize aggregation and truncation error