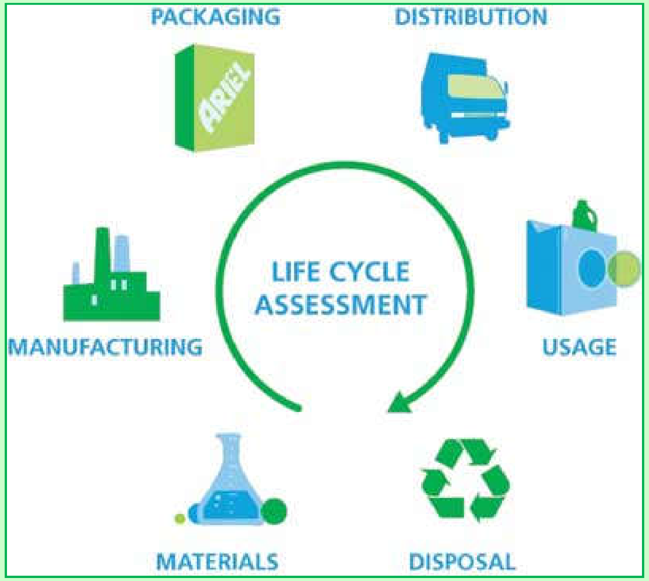

Life cycle assessment

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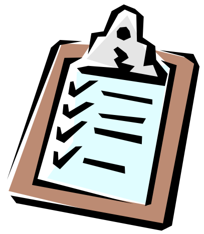
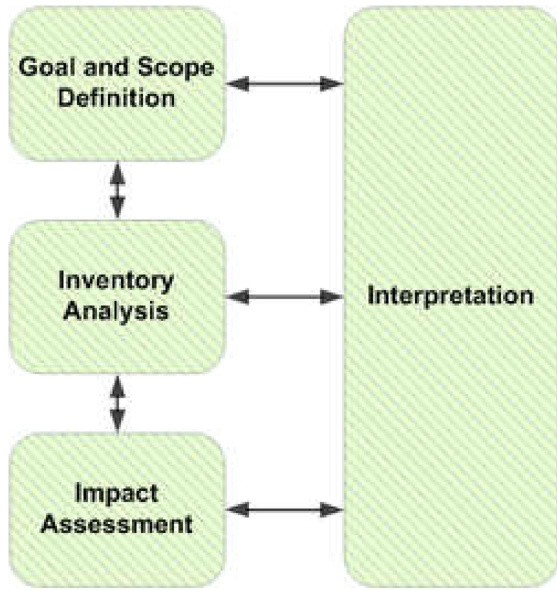
Jan 2018



Contents

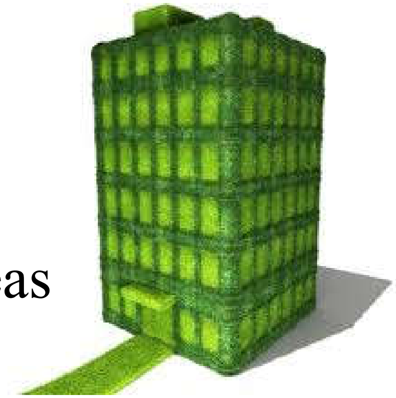
- LCA basic concepts
- LCA process
- Examples of LCA
- Evaluation methods
- Limitations of LCA

生命週期評估

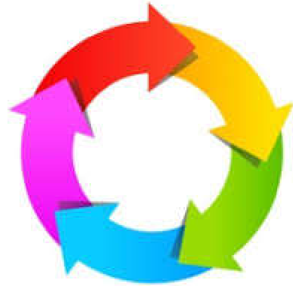


LCA basic concepts

- Three methods to evaluate green buildings:
  - 1. Single attribute
    - Such as energy efficiency, alternative energy, recycled green materials/products
  - 2. Multiple attribute
    - Green building rating systems
      - Multi-criteria standard, points earned in various areas
  - 3. Life cycle assessment (LCA)
    - Full and quantitative accounting of environmental impacts



LCA basic concepts



- Life cycle assessment (LCA) is a scientific method for evaluating environmental impacts associated with all the stages of a product's life
- LCA is being integrated into green building rating systems, building codes and standards
  - Such as LEED v4, Green Star, California Green Building Code, International Green Construction Code (IGCC), ASHRAE Standard 189.1

LCA basic concepts

- A brief history of LCA
  - Originated from energy analysis and some claim first LCA carried out by Coca Cola in 1969

  - SETAC (Society of Environmental Toxicology and Chemistry) set first standards in 1990
  - ISO produced series of standards in 1997/98 which were revised in 2006
    - ISO 14040:2006 outlining LCA principles and framework
    - ISO 14044:2006 for requirements and guidelines

ISO 14040
Approved Life
Cycle Assessment

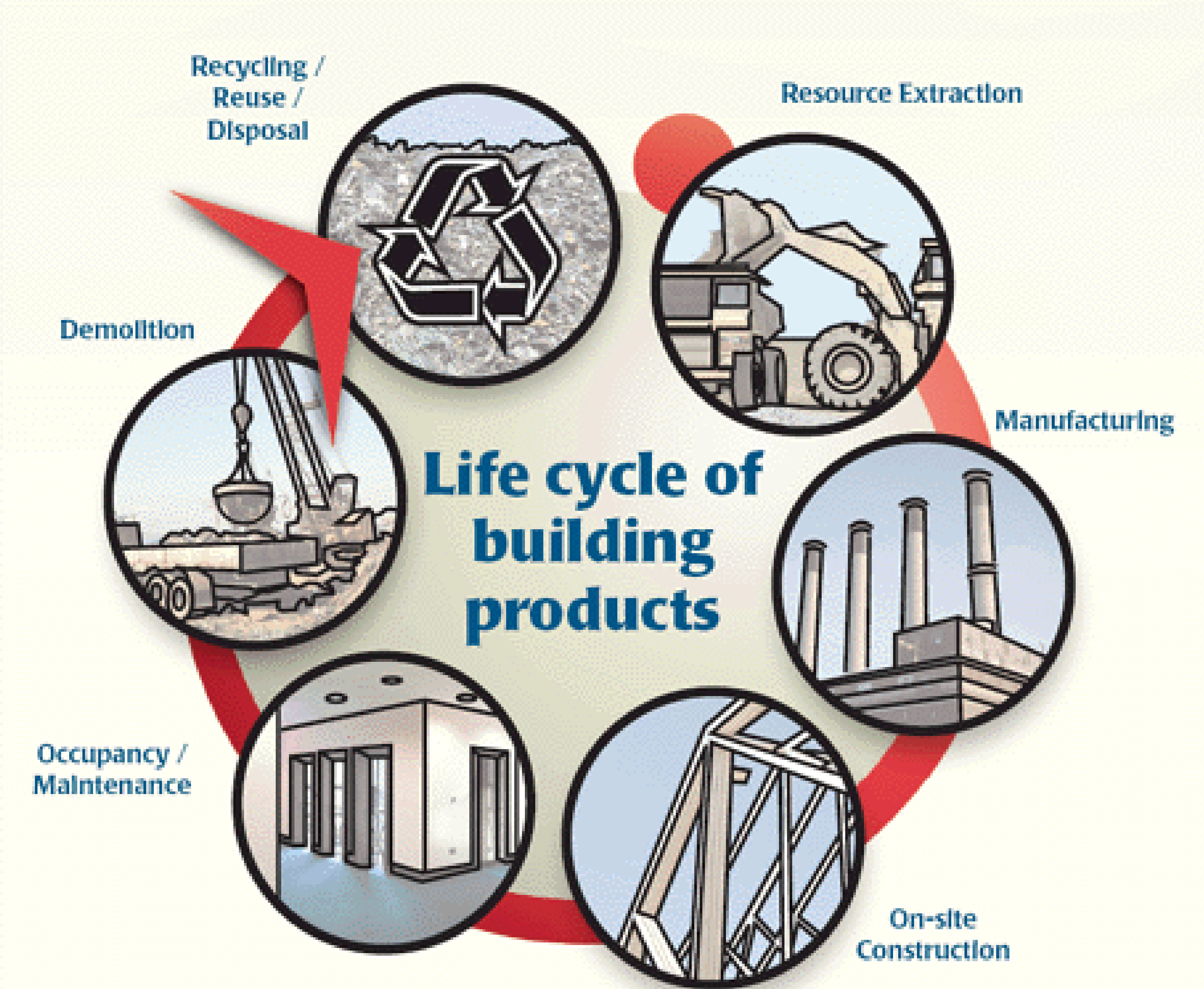
LCA basic concepts

- Definition of Life Cycle Assessment (LCA) [ISO 14040]: 生命週期評估
  - “*A compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle*”
- Also called “cradle-to-grave” analysis
- Embodied effects include:
  - Resource use (raw materials, land, water, energy)
  - Emissions to air, water and land

Cradle-to-Grave

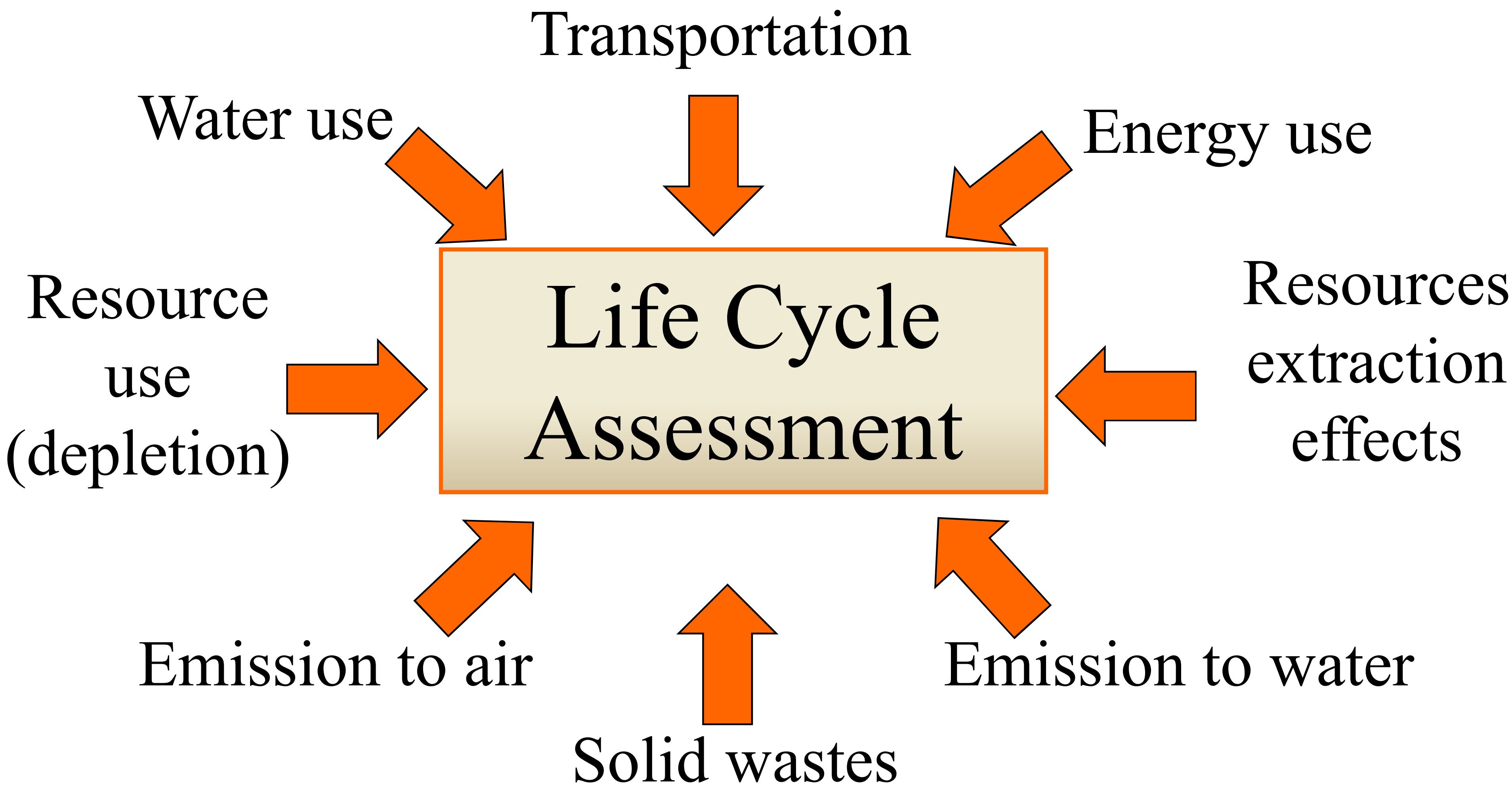
Cradle-to-grave is the full Life Cycle Assessment from resource extraction ('cradle') to use phase and disposal phase ('grave').

(Video: Life cycle (0:29), http://youtu.be/x9NqzVWIeX4)



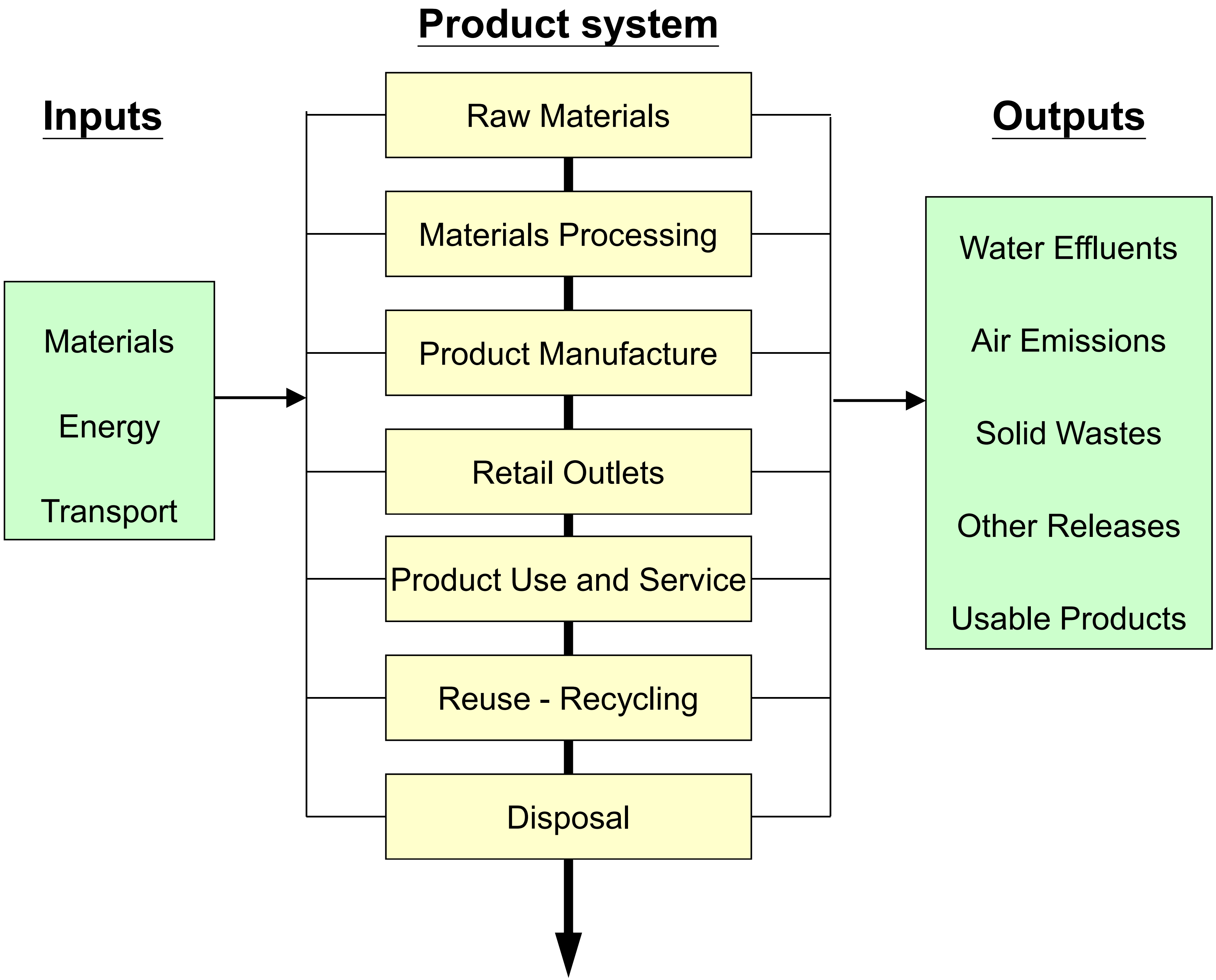
(Source: Athena Institute, www.athenasmi.org)

LCA: a methodology for assessing the life cycle environmental performance of products and processes



(Source: Athena Institute, www.athenasmi.org)

Areas covered by Life Cycle Assessment (LCA)



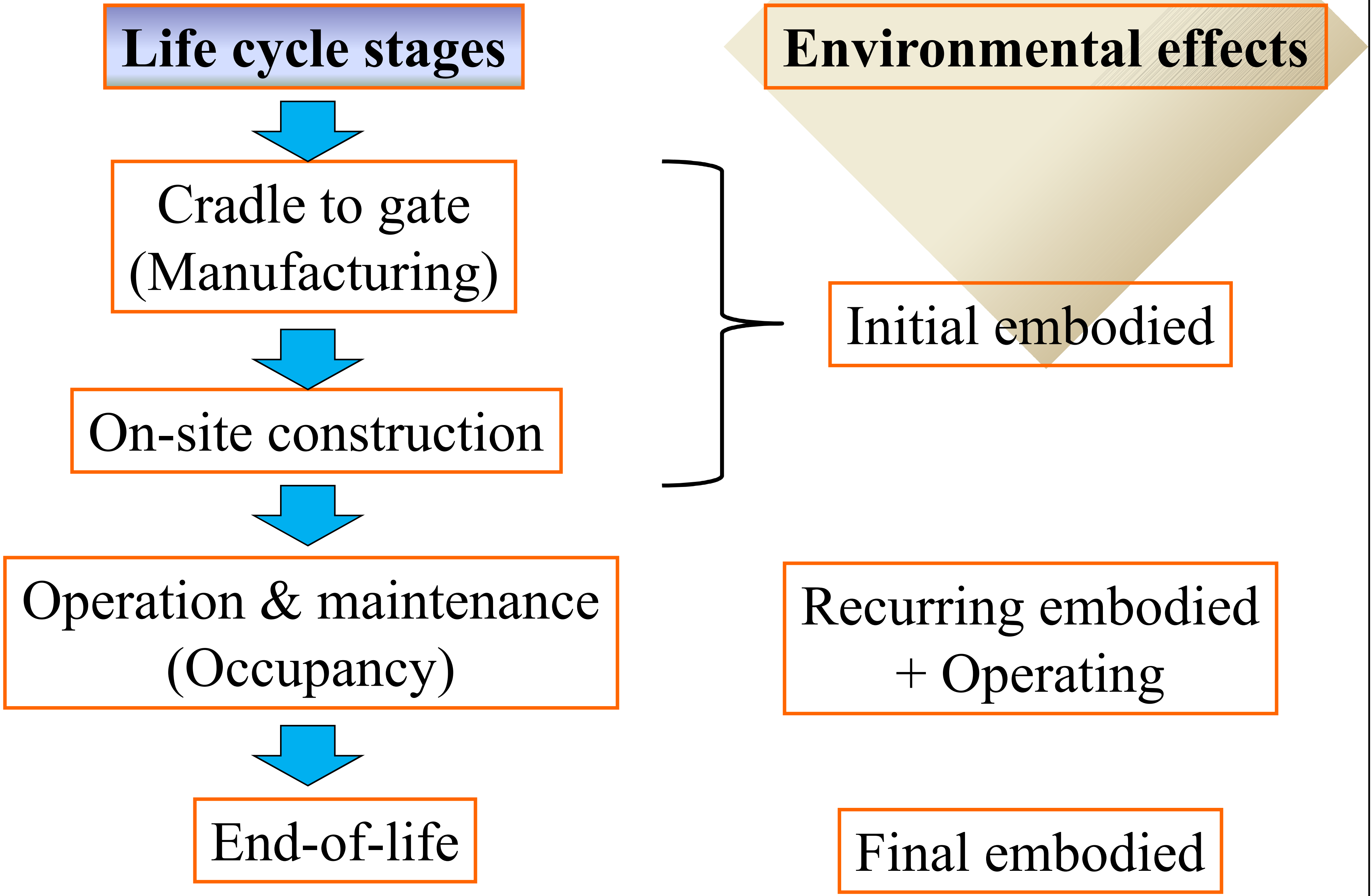
T-shirt example (cotton)

Do you know the life cycle of a T-shirt?

• Growing • Harvesting	Extraction of materials
• Spinning • Weaving/knitting	Processing of materials
• Bleaching, dyeing, washing and treatment • Cutting and sewing	Production
• Use - reuse	Use and maintenance
• Disposal – recycling • Downcycling, Upcycling	Disposal/end of life

(Video: The Life Cycle of a T-Shirt (4:07) https://youtu.be/5Ckgw5xvZV4)

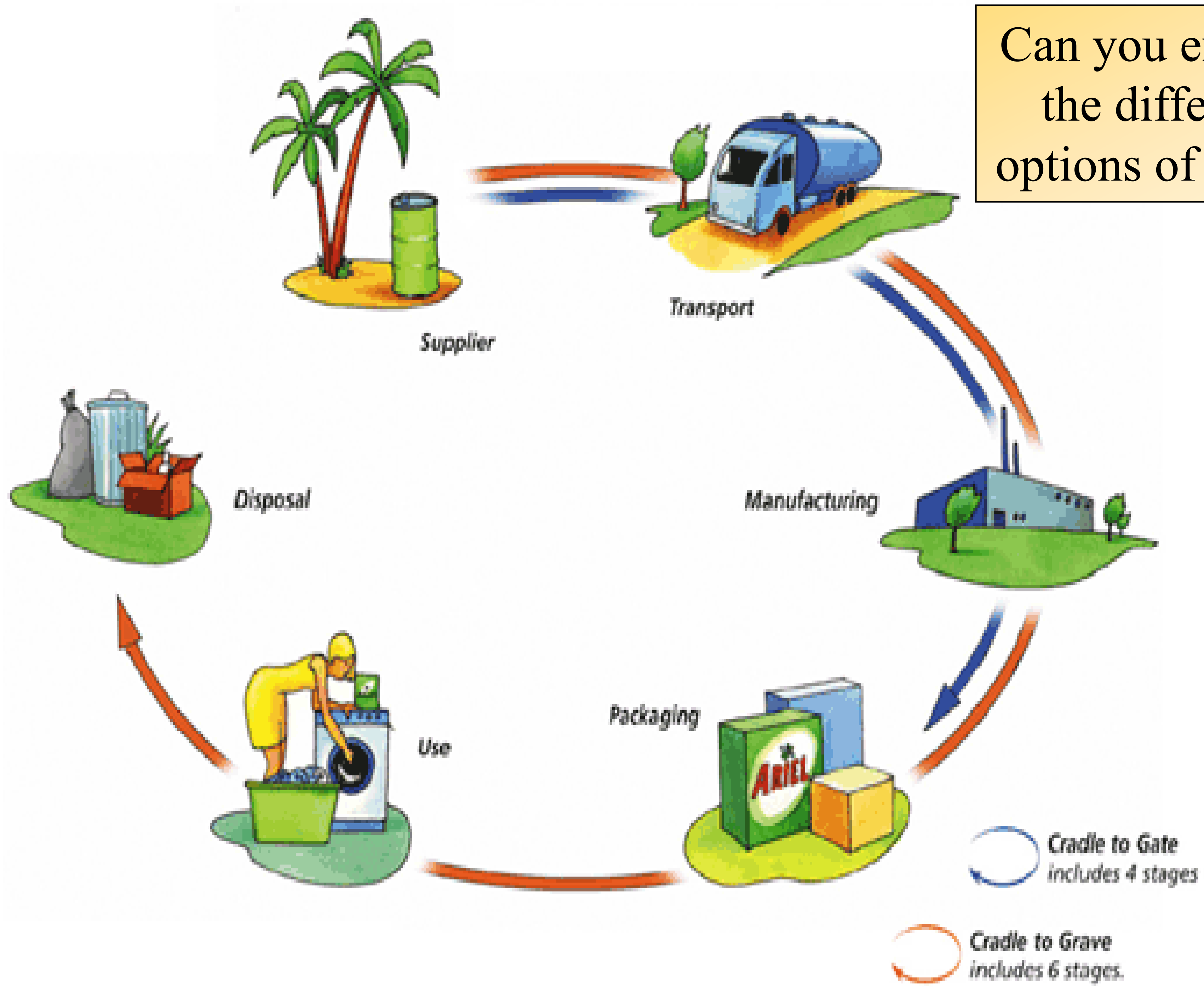
Life cycle stages and eff



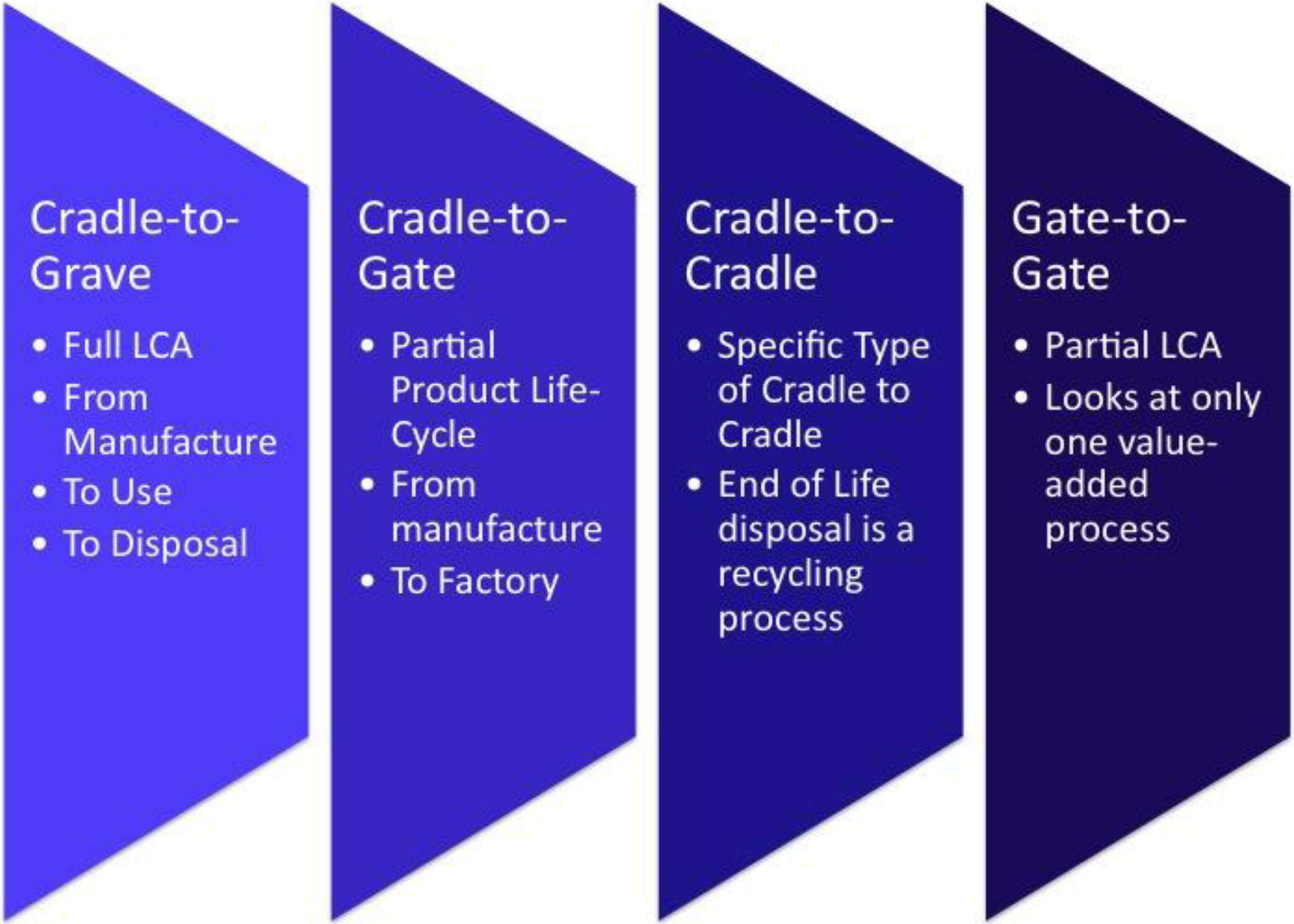
(Source: Athena Institute, www.athenasmi.org)

‘Cradle to Gate’ (4 stages) and ‘Cradle to Grave’ (6 stages)

Can you explain the different options of LCA?



Different options of life cycle assessment



(Source: AIA Guide to Building Life Cycle Assessment in Practice)

LCA basic concepts

- Objectives of LCA
  - To provide a complete a picture as possible of the interactions of an activity with the environment
  - To contribute to the understanding of the overall and interdependent nature of the environmental consequences of human activities
  - To provide decision makers with information which defines the environmental effects of these activities and identifies opportunities for environmental improvements

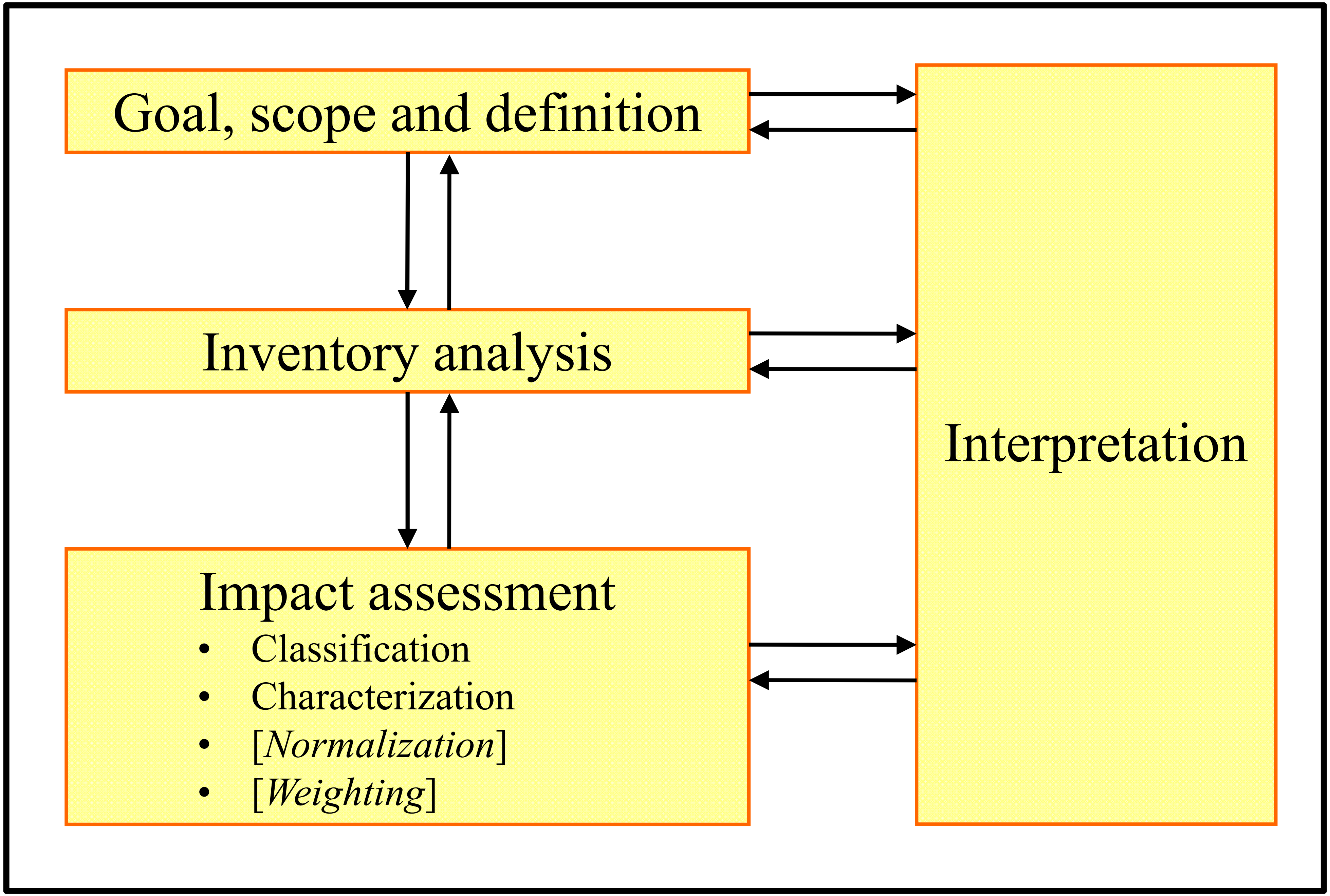
LCA process

- LCA considers the environmental loadings that can result from the manufacture, use, and disposal of a product
  - It expresses the results in energy units, mass units of pollutants, potential impacts, and other units
- Three major LCA impact assessment phases:
  - (a) Inventory
  - (b) Impact indicators
  - (c) Impact assessment (valuation/weighting)

LCA process

- The LCA process has four phases:
  - 1) Goal, scope and definition
    - Defines purpose of study, boundaries & functional units
  - 2) Life cycle inventory (LCI)
    - Provides inventory of input/output data
  - 3) Life cycle impact assessment (LCIA)
    - Assess the magnitude and significance of the impacts
  - 4) Life cycle interpretation
    - Provides conclusions and recommendations (areas for improvement)

Life cycle assessment framework (an iterative process)



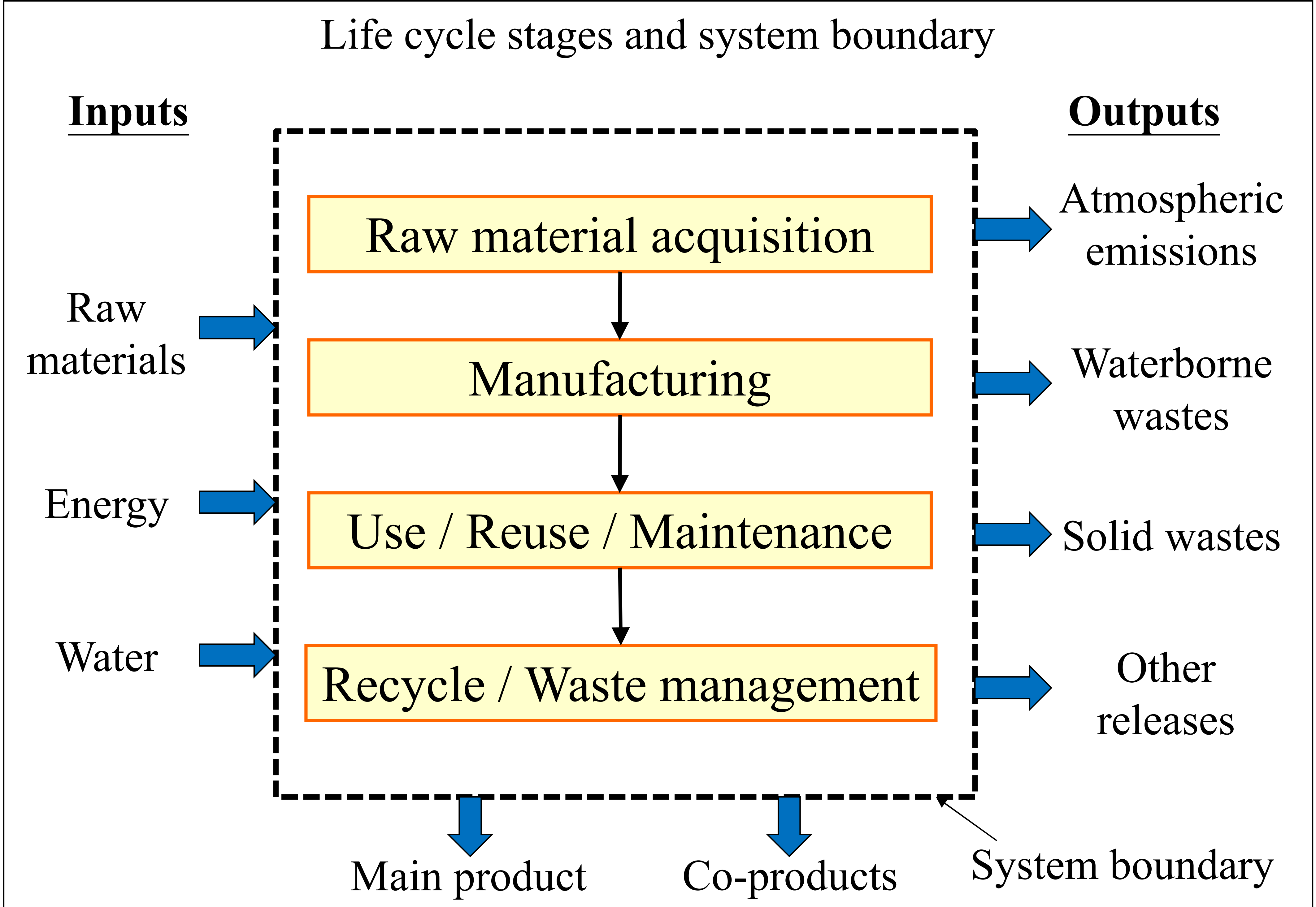
LCA process

- 1) Goal, scope and definition
  - The aim, breadth and depth of the study is established
  - (a) Goal definition
    - Intended application
      - Product development and improvement, strategic planning, public decision making, marketing, etc.
    - Reasons for carrying out the study
    - Intended audience
      - Who will read the results

LCA process

- 1) Goal, scope and definition (cont'd)
  - (b) Scope definition
    - Function, functional unit and reference flow
      - Comparison on the basis of an equivalent function
      - Example: 1000 liters of milk packed in glass bottles or packed in carton, instead of 1 glass bottle versus 1 carton

    - Initial choices of system boundaries, data quality, etc.
    - Critical review and other procedural aspects
      - To ensure consistency, scientific validity, transparency, etc.
      - Internal review, external review, review by interested parties
      - Procedural embedding : LCA as a (participatory) process

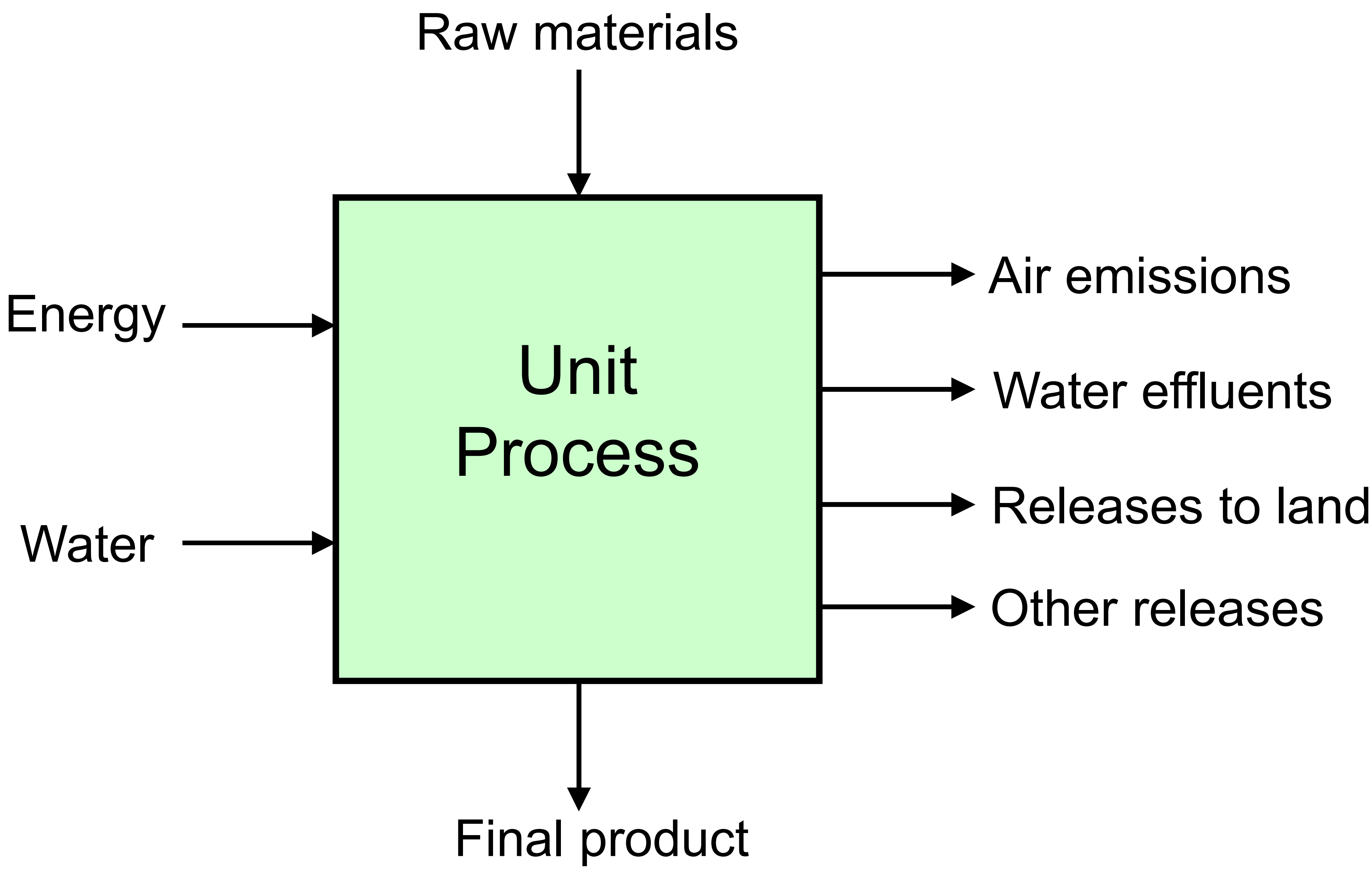


(Source: US-EPA)

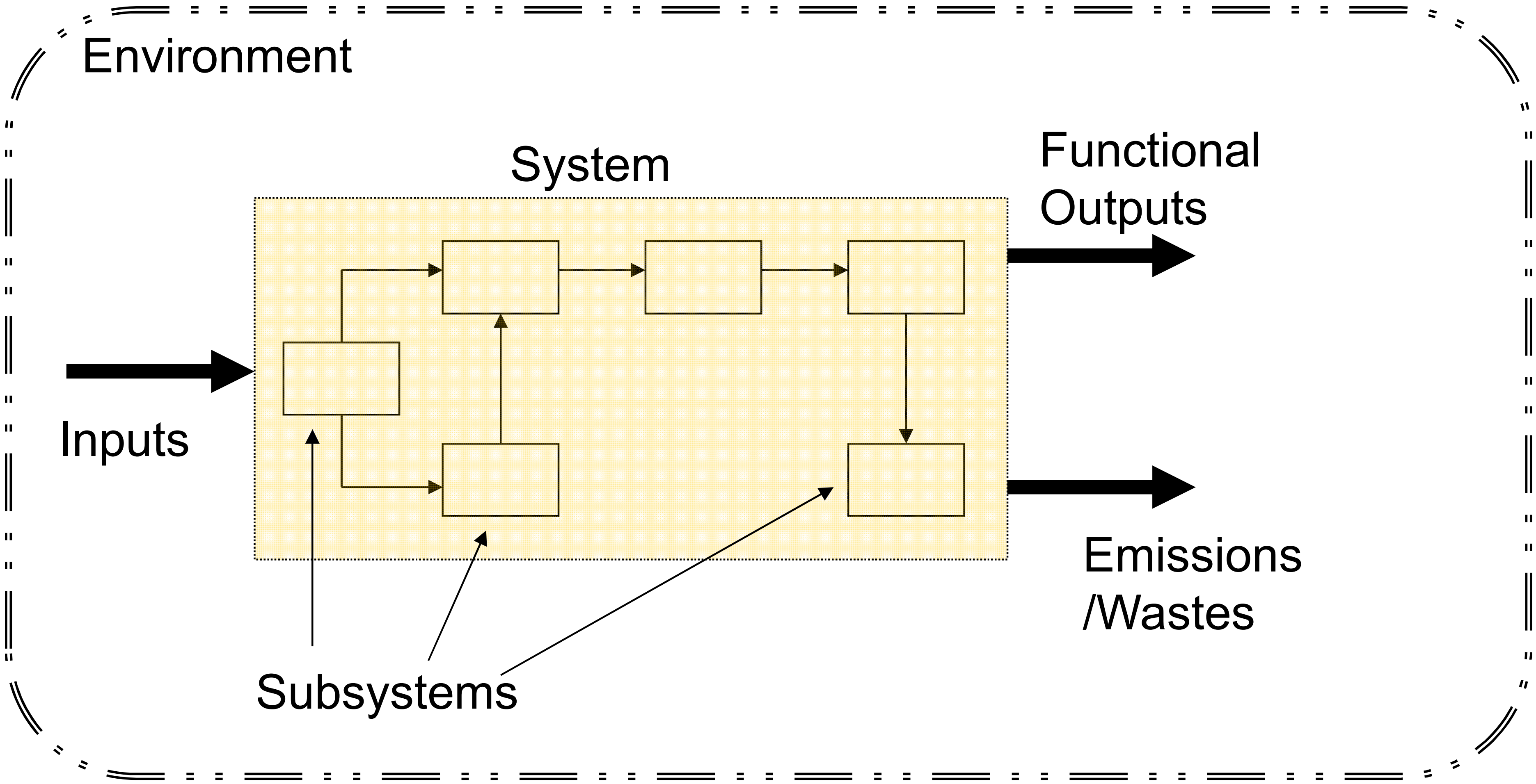
LCA process

- 2) Life cycle inventory (LCI)
  - Compilation and quantification of inputs and outputs, for a given product system throughout its life cycle
  - Steps:
    - Preparing for data collection
    - Data collection
    - Calculation procedures
    - Allocation and recycling

Inventory analysis model for life-cycle assessment



Life cycle inventory analysis for a system

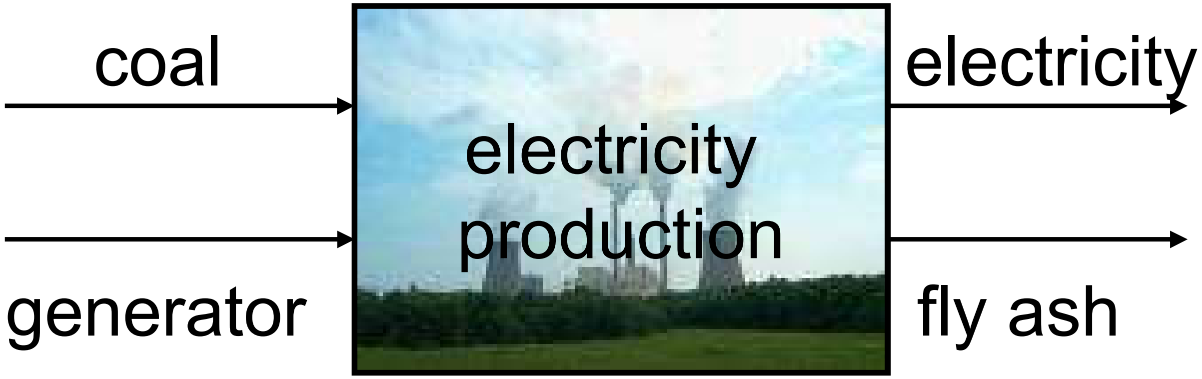


LCA process

- 2) Life cycle inventory (LCI) (cont'd)
  - Central position for unit process
    - Smallest portion of a product system for which data are collected
  - Typical examples:
    - Electricity production by coal combustion
    - PVC production
    - Use of a passenger car
    - Recycling of aluminum scrap

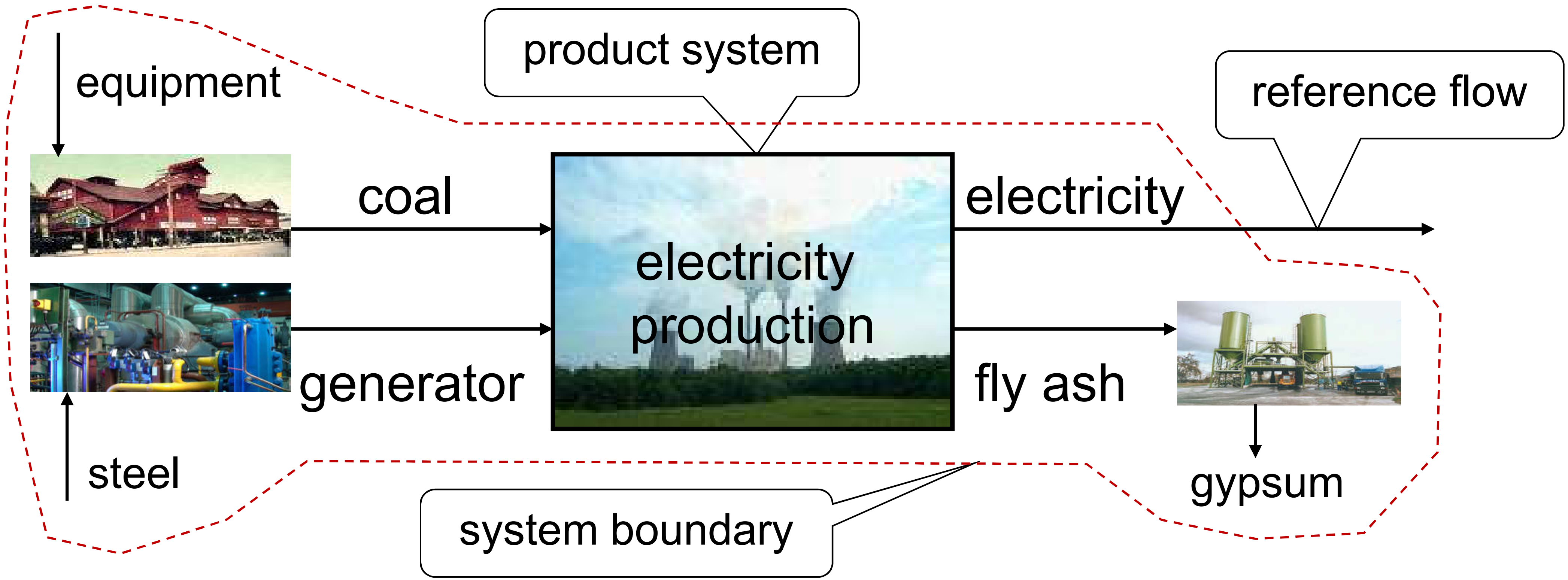
LCA process

- 2) Life cycle inventory (LCI) (cont'd)
  - Data collection for unit processes:
    - Flows of intermediate products or waste for treatment
    - Elementary flows from or to the environment

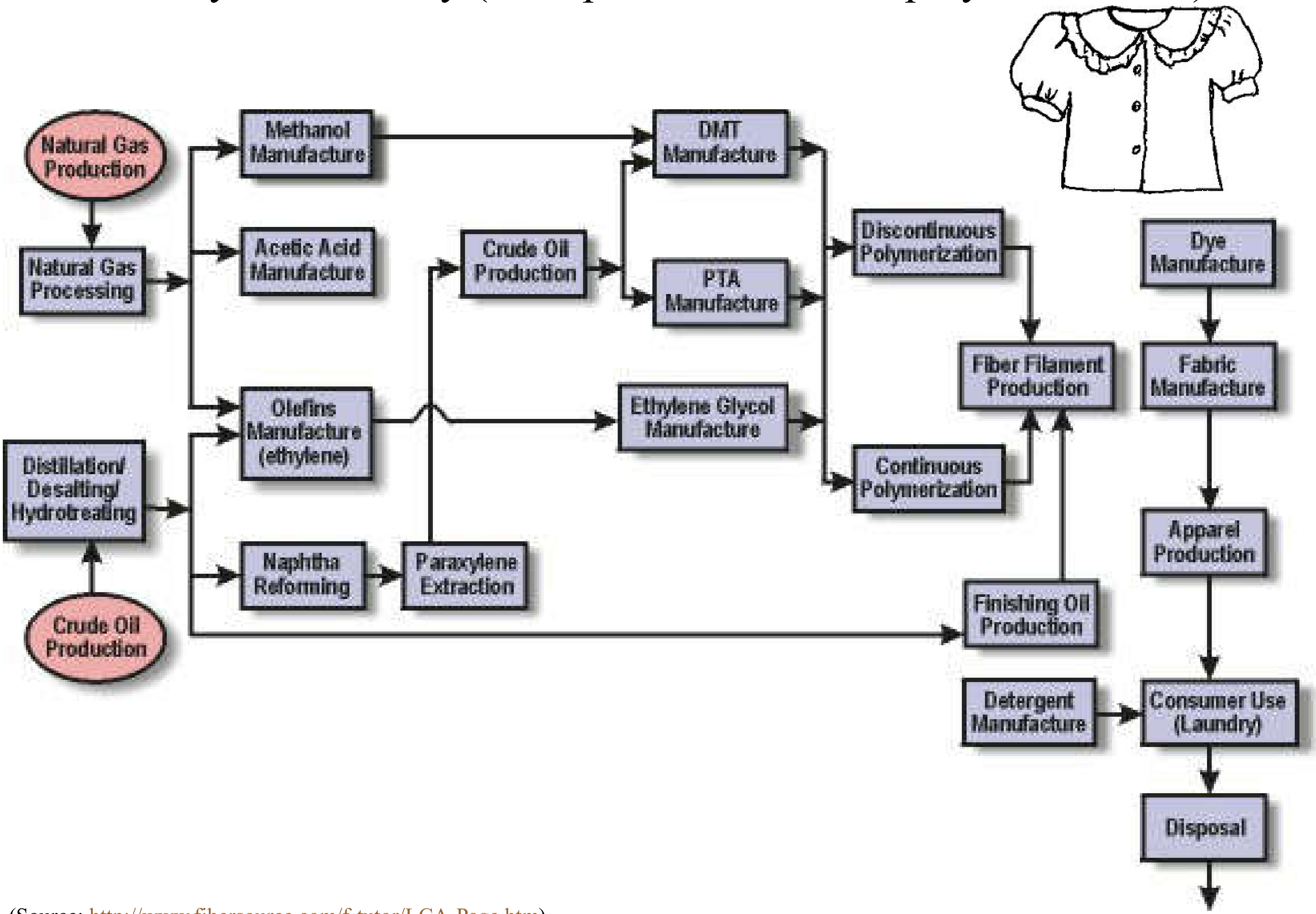


LCA process

- 2) Life cycle inventory (LCI) (cont'd)
  - Combine unit processes into a product system
  - Graphical representation in a flow diagram



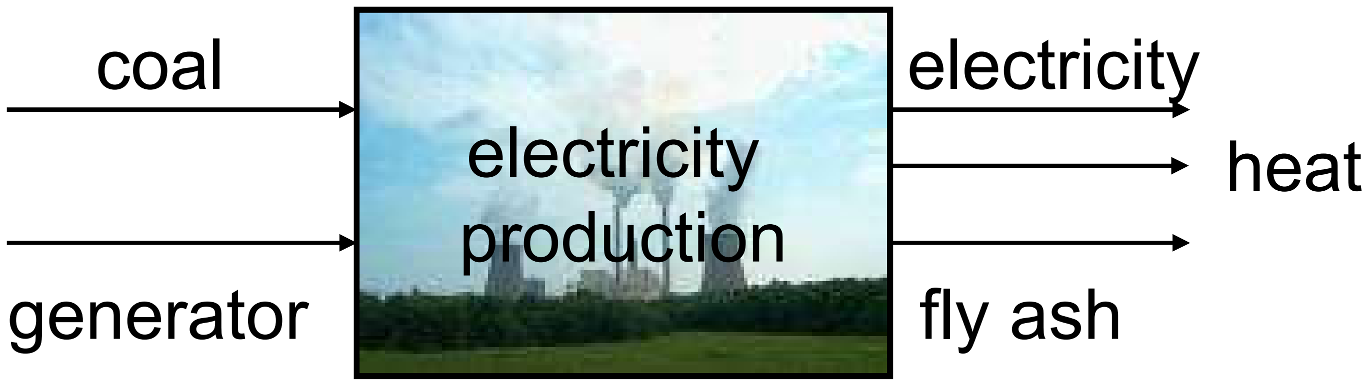
Life cycle inventory (example: woman's knit polyester blouse)



(Source: http://www.fibersource.com/f-tutor/LCA-Page.htm)

LCA process

- 2) Life cycle inventory (LCI) (cont'd)
  - Calculation procedures
    - Relate process data to functional unit (matrix algebra)
    - Allocation of multiple processes (multiple outputs, multiple inputs, re-use and recycling)
    - Aggregation over all unit processes in the inventory table



Example: Incandescent and fluorescent lamps

Product property	Incandescent lamp	Fluorescent lamp
power consumption	60 W	18 W
life span	1000 hr	5000 hr
mass	30 g	540 g
mercury content	0 mg	2 mg
etc	…	…

(Source: UNEP LCA Training Kit)

Example: Incandescent and fluorescent lamps - Inventory table

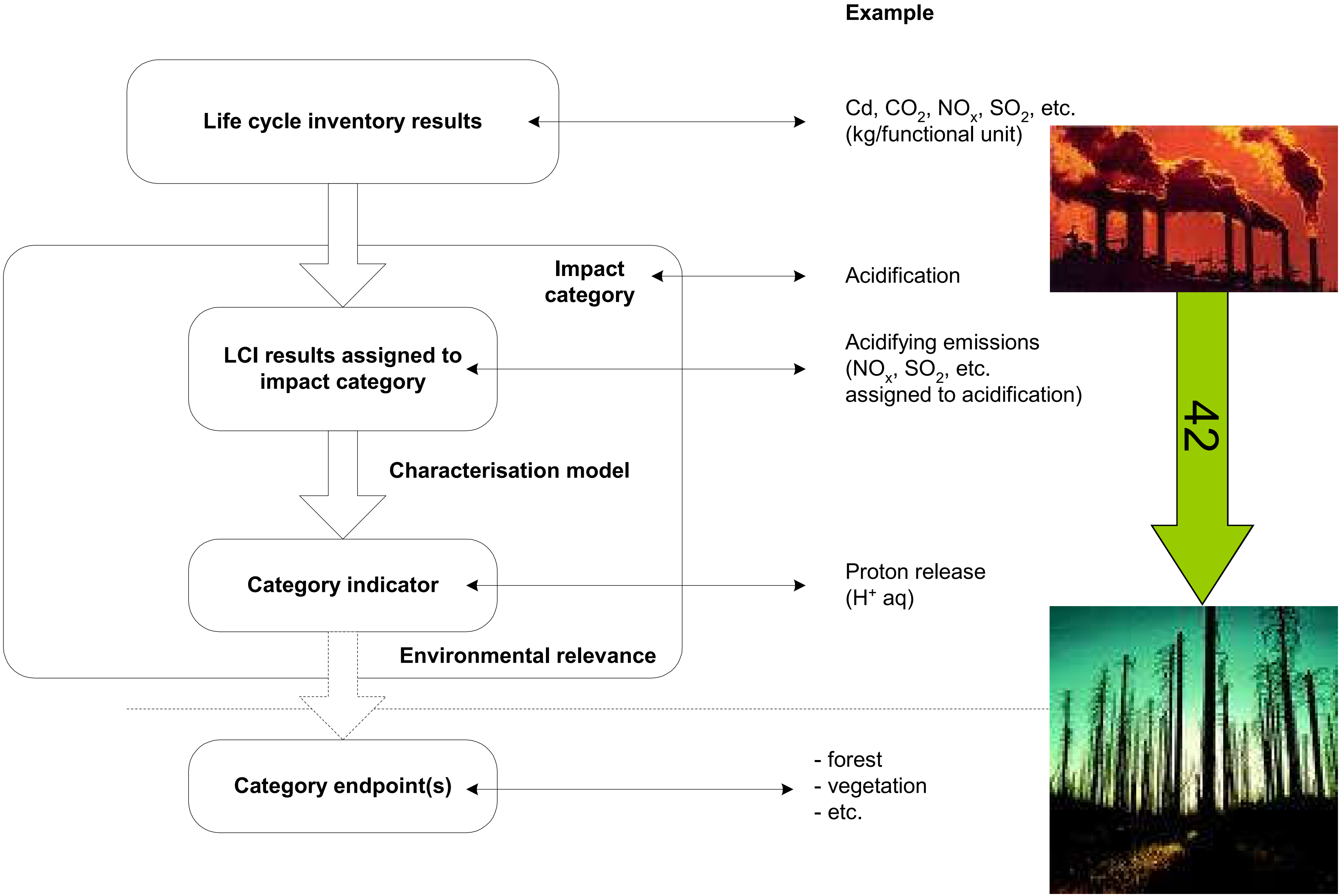
Elementary flow	Incandescent lamp	Fluorescent lamp
CO_2 to air	800000 kg	50000 kg
SO_2 to air	1000 kg	80 kg
Copper to water	3 g	20 g
Crude oil from earth	37000 kg	22000 kg
etc	…	…

(Source: UNEP LCA Training Kit)

LCA process

- 3) Life cycle impact assessment (LCIA)
  - Assess the importance of potential environmental effects on the results of the inventory analysis
  - Steps:
    - Selection and definition of impact categories, indicators and models
    - Classification
    - Characterisation
    - Normalisation
    - Aggregation and/or weighing

Life cycle impact assessment (LCIA)



(Source: UNEP LCA Training Kit)

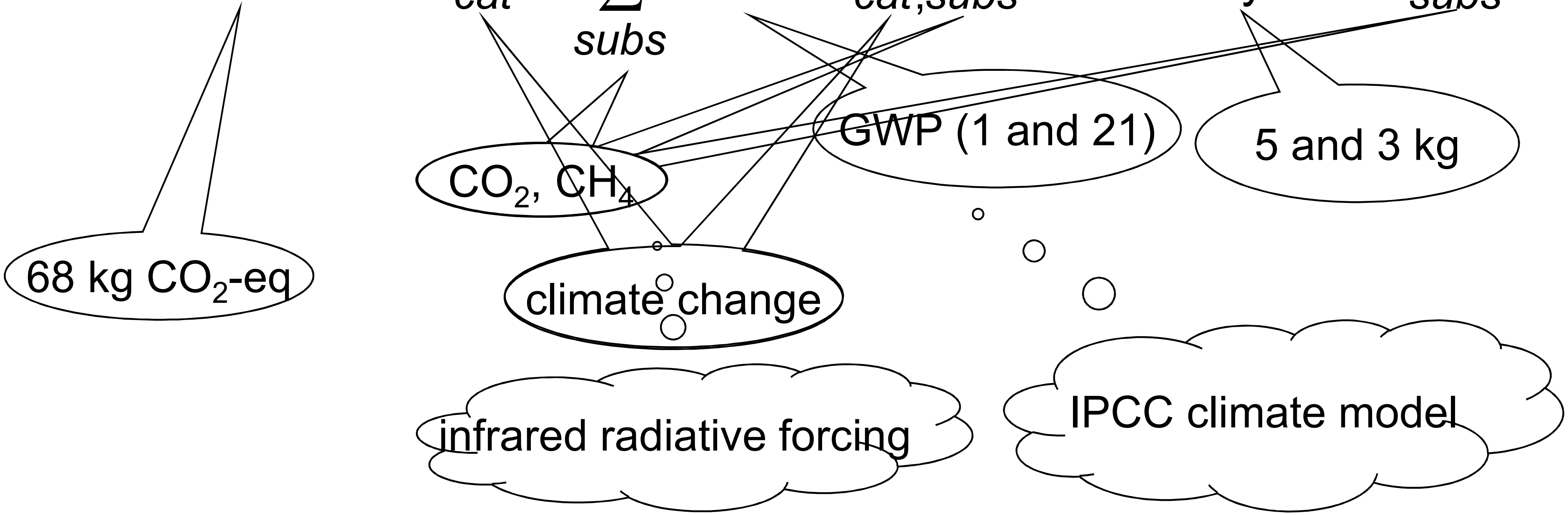
LCA process

- 3) Life cycle impact assessment (cont'd)
  - Example of a category indicator:-
  - Global Warming:
    - Global Warming Potential (GWP): measure for Global Warming in terms of radiative forcing of a mass-unit
  - Example calculation:
  - 5 kg CO_2 (GWP = 1) + 3 kg CH_4 (GWP = 21)
  - = 1 x 5 + 21 x 3 kg CO_2 - equivalents (= 68 kg CO_2 – equivalents)

LCA process

- 3) Life cycle impact assessment (cont'd)
  - Characterisation:
    - Simple conversion and aggregation of greenhouse gas (GHGs):

$$IndicatorResult_{cat} = \sum_{subs} CharFact_{cat,subs} \times InventoryResult_{subs}$$



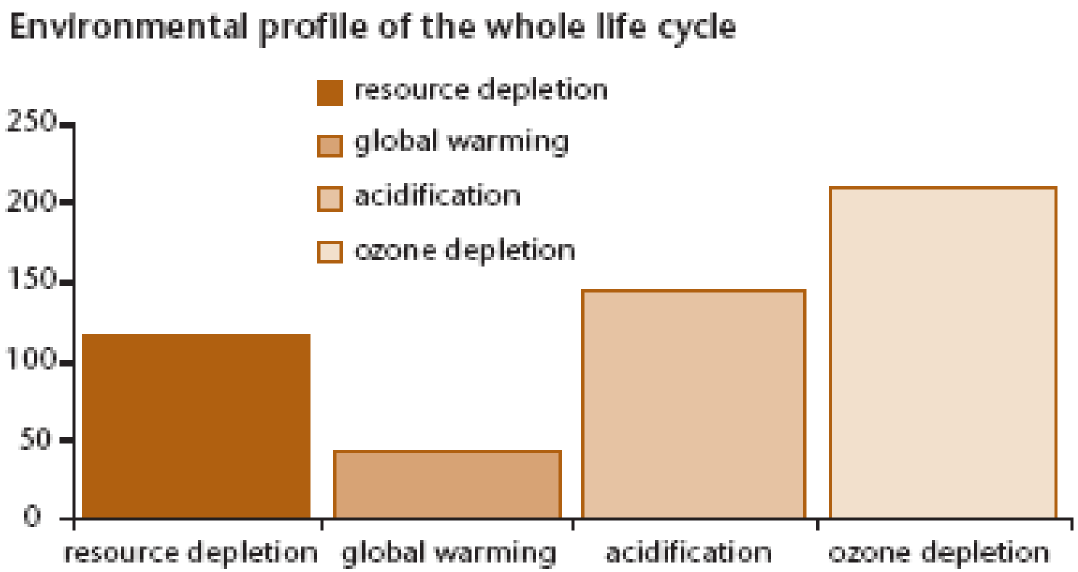
Example: Incandescent and fluorescent lamps – impact assessment

Impact category	Incandescent lamp	Fluorescent lamp
Climate change	120000 kg CO_2-eq	40000 kg CO_2-eq
Ecotoxicity	320 kg DCB-eq	440 kg DCB-eq
Acidification	45 kg SO_2-eq	21 kg SO_2-eq
Depletion of resources	0.8 kg antinomy-eq	0.3 kg antinomy-eq
etc	…	…

(Source: UNEP LCA Training Kit)

LCA process

- 3) Life cycle impact assessment (cont'd)
  - The final result of the characterisation step is a list of potential environmental impacts
  - This list of effect scores, one for each category, is called the *environmental profile*



LCA process

- 3) Life cycle impact assessment (cont'd)
  - Impact category results still difficult to understand:
    - Difference in units
    - Difference in scale
  - Normalisation step to relate the results to a reference value
    - e.g., total world impacts in 2002
    - Result often referred to as the normalised environmental profile

Example: Incandescent and fluorescent lamps – impact assessment (with normalisation to a reference value)

Impact category	Incandescent lamp	Fluorescent lamp
Climate change	1.2×10^{-11} yr	4×10^{-12} yr
Ecotoxicity	1.6×10^{-10} yr	2.2×10^{-10} yr
Acidification	9×10^{-11} yr	4.2×10^{-11} yr
Depletion of resources	24×10^{-12} yr	9×10^{-13} yr
etc	…	…

(Source: UNEP LCA Training Kit)

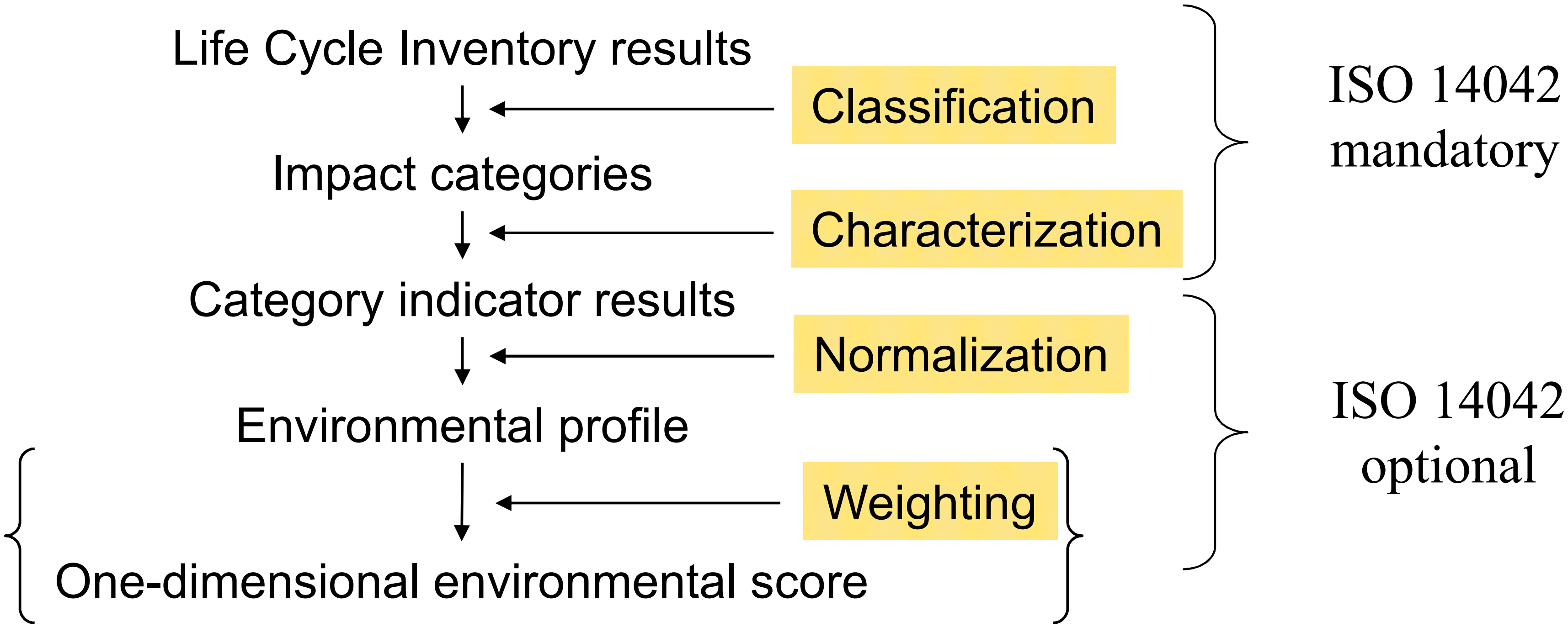
LCA process

- 3) Life cycle impact assessment (cont'd)
  - Even after normalisation no clear answer
    - Aggregation of (normalized) impact category results into a single index
    - Subjective weighting factors needed
    - Example of a weighted environmental index:

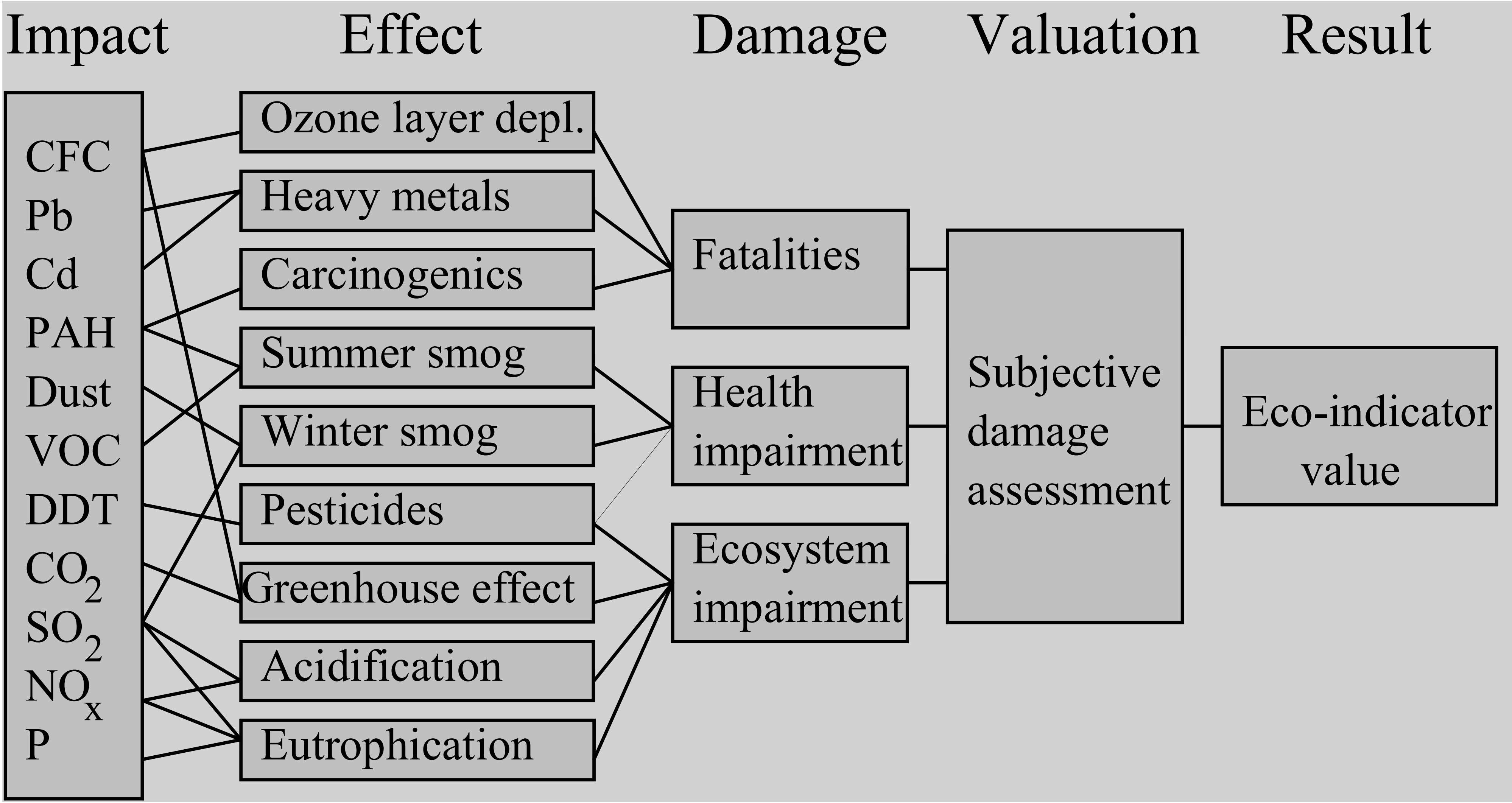
Weighed index	Incandescent lamp	Fluorescent lamp
Weighted index	8.5×10^{-10} yr	1.4×10^{-10} yr

Life cycle impact assessment

The impact assessment focuses on characterizing the type and severity of environmental impact more specifically



Schematic representation of the Eco-indicator weighting method



Examples of Eco-indicator weighting methods:

- Eco-indicator 99, Eco-indicator 95, MIPS, Ecopoints, EDIP\UMIP, EDIP/UMIP 96, EPS 2000, Economic Input Output

LCA process

- 4) Life cycle interpretation
  - Evaluate and interpret results and generate report for decision making
  - Key steps to interpret the results of the LCA
    - 1. Identification of the significant issues based on the LCI and LCIA
    - 2. Evaluation which considers:
      - Completeness check
      - Sensitivity check, uncertainty check
      - Consistency check
    - 3. Conclusions, recommendations, and reporting

LCA process

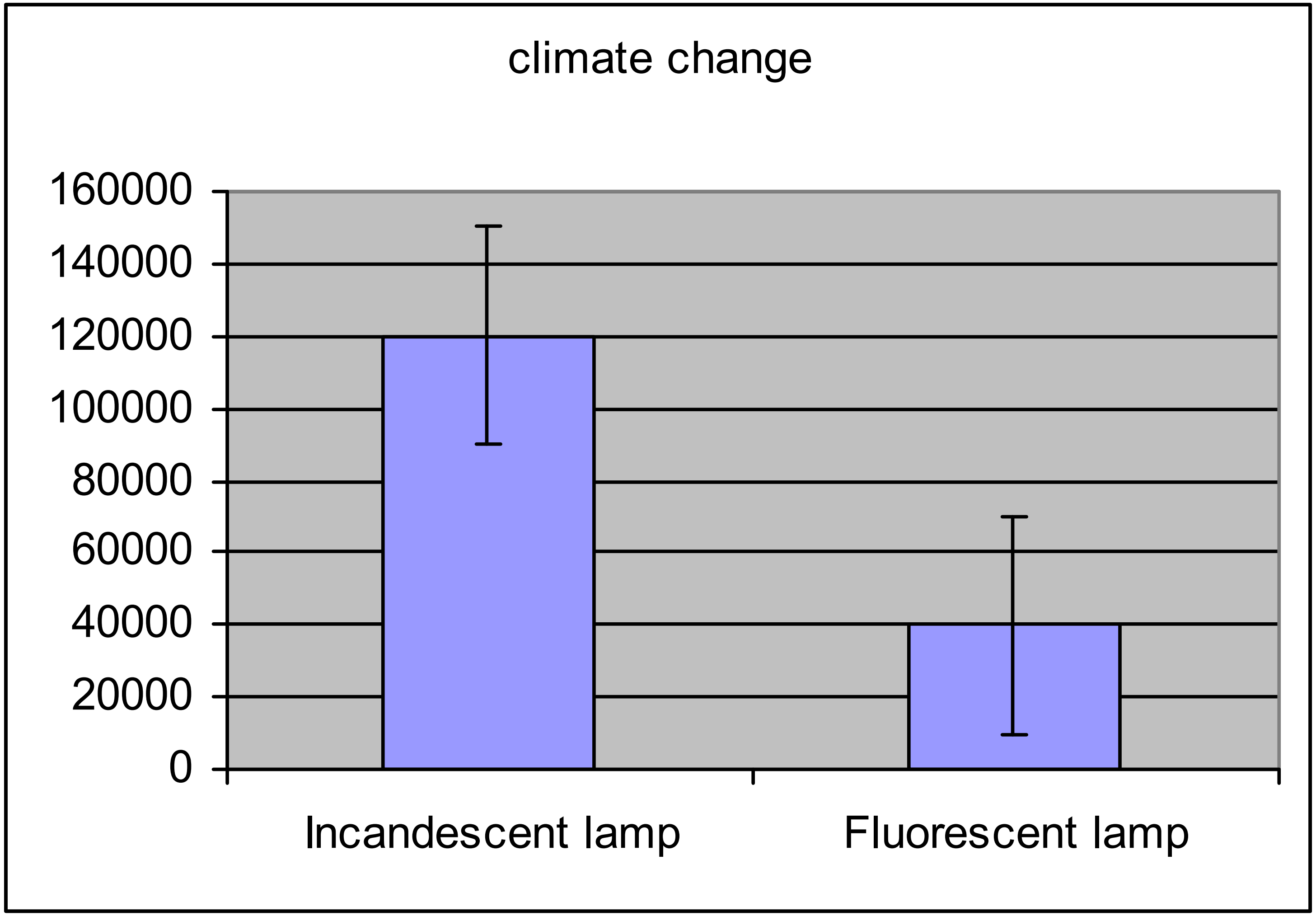
- 4) Life cycle interpretation (cont'd)
  - Identifies areas for improvement within a system
    - Reliant on the user noticing not only areas which have significant environmental effects but also those with smaller effects where changes could be made easily
  - Conclusions, recommendations, analysis, all related to goal and scope of the research
    - Among others based on data quality and sensitivity analysis
    - Also: critical review by independent experts

Example of a contribution analysis

Process	Incandescent lamp	Fluorescent lamp
Electricity production	88%	60%
Copper production	5%	15%
Waste disposal	2%	10%
Other	5%	15%
Total climate change	120000 kg CO_2-eq	40000 kg CO_2-eq

(Source: UNEP LCA Training Kit)

Example of an uncertainty analysis



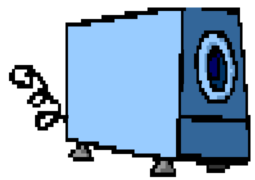
(Source: UNEP LCA Training Kit)

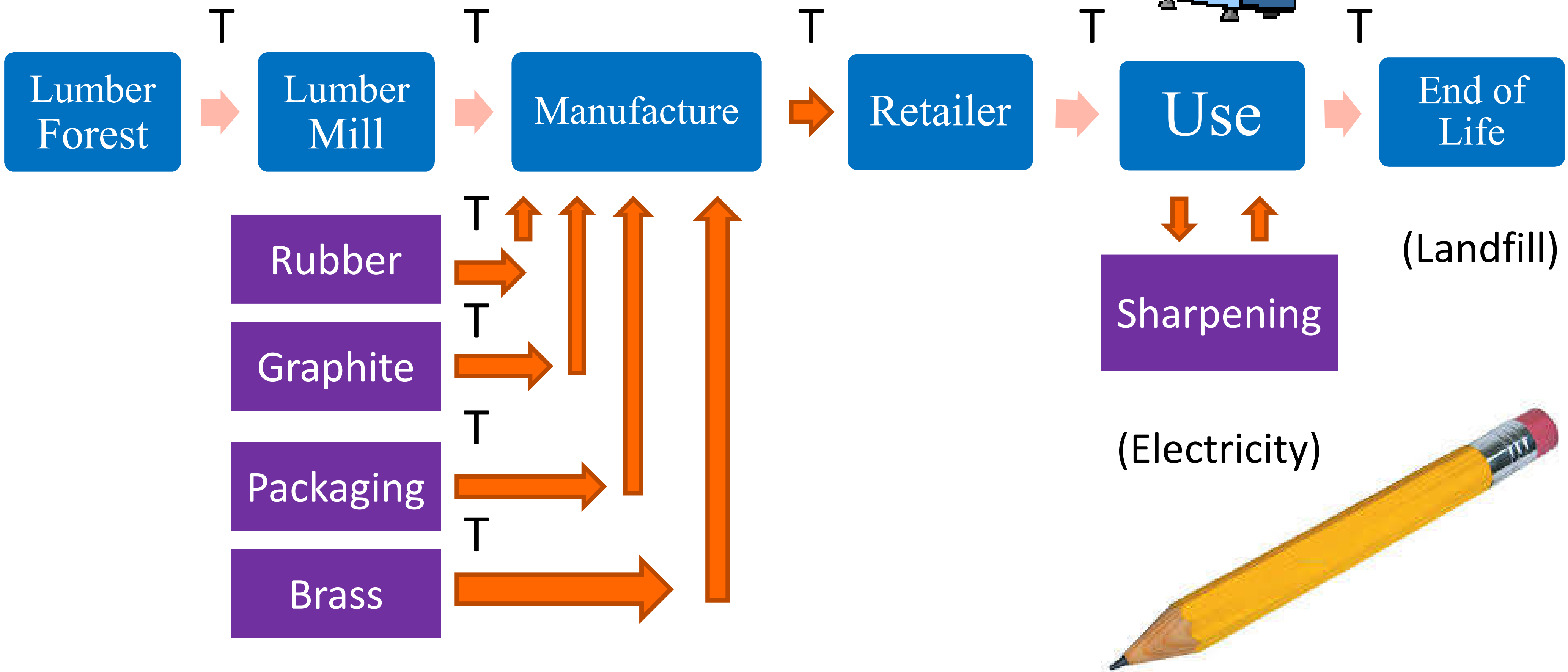
Example of life cycle assessment: Wooden Pencil vs. Mechanical Pencil

Goal = Compare 2 writing utensils for classroom use.

Scope: Wooden Pencil (T = Transportation)

Process Flow Diagram





(Source: Dr. Michael Lepech, Stanford University)

Scope: Mechanical Pencil

PE = Polyethylene

PP = Polypropylene

Both materials are **plastic polymers** (large molecules) used to make many products.

Oil → T → PE / PP → T → Manufacture → T → Retailer → T → Use → T → End of Life

(Landfill)

Rubber → T → Manufacture

Graphite → T → Manufacture

Packaging → T → Manufacture

Spring → T → Manufacture

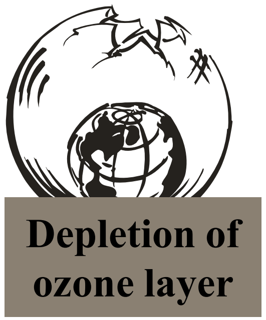
T = Transportation

(Source: Dr. Michael Lepech, Stanford University)

Global Impact Categories

- **Source:** Use of copper, zinc, oil etc.
- **Effect:** Reduction of possibilities for future generations

- **Source:** Combustion (transport, energy etc.)
- **Effect:** Increase in temperature, desert formation etc.



- **Source:** CFC and HCFC from foam and coolants
- **Effect:** UV radiation, skin cancer etc.

(Source: Loughborough University)

Regional Impact Categories

Ozone formation

- **Source:** Transport, energy, industry (Hydrocarbons etc.)
- **Effect:** Ozone formation (Damage of lung tissue etc.)

Acidification

- **Source:** Transport, energy, agriculture
- **Effect:** Damage to woodlands, lakes and buildings (SO_x, NO_x, NH_3)

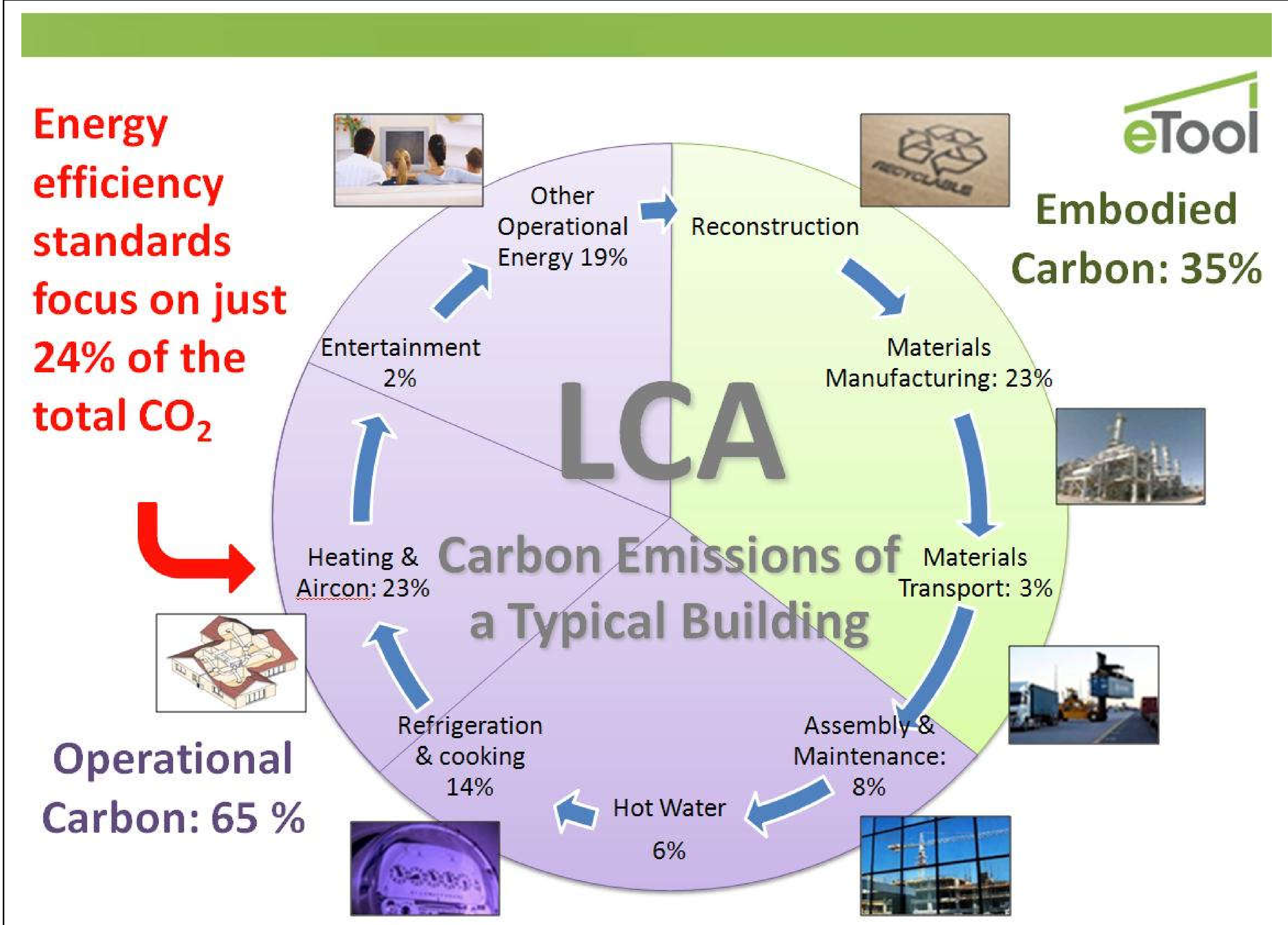
Eutrofication

- **Source:** Fertilisers, waste water, transport and energy
- **Effect:** Eutrophication **(**Damage to plants and fish)

Persistent toxicity

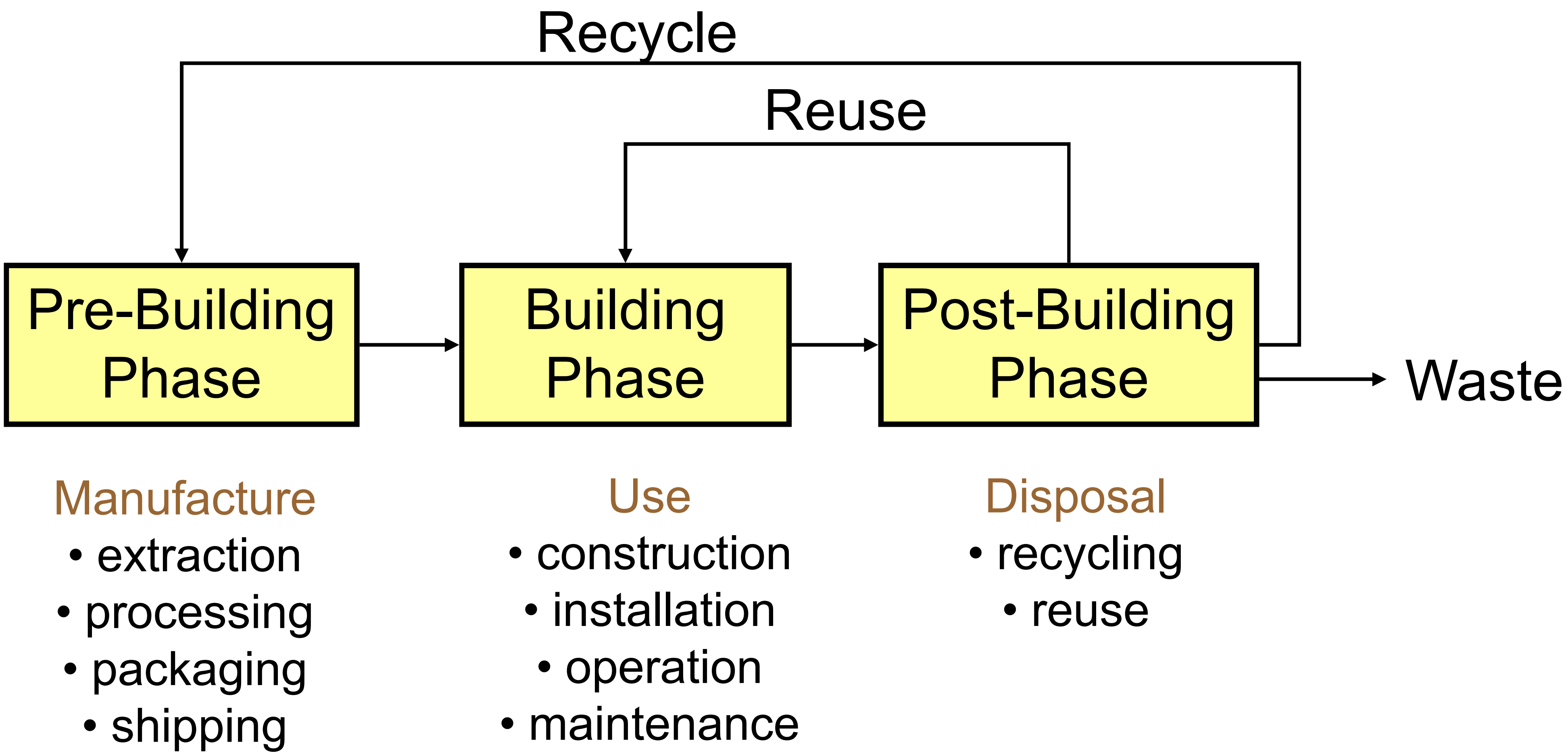
- **Source:** Waste water, incineration, industry, ships etc.
- **Effect:** Accumulation: Chronic damage to ecosystems and organisms

(Source: Loughborough University)

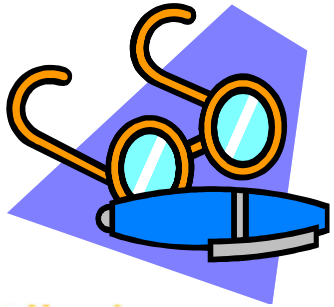


(Source: http://etool.net.au)

Three phases of building material life cycle



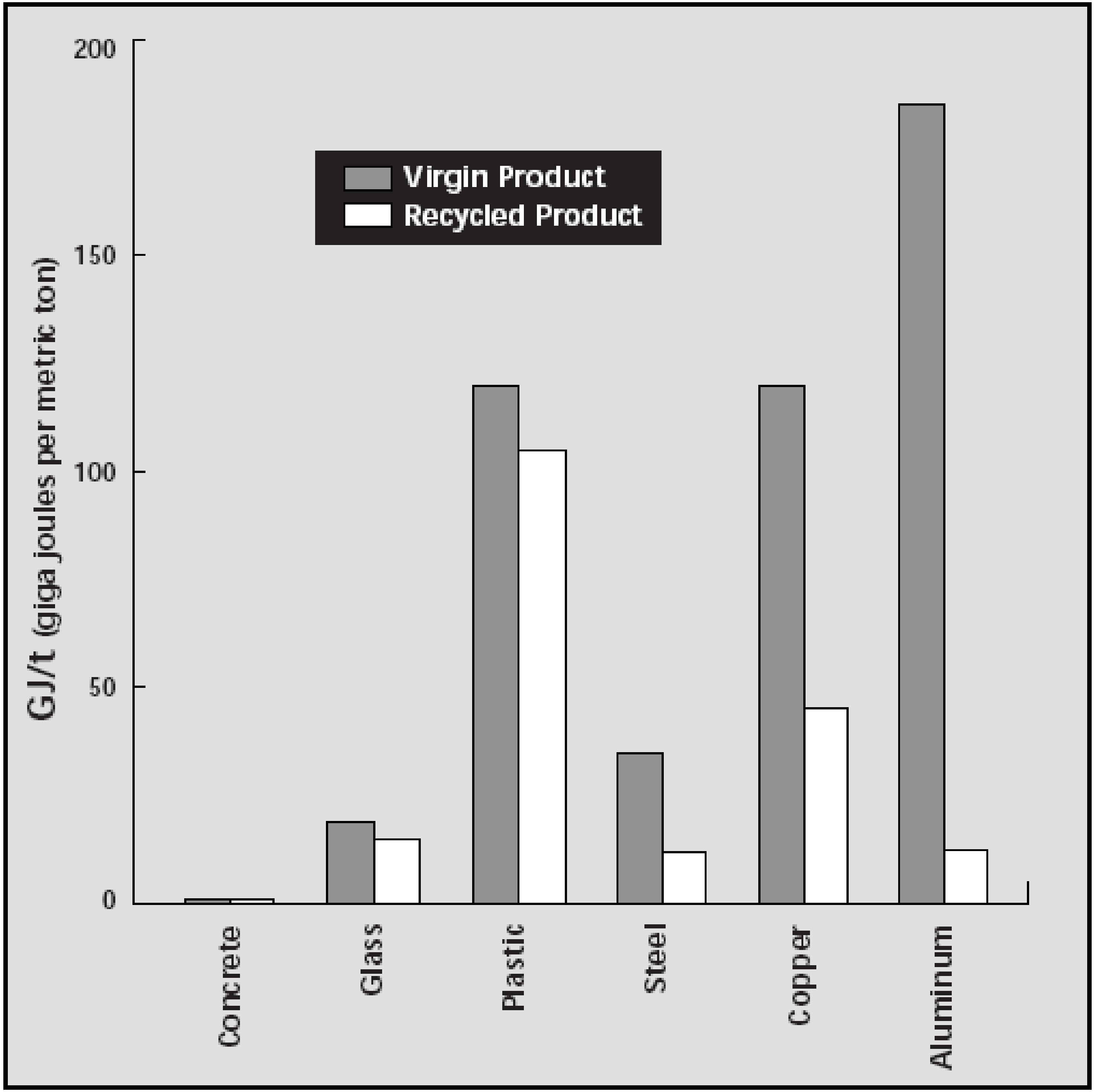
Evaluation methods



- 1. Pre-building phase
  - Materials acquisition & preparation
    - Land degradation & depletion of resources
  - Manufacturing & fabrication
    - Energy & water use
    - Fugitive emissions
    - Water pollution
  - Distribution & transport
    - Fuel use & air pollution

Energy efficiency by mode of transport

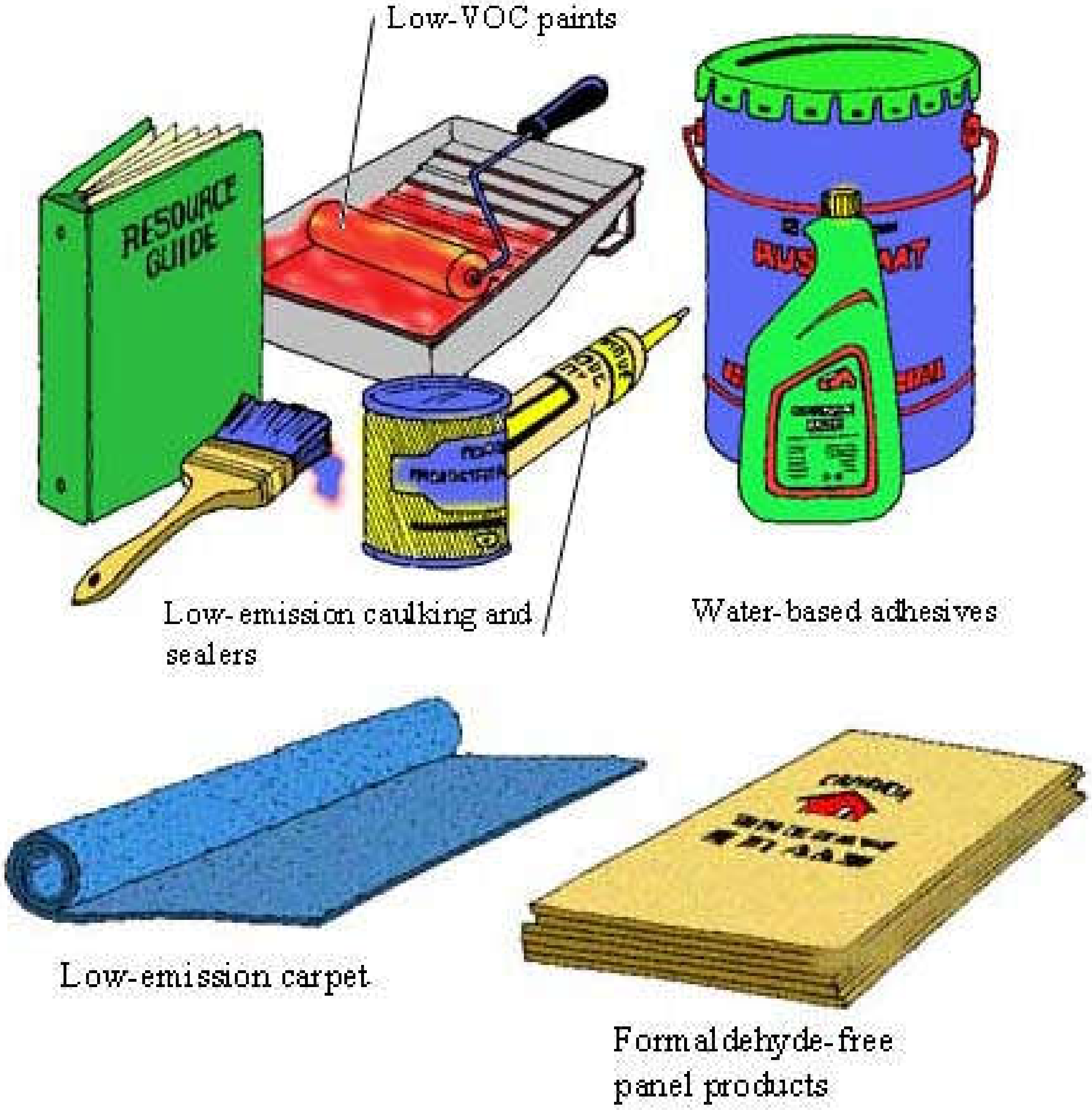
	kJ/tonne-km
Truck	2,128
Railroad	248
Barge (on river)	287
Ship	123



Embodied energy of virgin and recycled products

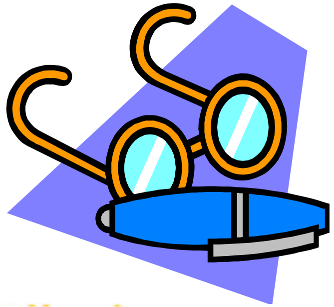
Evaluation methods

- 2. Building phase
  - Construction & installation on site
    - Noise, waste & pollutants from construction site
  - Maintenance & repair
    - Energy & water use
    - Maintenance & operation requirements
  - Use & operation of the building
    - Effects on indoor air quality & occupants' health

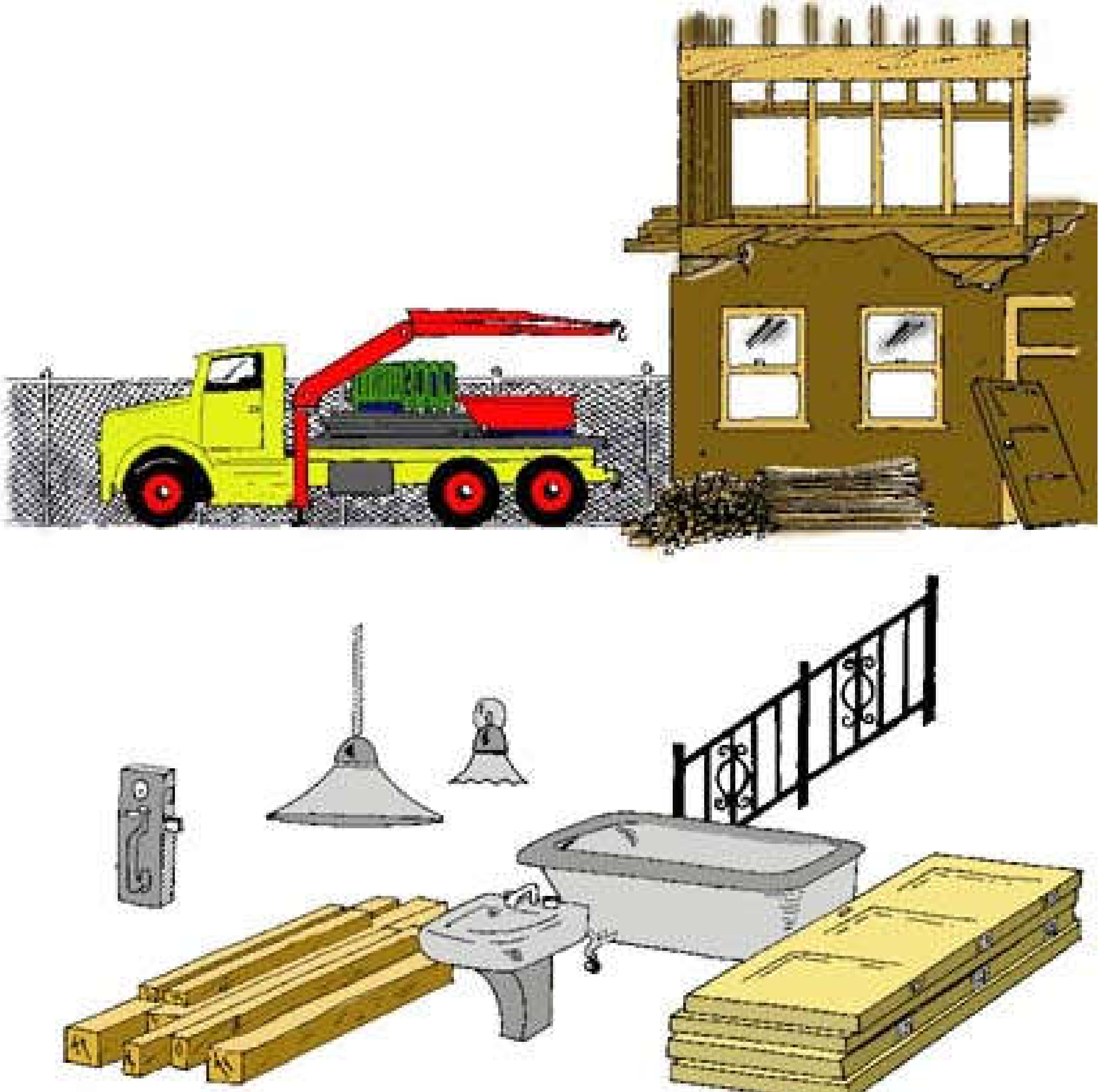


Enhance indoor air quality and minimise health effects

Evaluation methods

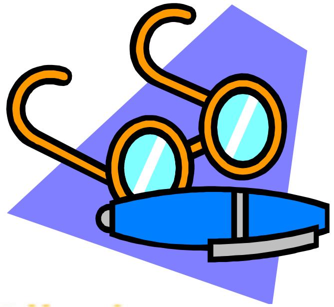


- 3. Post-building phase
  - Demolition
    - Noise, air & water pollution during demolition
  - Disposal
    - Need for transportation, landfil, etc. for the waste
  - Reuse or recycling
    - Energy & water use
- "De-construction"
  - Building disassembly & materials salvage



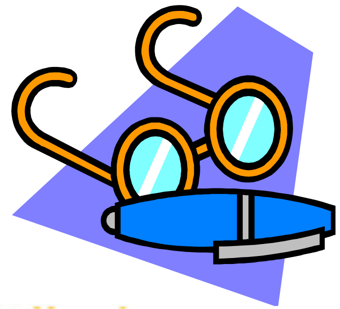
Separate recyclables from demolition and reuse salvaged materials

Evaluation methods



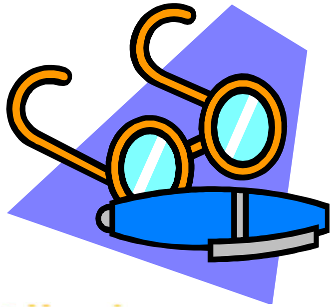
- Criteria in material selection:
  - Resource quantity (use less & more efficiently)
  - Reused materials (salvaged & reused)
  - Recycled content (post- & pre-consumer waste)
  - Renewable materials (e.g. sustainable forestry)
  - Local content and reduced transportation
  - Life-cycle cost & maintenance requirements
  - Resource recovery & recycling
  - Effects on health & indoor air quality

Evaluation methods



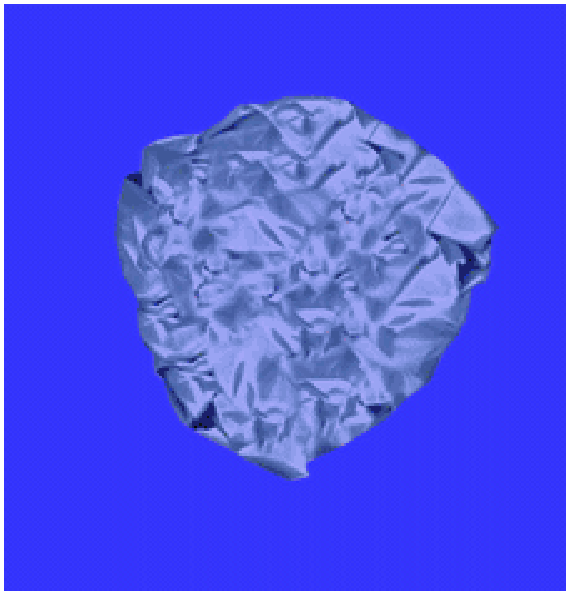
- Important considerations
  - Not just replace one material by another
  - Need to consider how the material is used
  - May require cultural change in design and in using the new materials
- Product to service shift
  - e.g. carpeting service (by Interface, Inc.)
    - Provide “service” instead of just “product”
  - Supplier to reuse or recycle the materials

Evaluation methods



- Evaluate building materials
  - Collect as much information as possible
  - Make judgements & assumptions if needed
- Basic questions
  - What is in them?
  - How they are made?
  - Where they come from?
  - How they perform in the building?
  - What happens to them afterwards?

"Waste - a resource in the wrong place"
-- An old Chinese proverb.



The True Cost of Waste

Purchase price & transportation costs of materials

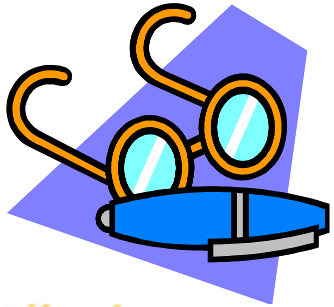
+

Cost of storage, transport & disposal of waste

+

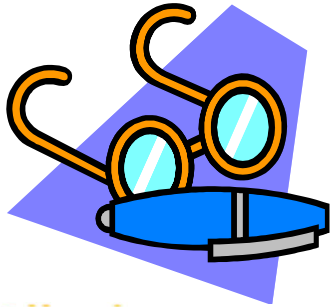
Loss of income from not salvaging waste materials

Evaluation methods



- Examples of LCA analysis software tools
  - ATHENA Impact Estimator and EcoCalculator (Canada) http://www.athenaSMI.ca
  - BEES (Building for Environmental and Economic Sustainability) Online version (USA)
    - https://www.nist.gov/services-resources/software/bees
  - GaBi (Germany) http://www.gabi-software.com
  - SimaPro (The Netherlands) http://www.pre.nl/simapro.html

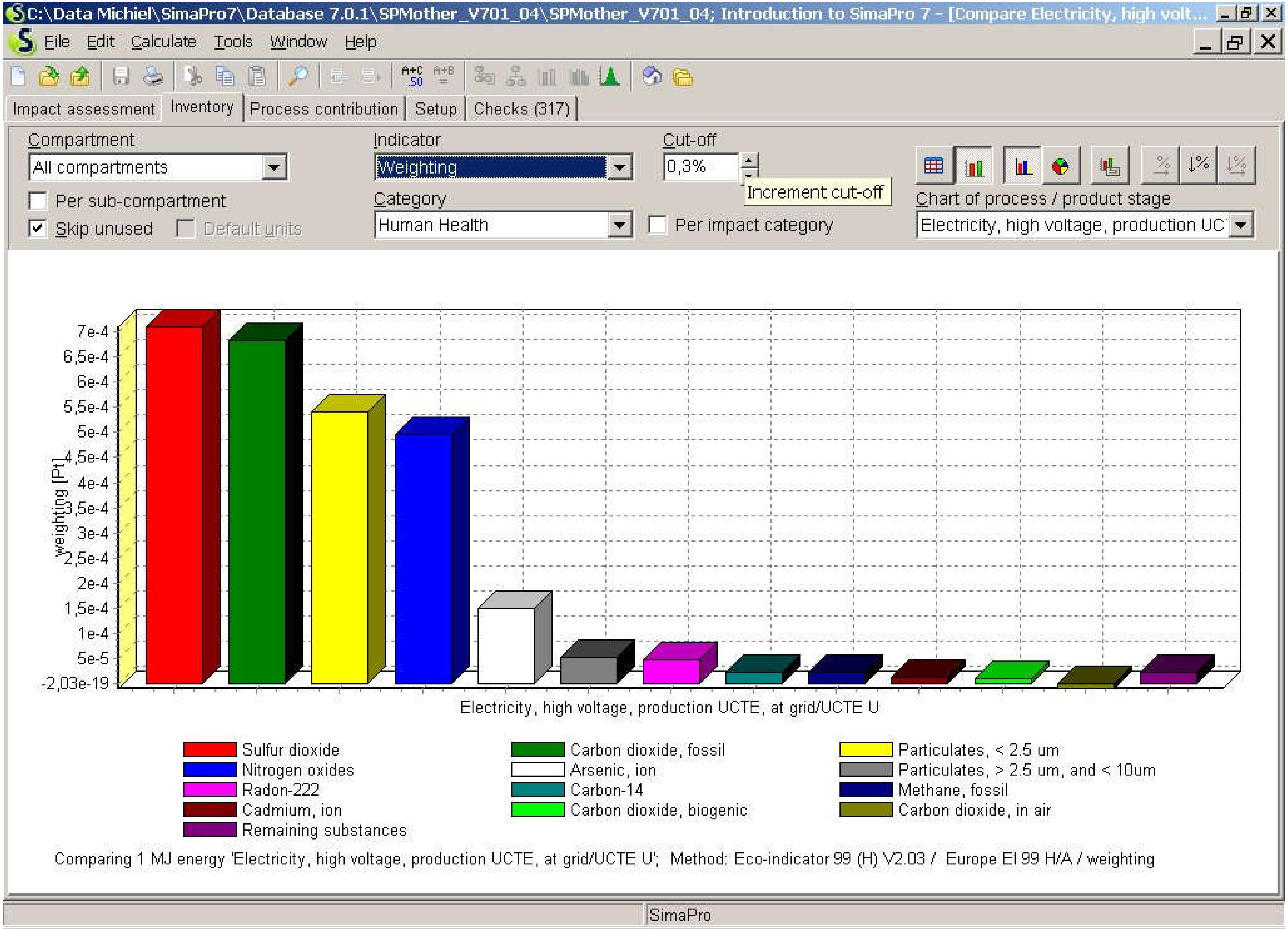
Evaluation methods



- SimaPro LCA software (by PRé Consultants)
  - http://www.pre.nl/simapro.html
  - Tool to collect, analyze and monitor the environmental performance of products, processes and services
  - Follow the ISO 14040 series recommendations
  - SimaPro inventory databases
  - SimaPro 8 latest version

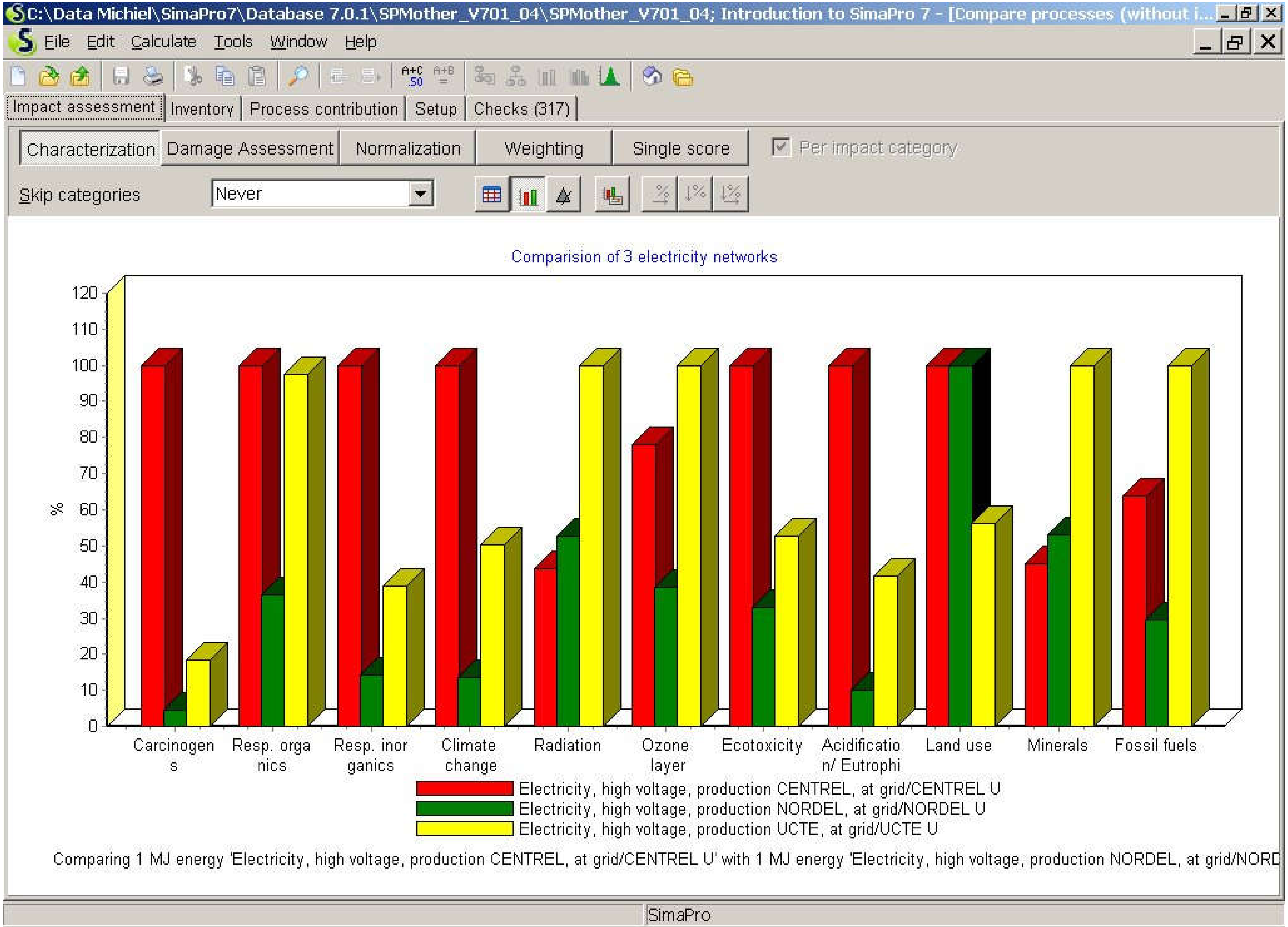
SimaPro

Features of SimaPro



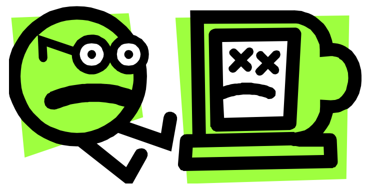
(Source: www.pre.nl/simapro/)

Compare models in SimaPro



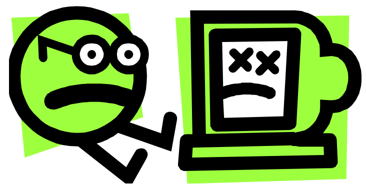
(Source: www.pre.nl/simapro/)

Limitations of LCA



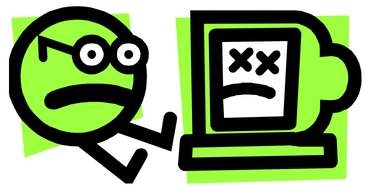
- Difficulties in LCA
  - 1. Data quality and quantity is often not sufficient for a comprehensive LCA
  - 2. A possible consequence of discrepancies in the data is that two independent studies analysing the same products may generate very different results. Ostensibly comparable LCA’s may therefore be incomparable
  - 3. Differing data used in the characterisation stage may mean that LCAs are incomparable
  - 4. Use of alternative methodologies for the impact assessment stage can yield different results

Limitations of LCA



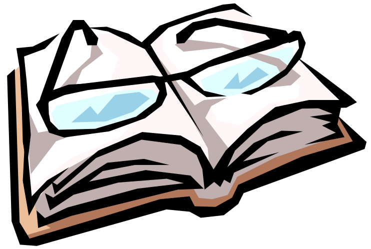
- LCA has attracted some criticisms
  - A lack of standardised information
  - Excessive detail that may be difficult to follow
  - Confusing the issues of human health with those of the environment (human- and eco-toxicity)
  - Weightings are lacking transparency and being subjective
    - It does not allow the findings of different studies to be compared easily

Limitations of LCA



- Problems of LCA:
  - The cost is high, since collecting appropriate data is time consuming
  - Where there are gaps in the data, assumptions have to be made
  - It only provides a snapshot view based on data at the time of collection
  - It does not integrate environmental impact with the social and economic aspects of sustainability

Further reading



- Videos:
  - The principles of Life Cycle Assessment (LCA) (2:55) https://youtu.be/r0ucT1KRiO4
  - Life Cycle Assessment as part of Strategic Sustainability for Product (3:03) https://youtu.be/fGhoInz-VUs
- Life cycle assessment - Wikipedia https://en.wikipedia.org/wiki/Life_cycle_assessment
- Defining Life cycle Assessment https://www.gdrc.org/uem/lca/lca-define.html
- What is the Life Cycle Assessment (LCA) Methodology? https://www.thinkstep.com/life-cycle-assessment-lca-methodology