

## Energy and Environmental Design (II)



*Ir Dr. Sam C. M. Hui*

Department of Mechanical Engineering

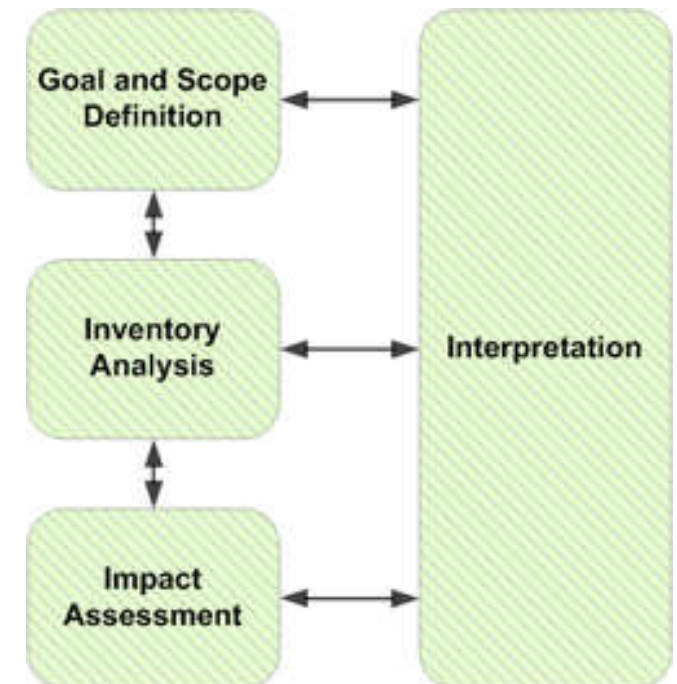
The University of Hong Kong

E-mail: [cmhui@hku.hk](mailto:cmhui@hku.hk)

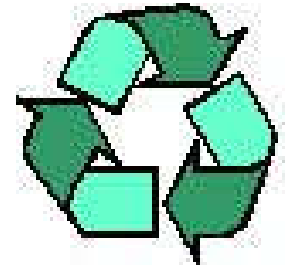
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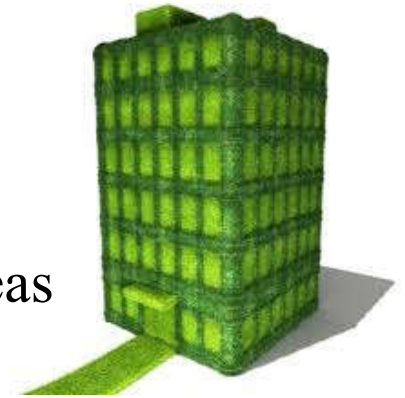
- Life cycle assessment
- LCA process
- Examples of LCA
- Evaluation methods
- Limitations of LCA



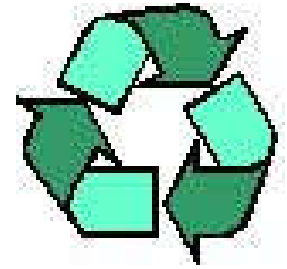
# Life cycle assessment



- 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 & quantitative accounting of environmental impacts



# Life cycle assessment

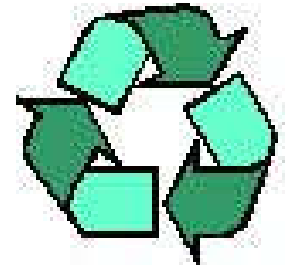


- Life cycle assessment (LCA) is a scientific method for evaluating environmental impacts
- LCA is being integrated into green building rating systems, building codes and standards
  - Such as LEED v4, Green Star, California Green Building Code, International Green Construction Code (IGCC), ASHRAE Standard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

LCA = 生命週期評估

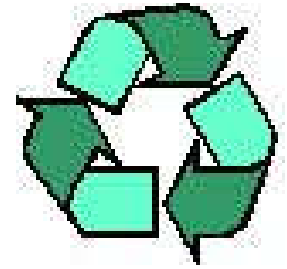


# Life cycle assessment



- 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

# Life cycle assessment



- Definition of **Life Cycle Assessment (LCA)**  
[ISO 14040]:

- *“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

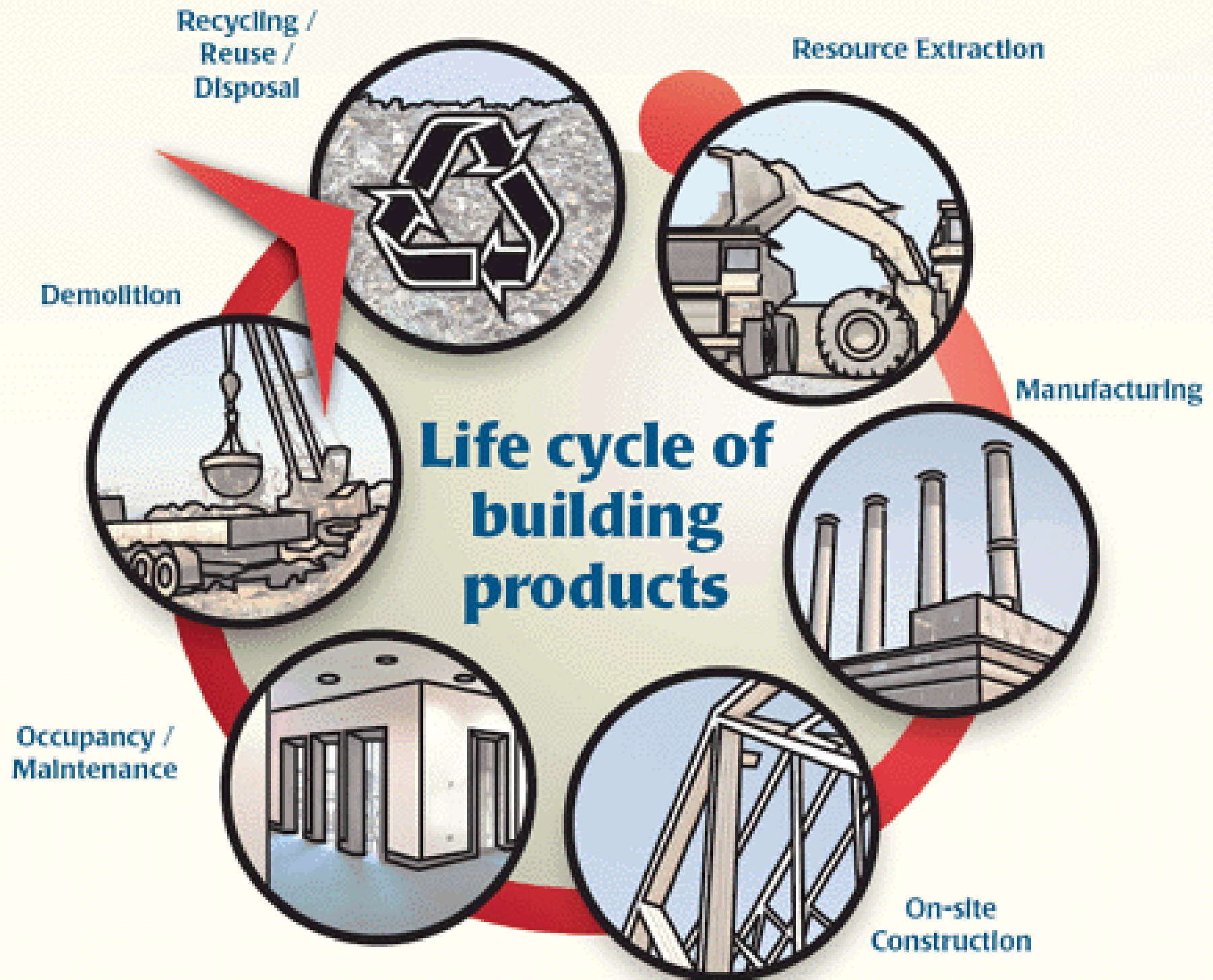


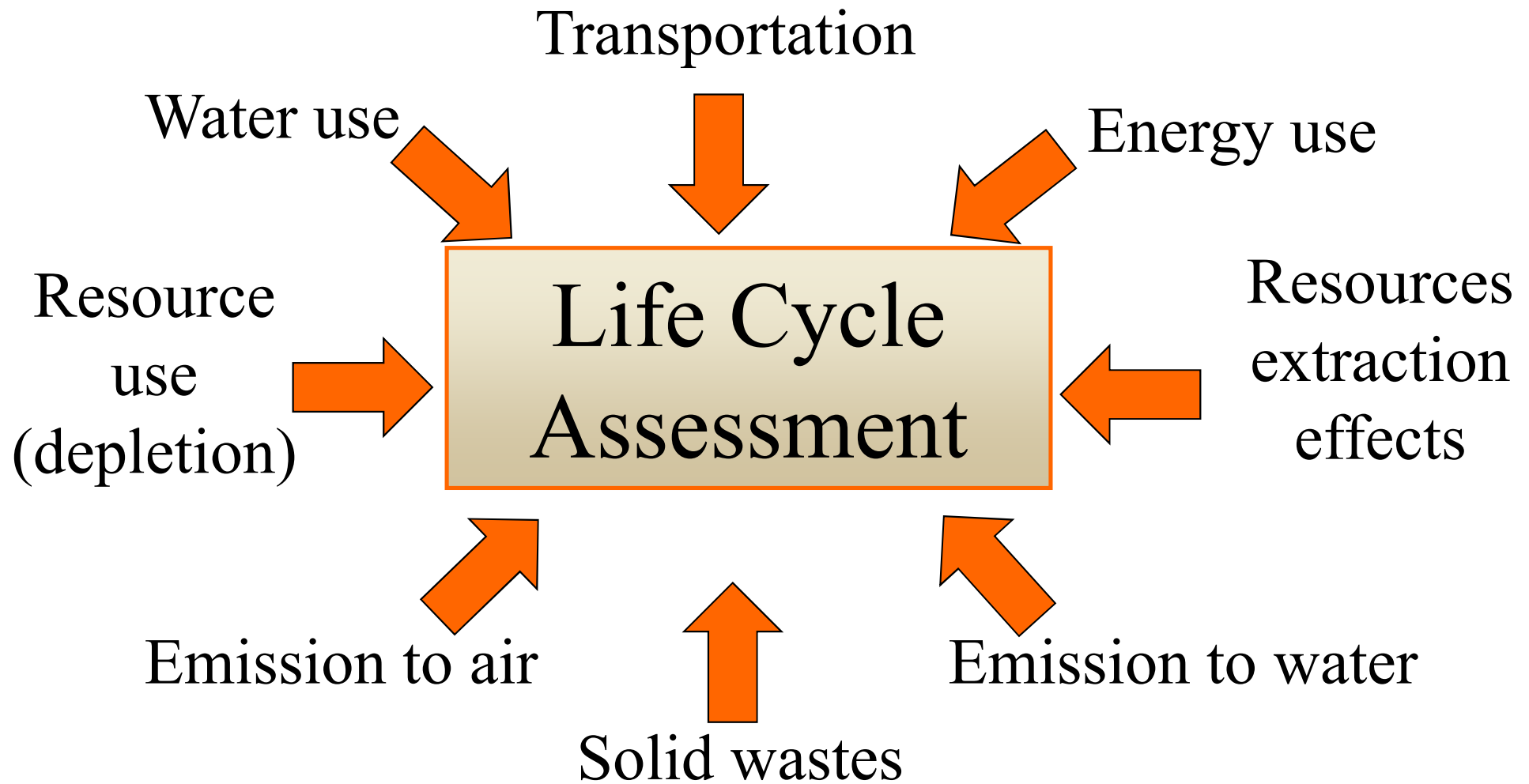
- Embodied effects include:

- Resource use (raw materials, land, water, energy)
- Emissions to air, water and land



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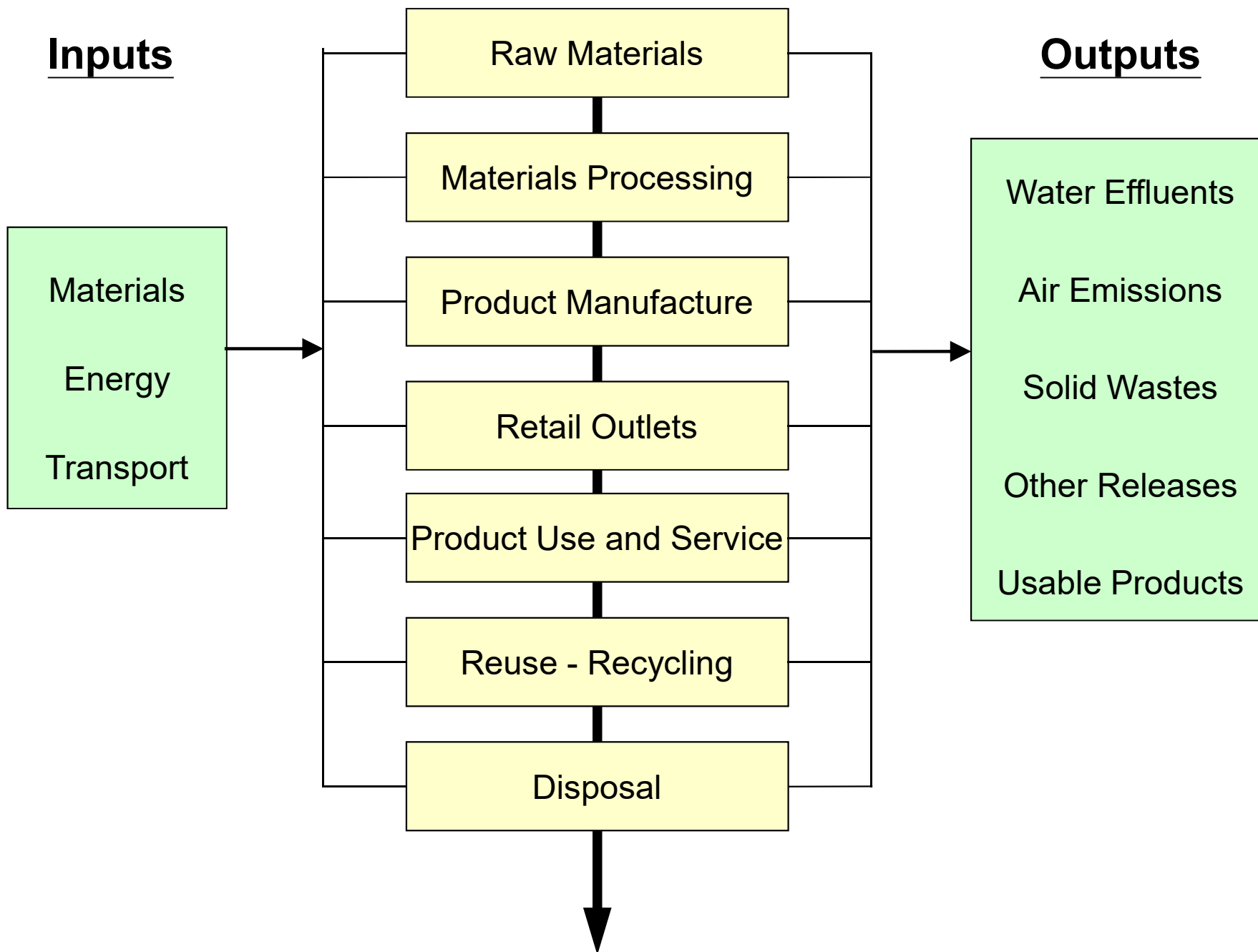


*LCA: a methodology for assessing the life cycle environmental performance of products and processes*



# Areas covered by LCA

## Product system

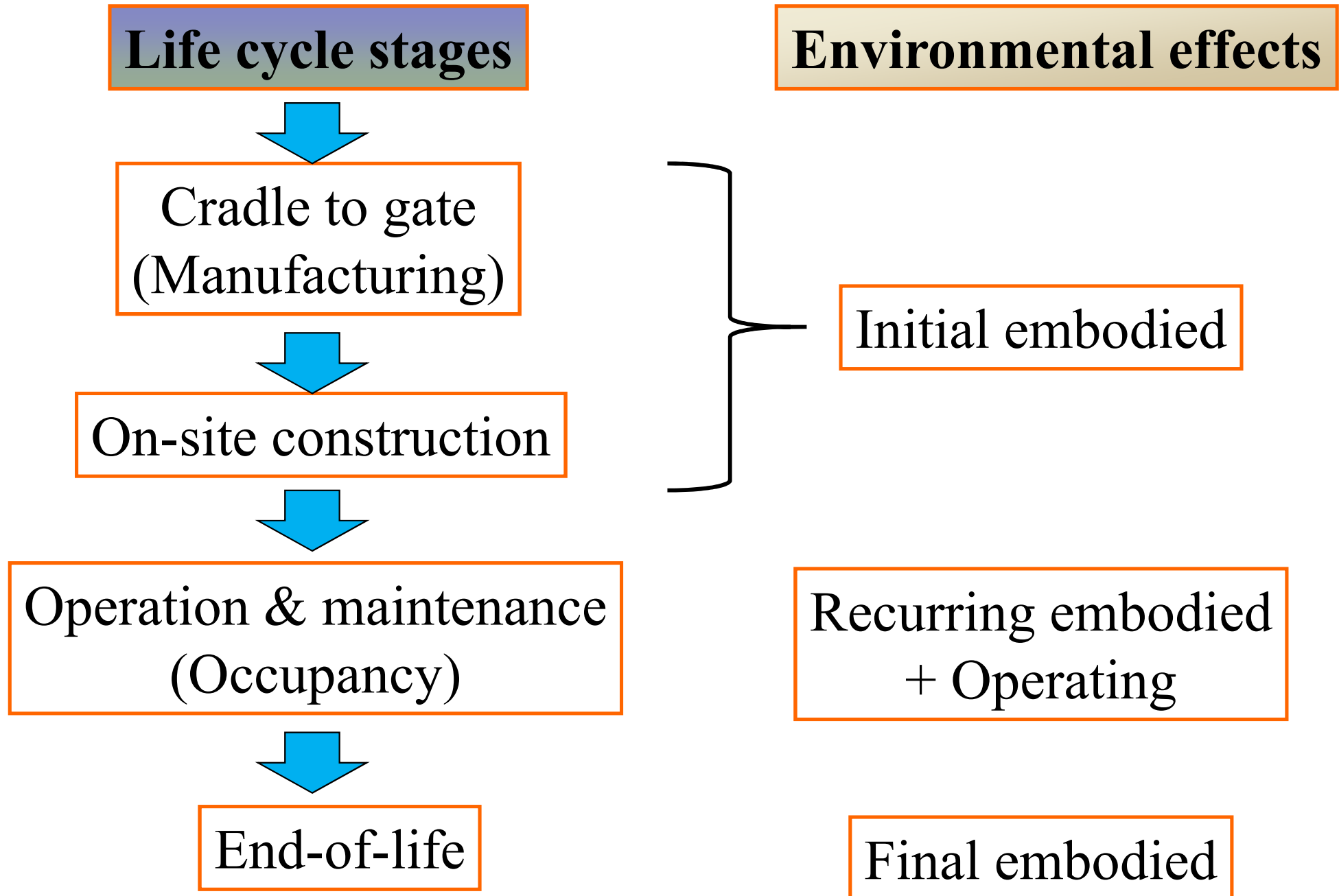


# T-shirt example (cotton)



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

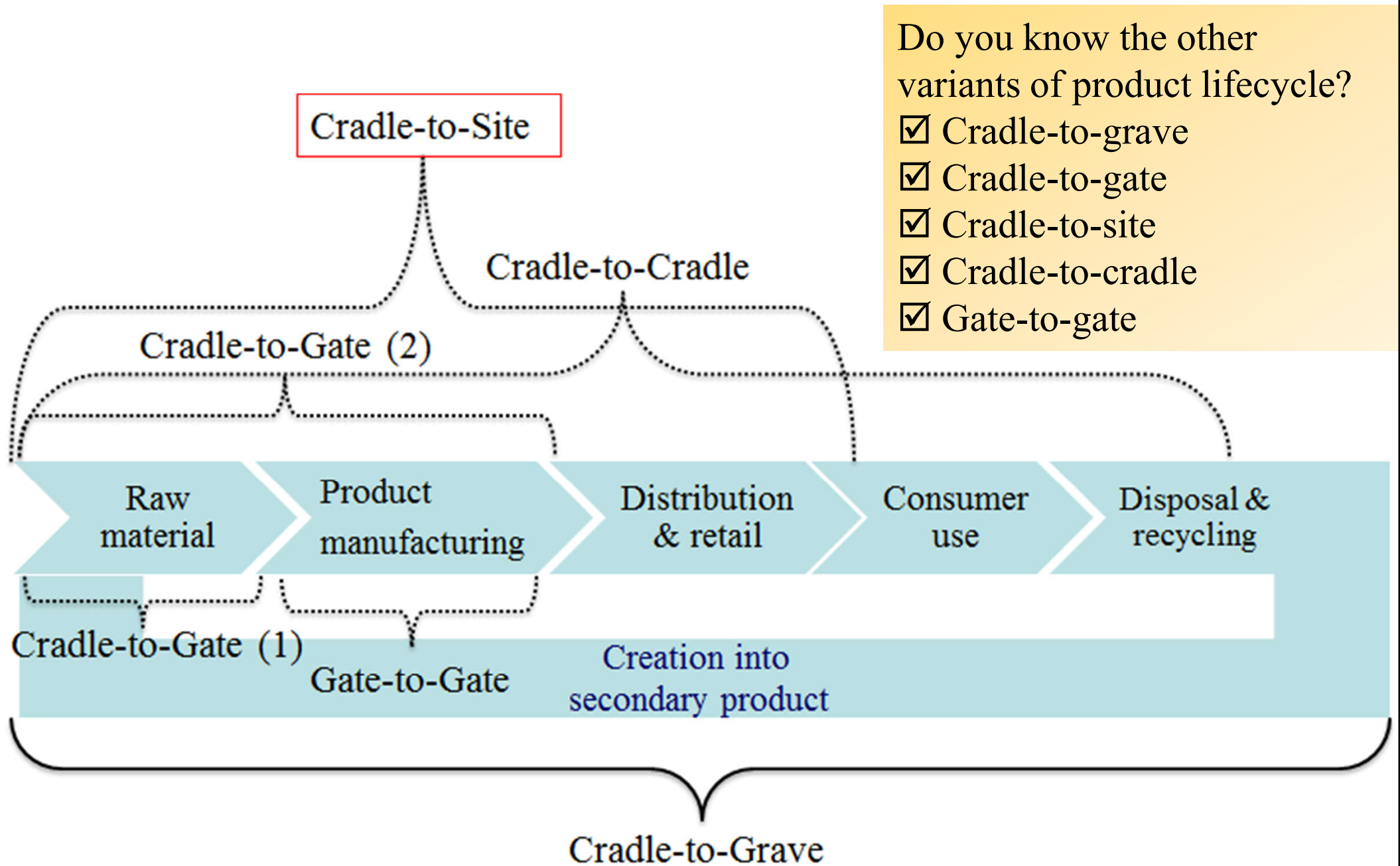
# Life cycle stages and effects



# 'Cradle to Gate' (4 stages) and 'Cradle to Grave' (6 stages)



# Life cycle boundary and variants of LCA



Do you know the other variants of product lifecycle?

- Cradle-to-grave
- Cradle-to-gate
- Cradle-to-site
- Cradle-to-cradle
- Gate-to-gate

# Different options of life cycle assessment

## Cradle-to-Grave

- Full LCA
- From Manufacture
- To Use
- To Disposal

## Cradle-to-Gate

- Partial Product Life-Cycle
- From manufacture
- To Factory

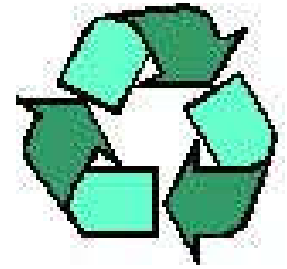
## Cradle-to-Cradle

- Specific Type of Cradle to Cradle
- End of Life disposal is a recycling process

## Gate-to-Gate

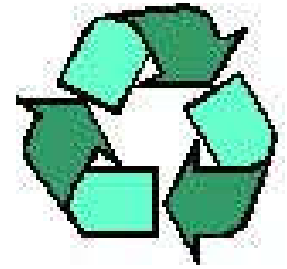
- Partial LCA
- Looks at only one value-added process

# Life cycle assessment



- 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**

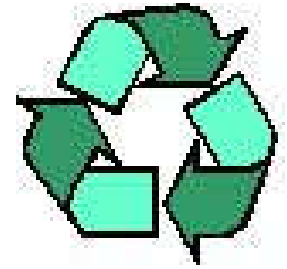
# LCA process



- 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)

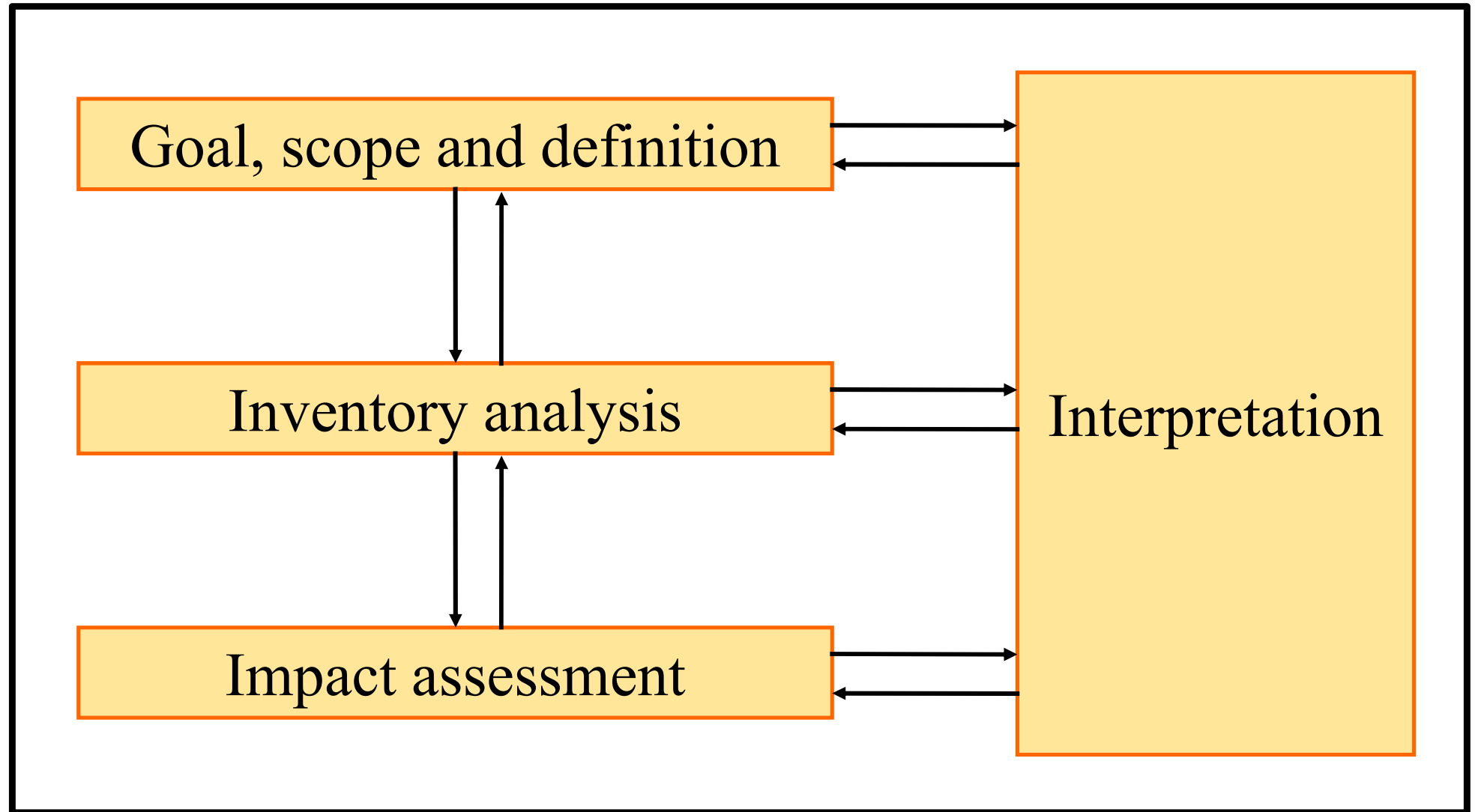


# LCA process

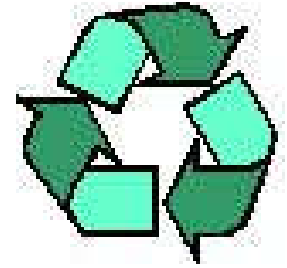


- The LCA process has four phases:
  - 1) Goal, scope and definition
    - Defines purpose of study, boundaries & functional units
  - 2) Life cycle inventory (LCI)
    - Provides inventory of input/output data
  - 3) Life cycle impact assessment (LCIA)
    - Assess the magnitude and significance of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

# Life cycle assessment framework (an iterative process)



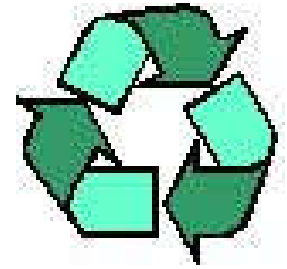
# LCA process



- 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



# 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



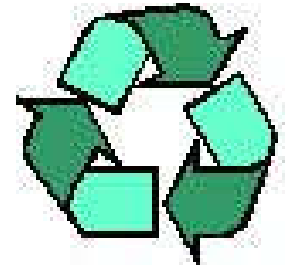
- Initial choices of system boundaries, data quality, etc.

- 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



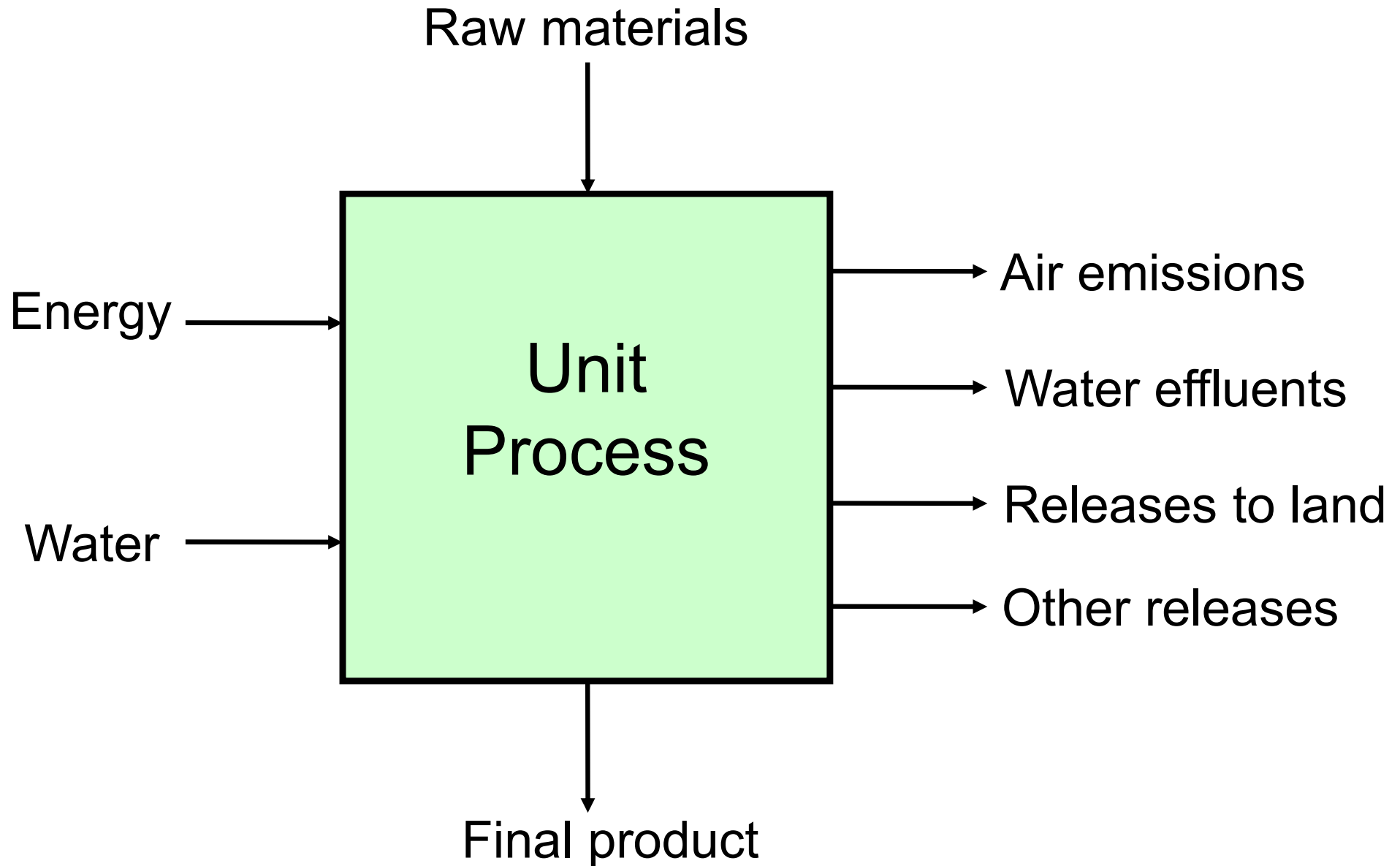
# LCA process



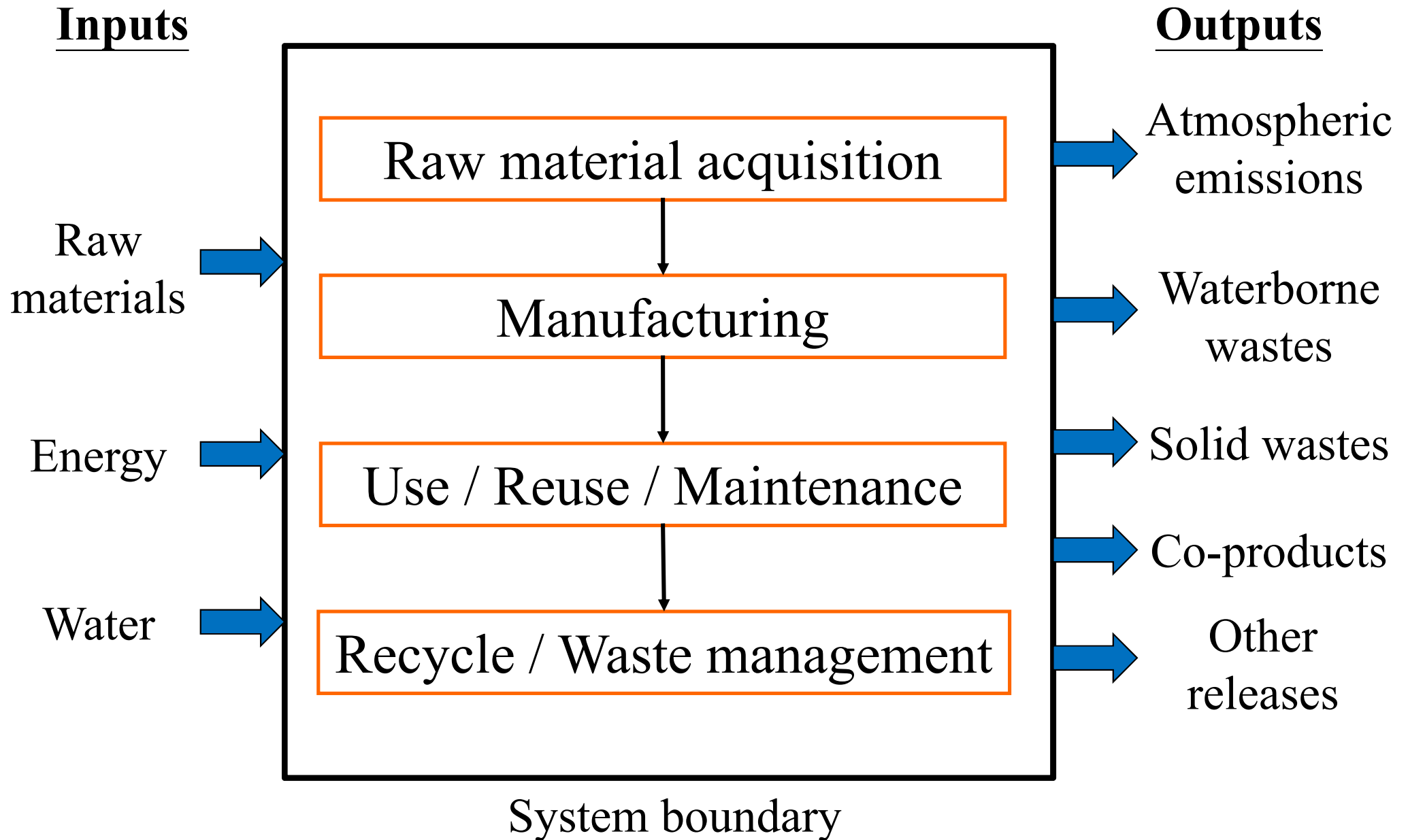
- 2) Life cycle inventory (LCI)
  - Compilation and quantification of inputs and outputs, for a given product system throughout its life cycle
  - Steps:
    - Preparing for data collection
    - Data collection
    - Calculation procedures
    - Allocation and recycling



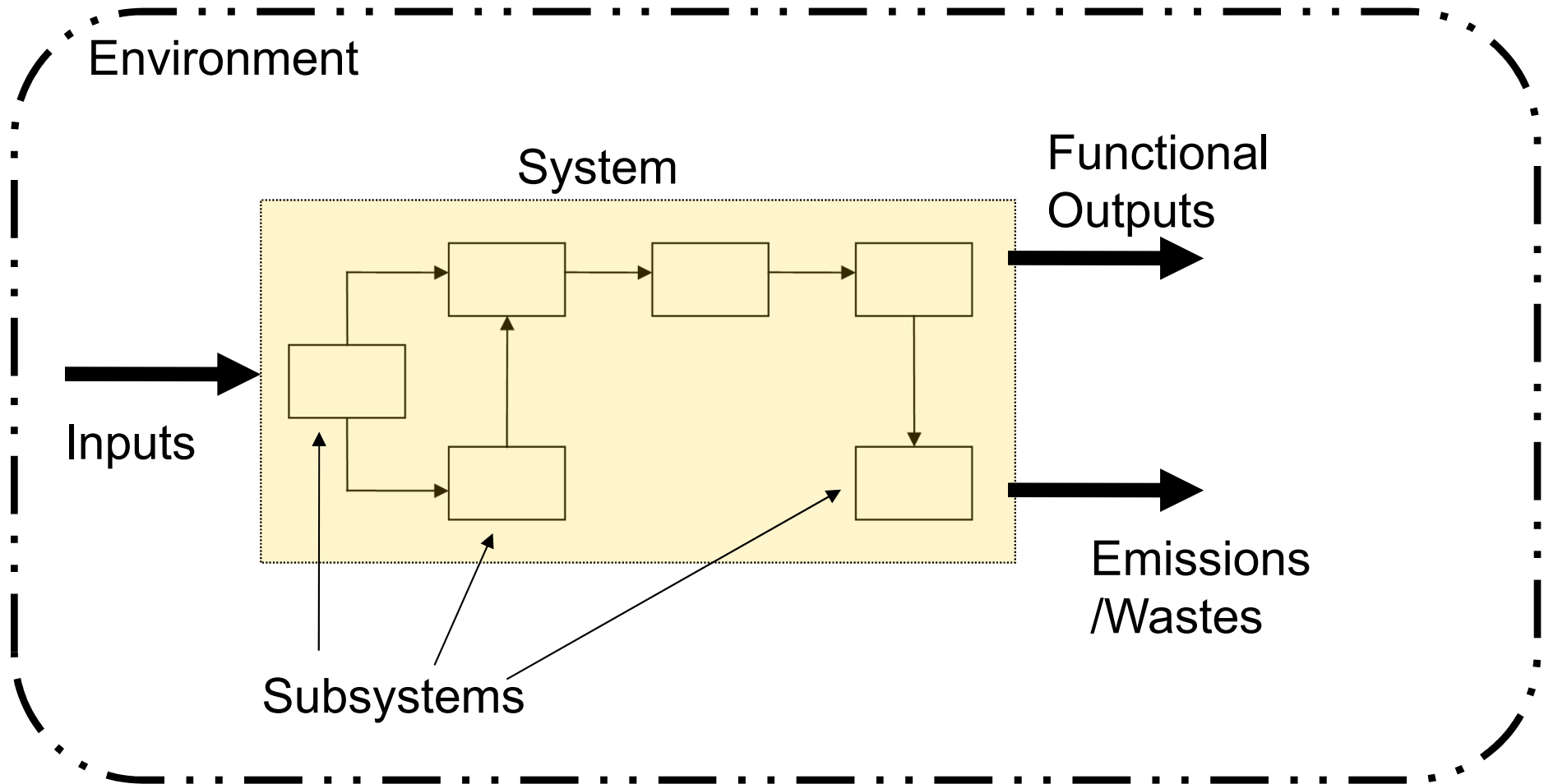
# Inventory analysis model for life-cycle assessment



# Life cycle stages and system boundary

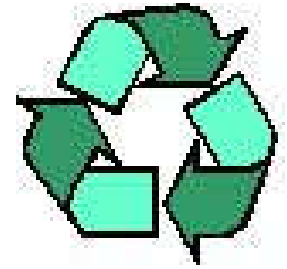


# Life cycle inventory analysis



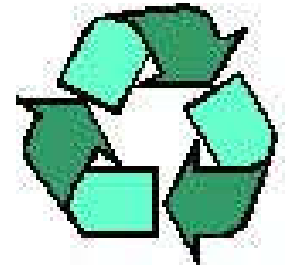


# LCA process



- 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

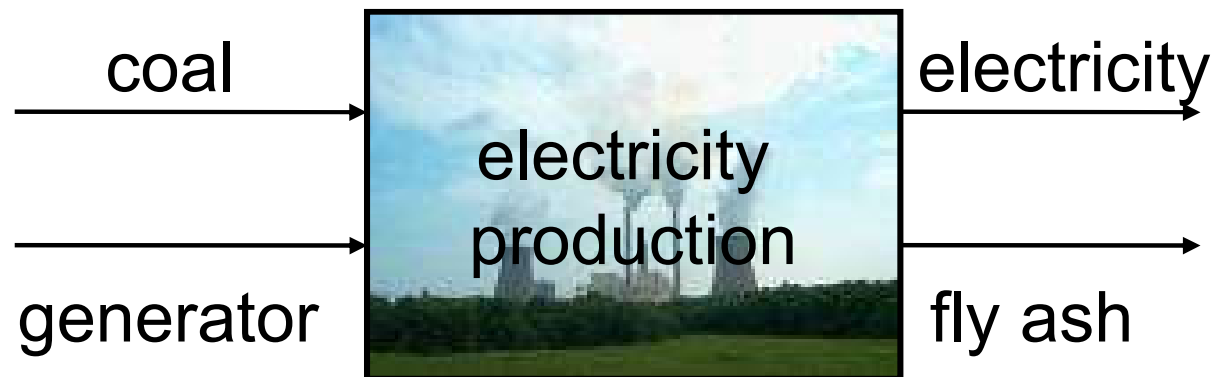
# LCA process

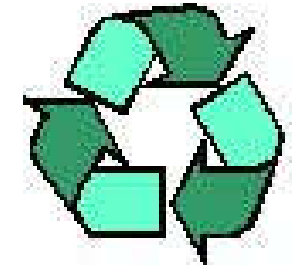


- 2) Life cycle inventory (LCI) (cont'd)

- Data collection for unit processes:

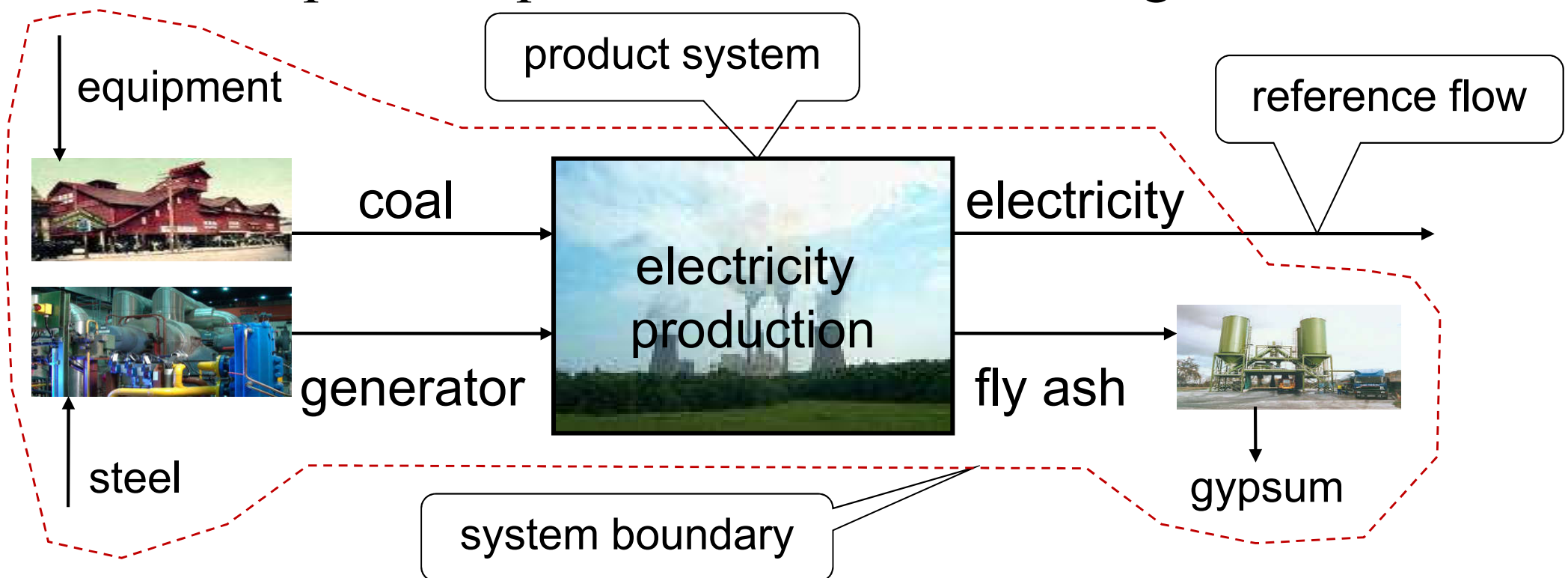
- Flows of intermediate products or waste for treatment
- Elementary flows from or to the environment



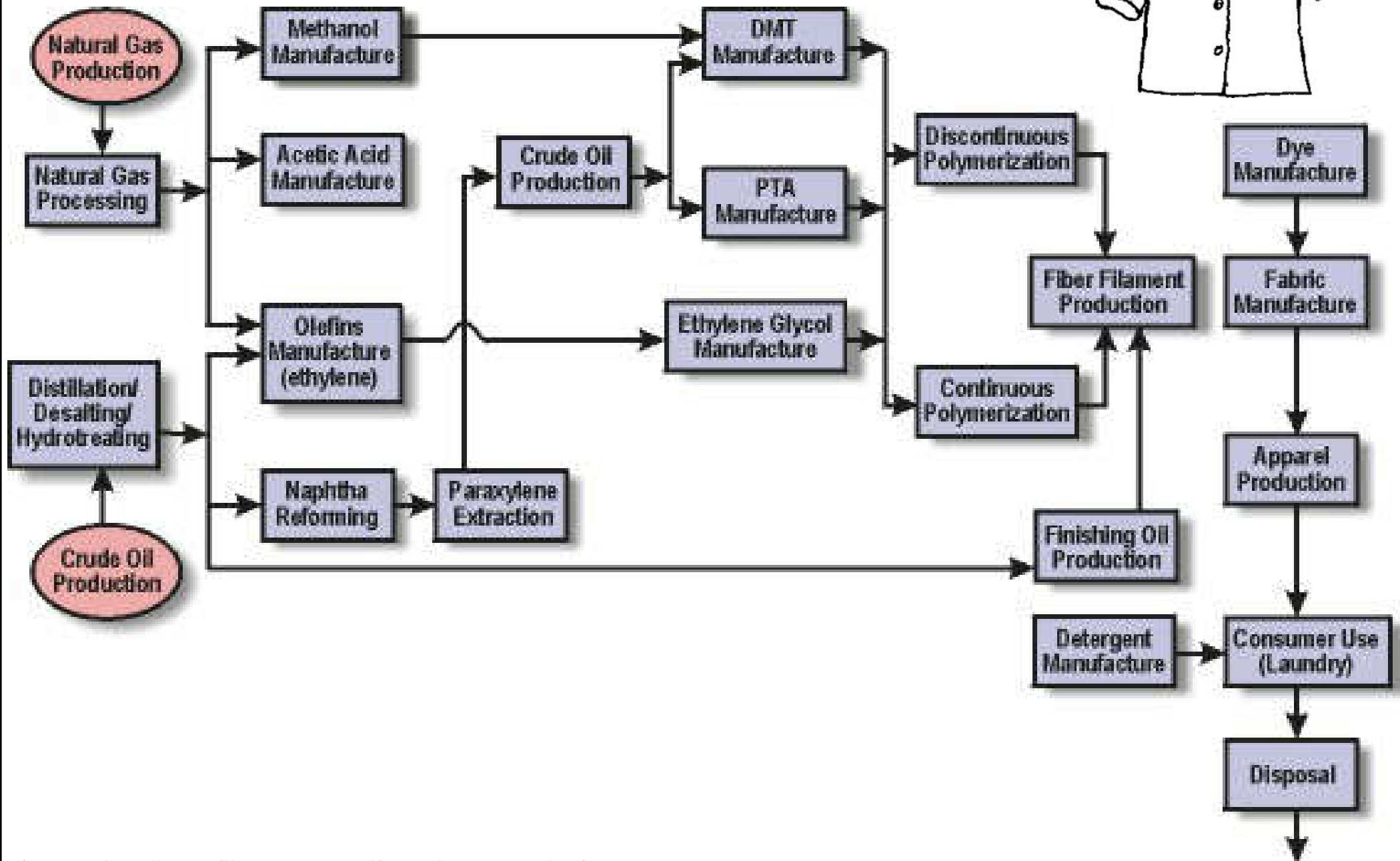


# LCA process

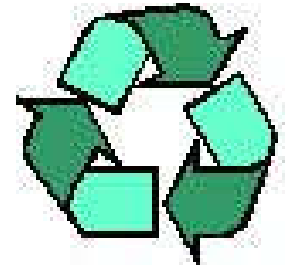
- 2) Life cycle inventory (LCI) (cont'd)
  - Combine unit processes into a product system
  - Graphical representation in a flow diagram



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



# 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



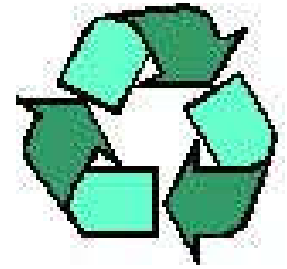
Product property	Incandescent lamp	Fluorescent lamp
power consumption	60 W	18 W
life span	1000 hr	5000 hr
mass	30 g	540 g
mercury content	0 mg	2 mg
etc	...	...

# Example: Incandescent and fluorescent lamps - Inventory table



Elementary flow	Incandescent lamp	Fluorescent lamp
CO <sub>2</sub> to air	800000 kg	50000 kg
SO <sub>2</sub> to air	1000 kg	80 kg
Copper to water	3 g	20 g
Crude oil from earth	37000 kg	22000 kg
etc	...	...

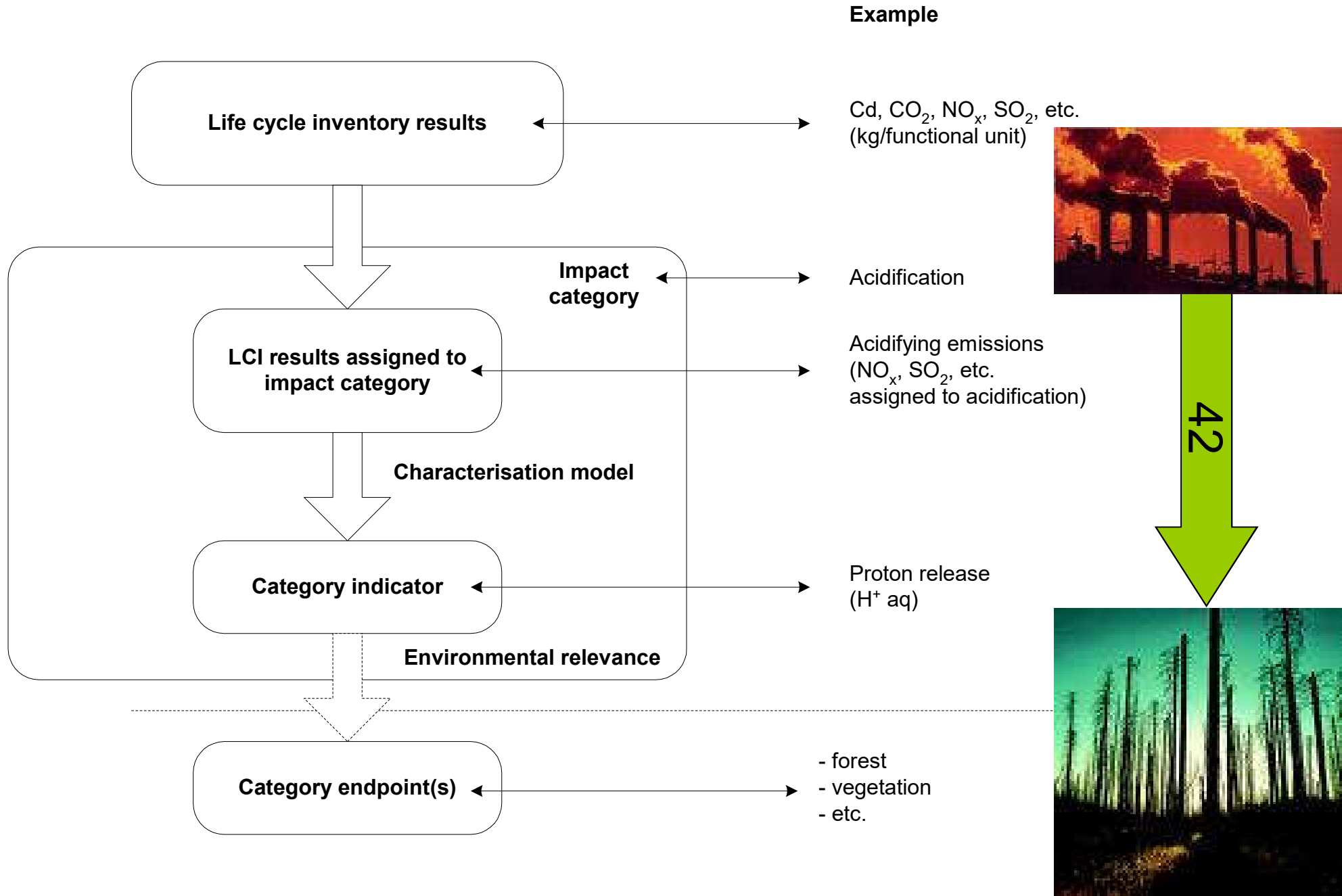
# LCA process



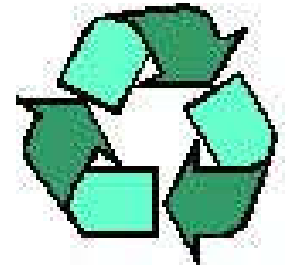
- 3) Life cycle impact assessment (LCIA)
  - Assess the importance of potential environmental effects on the results of the inventory analysis
  - Steps:
    - Selection and definition of impact categories, indicators and models
    - Classification
    - Characterisation
    - Normalisation
    - Aggregation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



# Life cycle impact assessment (LCIA)



# LCA process



- 3) Life cycle impact assessment (cont'd)

- Example of a category indicator

- Global Warming:

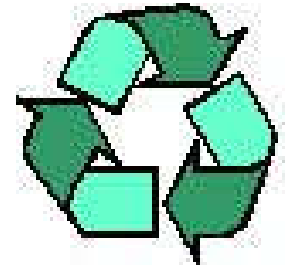
- Global Warming Potential (GWP): measure for Global Warming in terms of radiative forcing of a mass-unit

- Example calculation:

- $5 \text{ kg CO}_2 \text{ (GWP = 1)} + 3 \text{ kg CH}_4 \text{ (GWP = 21)}$

- $= 1 \times 5 + 21 \times 3 \text{ kg CO}_2 \text{ - equivalents (= 68 kg CO}_2 \text{ - equivalents)}$

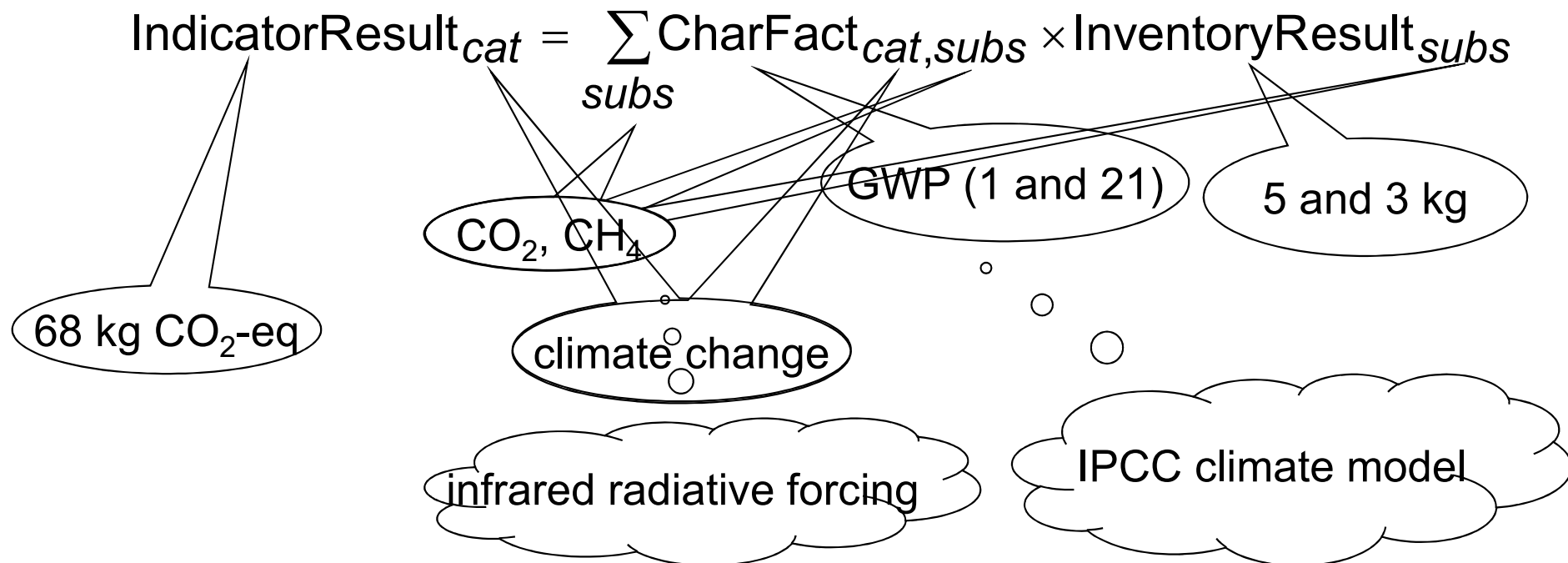
# LCA process



## 3) Life cycle impact assessment (cont'd)

### • Characterisation:

- Simple conversion and aggregation of greenhouse gas (GHGs):



## Impact categories, characterisation methods and characterisation models: some baseline examples

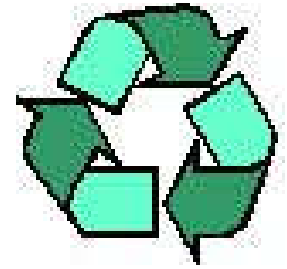
<b>impact category</b>	<b>category indicator</b>	<b>characterisation model</b>	<b>characterisation factor</b>
abiotic depletion	ultimate reserve irt annual use	Guinee & Heijungs 95	ADP
climate change	infrared radiative forcing	IPCC model	GWP
stratospheric ozone depletion	strat. ozone breakdown	WMO model	ODP
human toxicity	PDI/ADI	Multimedia model, e.g. EUSES, CalTox	HTP
ecotoxicity (aquatic, terrestrial etc.)	PEC/PNEC	Multimedia model, e.g. EUSES, CalTox	AETP, TETP, etc.
photo-oxidant formation	trop. ozone formation	UNECE Trajectory model	POCP
acidification	deposition/ac.critical load	RAINS	AP
...	...	...	...

# Example: Incandescent and fluorescent lamps – impact assessment



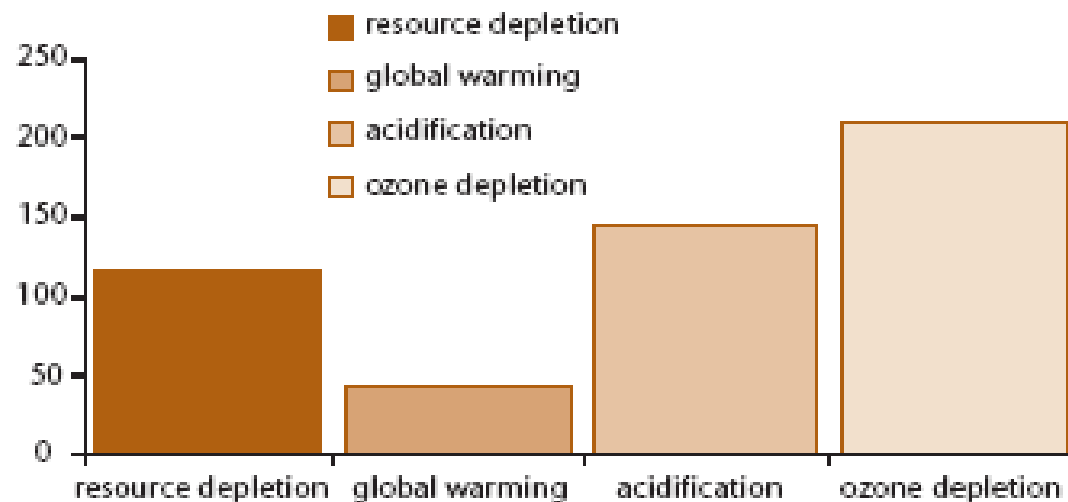
Impact category	Incandescent lamp	Fluorescent lamp
Climate change	120000 kg CO <sub>2</sub> -eq	40000 kg CO <sub>2</sub> -eq
Ecotoxicity	320 kg DCB-eq	440 kg DCB-eq
Acidification	45 kg SO <sub>2</sub> -eq	21 kg SO <sub>2</sub> -eq
Depletion of resources	0.8 kg antimony-eq	0.3 kg antimony-eq
etc	...	...

# LCA process

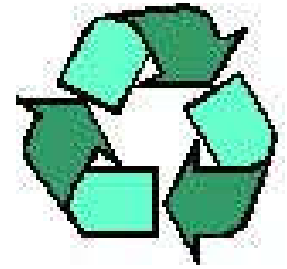


- 3) Life cycle impact assessment (cont'd)
  - The final result of the characterisation step is a list of potential environmental impacts
  - This list of effect scores, one for each category, is called the *environmental profile*

Environmental profile of the whole life cycle



# 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

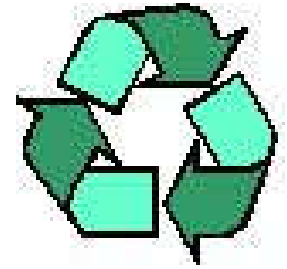
# Example: Incandescent and fluorescent lamps – impact assessment (with normalisation to a reference value)



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



# LCA process

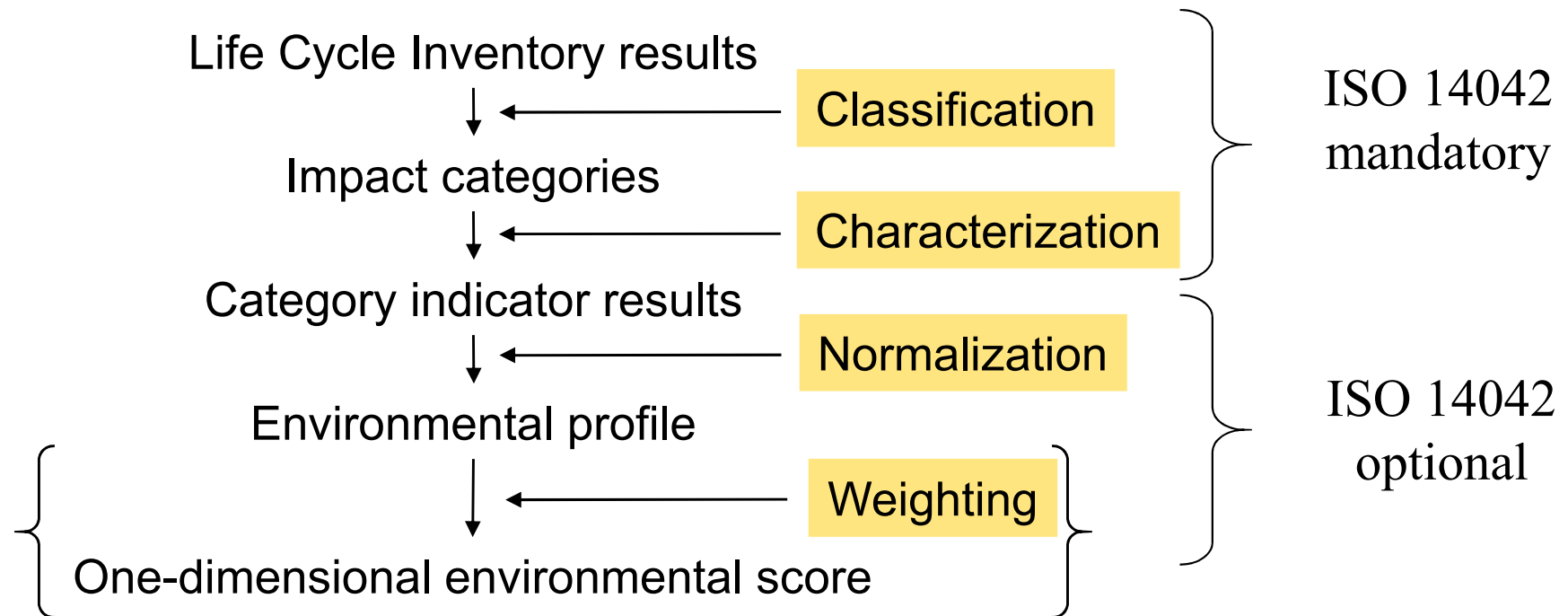


- 3) Life cycle impact assessment (cont'd)
  - Even after normalisation no clear answer
    - Aggregation of (normalized) impact category results into a single index
    - Subjective weighting factors needed
    - Example of a weighted environmental index:

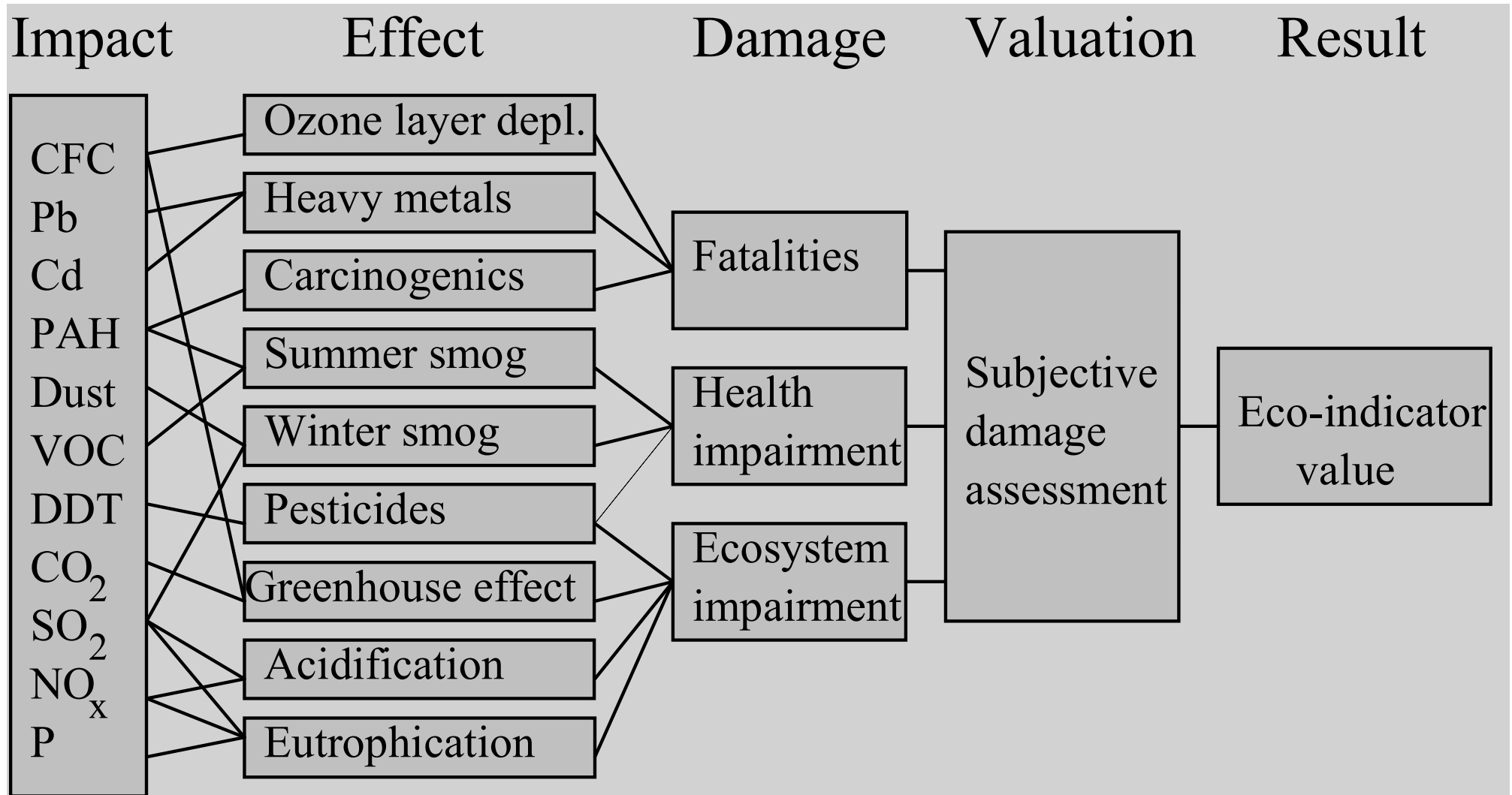
Weighed index	Incandescent lamp	Fluorescent lamp
Weighted index	$8.5 \times 10^{-10}$ yr	$1.4 \times 10^{-10}$ yr

# Life cycle impact assessment

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



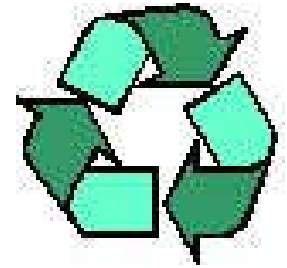
# Schematic representation of the Eco-indicator weighting method



Examples of Eco-indicator weighting methods:

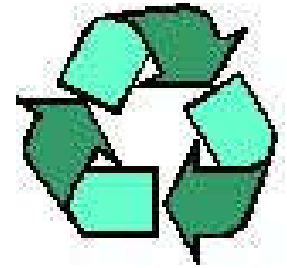
- Eco-indicator 99, Eco-indicator 95, MIPS, Ecopoints, EDIP\UMIP, EDIP/UMIP 96, EPS 2000, Economic Input Output

# 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
      - Consistency check
    - 3. Conclusions, recommendations, and reporting

# LCA process



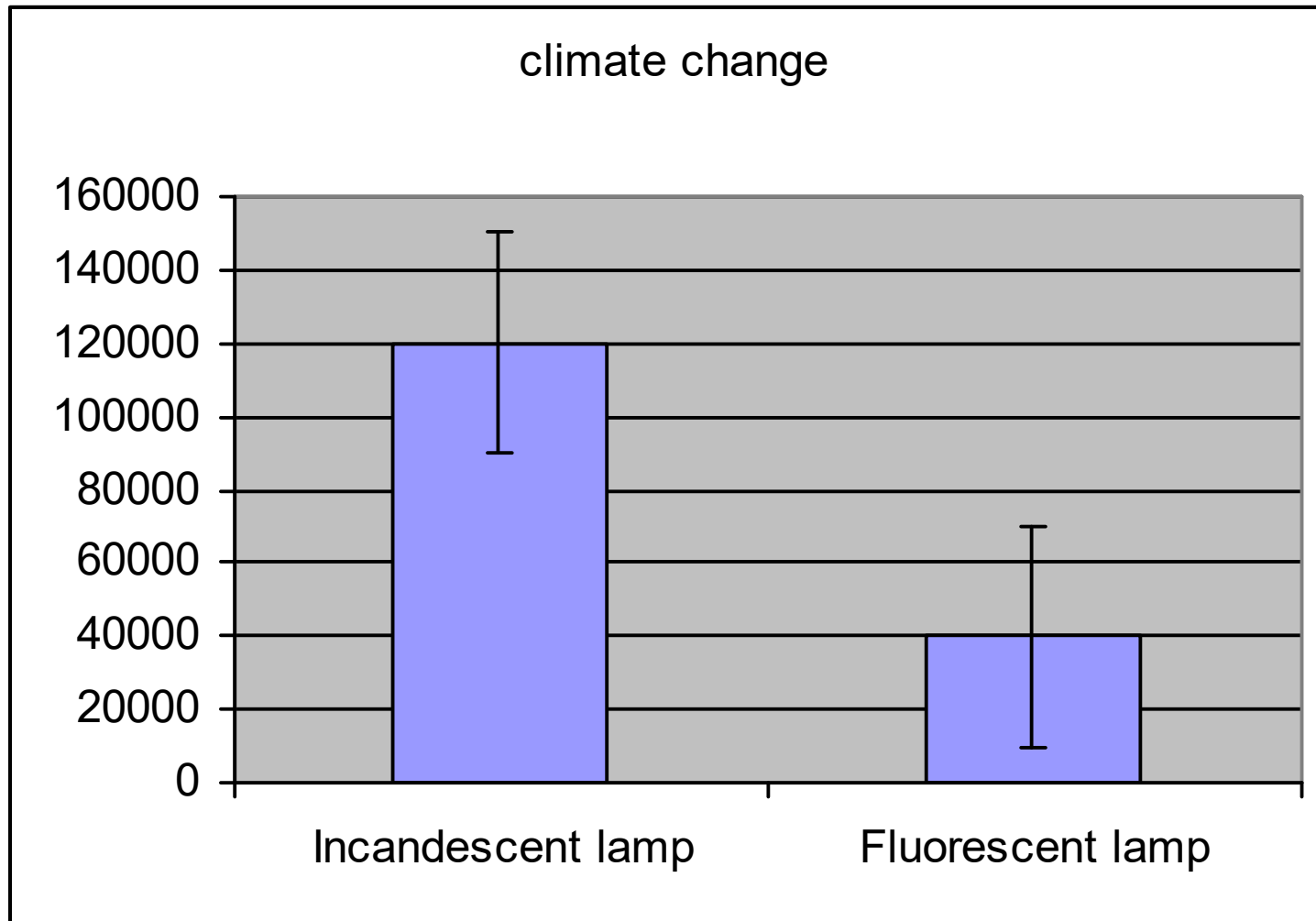
- 4) Life cycle interpretation (cont'd)
  - Identifies areas for improvement within a system
    - Reliant on the user noticing not only areas which have significant environmental effects but also those with smaller effects where changes could be made easily
  - Conclusions, recommendations, analysis, 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 <sub>2</sub> -eq	40000 kg CO <sub>2</sub> -eq

# Example of an uncertainty analysis



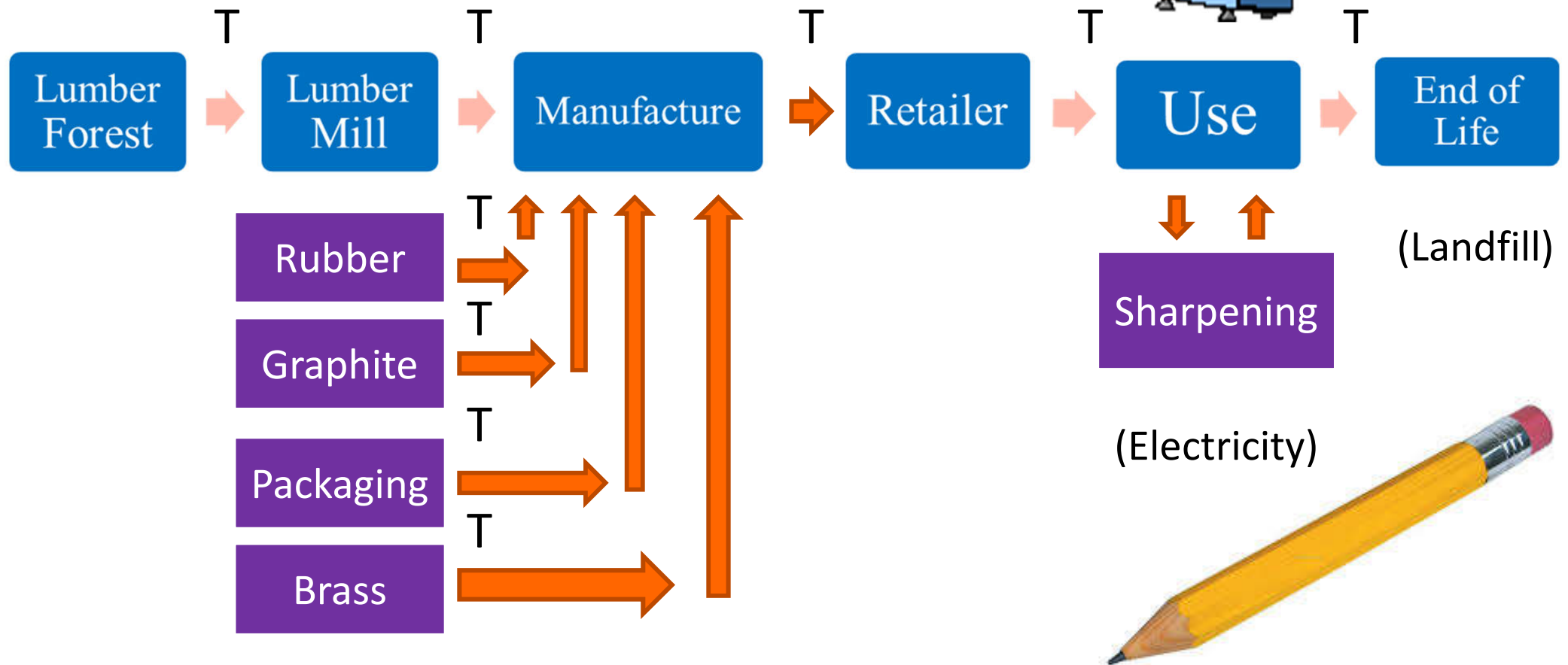


# Example of life cycle assessment: Wooden Pencil vs. Mechanical Pencil

**Goal** = Compare 2 writing utensils for classroom use.

**Scope:** Wooden Pencil (T = Transportation)

## Process Flow Diagram



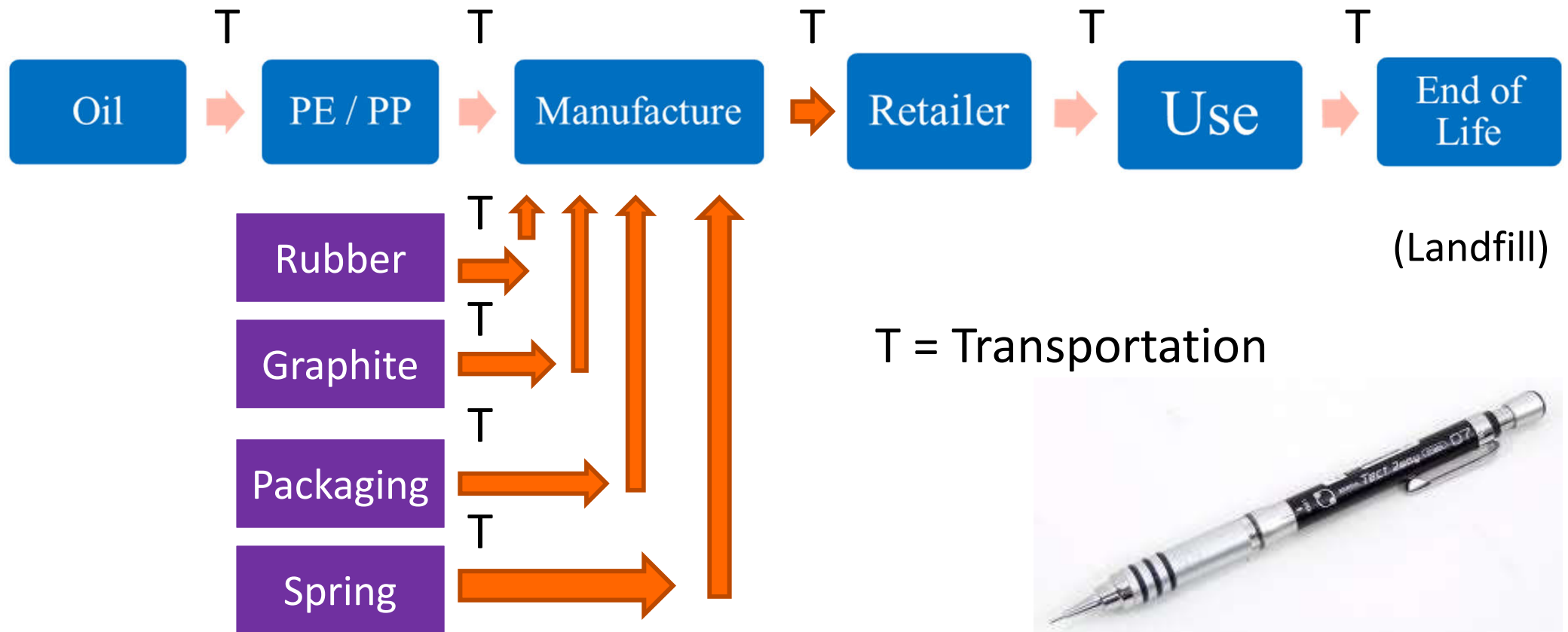


# Scope: Mechanical Pencil

PE = Polyethylene

PP = Polypropylene

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





# Function & Functional Unit

## Function

- Service provided by a system
- What it does!

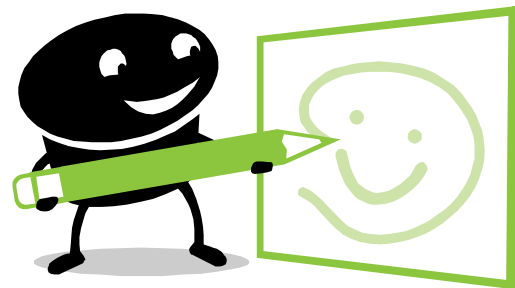
## Functional Unit

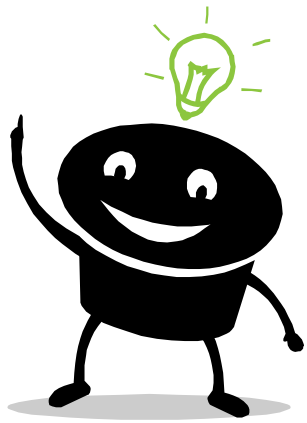
- Gives the function a number value
- Allows comparison between products
- Reference point

## Example

### Wooden Pencil vs. Mechanical Pencil

- Function = “Writing”
- Functional Unit = “1 meter of writing”





# Items To Consider??

## Inputs

What is needed to make the substance!

1. Energy
2. Materials
3. Labor



## Outputs

What comes out of the system!

1. Products (electricity, materials, goods, services)
2. Waste
3. Emissions
4. Co-products



# Data Collection

## Life Cycle Inventory Analysis

1. Time-sensitive = past 5 years
2. Geographical = does it match the location from the goal
3. Technology = best available technology for process
4. Representativeness = reflects population of interest
5. Consistency = matches the procedure
6. Reproducibility = another person could find it

Never Forget . . . . .

### Precision:

The consistent reproducibility of a measurement

### Completeness:

Covers all the areas outlined in the scope

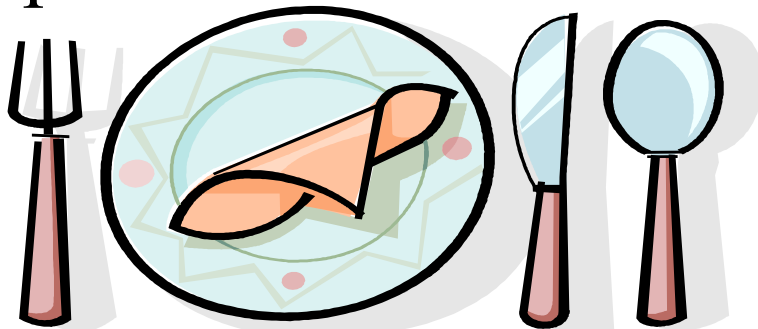




# LCA in Action: Think About It!

Paper Plate vs. China (Plate You Wash & Reuse)

- ✓ What is the function?
- ✓ What is the functional unit?
- ✓ What materials & resources are used?
- ✓ What does it take to produce both?
- ✓ What are the impacts to the environment?
- ✓ Is there waste?
- ✓ Does washing the China produce waste?
- ✓ What types of data do you need?
- ✓ How do you know which is better?





# Data Analysis

## Environmental Impact Categories

### Global Warming Potential

- Gases in the atmosphere that absorb and emit radiation
- Trap heat from the sun
- Water vapor, CO<sub>2</sub>, CH<sub>4</sub>, ozone, NO<sub>2</sub>



### Abiotic Depletion

- Consumption of non-living resources

### Human Toxicity Potential

- Value that shows harms to humans from chemicals

### Land Use

- How much land is needed



# Environmental Impact Categories

Continued . . . . .

## Eutrophication

- Increase in chemical nutrients containing nitrogen or phosphorus
- land or water
- overgrowth of plants
- killing organisms at bottom of water

Water Use  
Mercury

## Acidification

- caused by pollution from fuels & acid rain
- low pH

Smog (Winter or Summer)

Energy Use

Solid Waste

Oil

... AND MANY MORE!!



# Global Impact Categories



Resource  
depletion

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



Green house  
effect

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



Depletion of  
ozone layer

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



# 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<sub>x</sub>, NO<sub>x</sub>, NH<sub>3</sub> )



Eutrophication

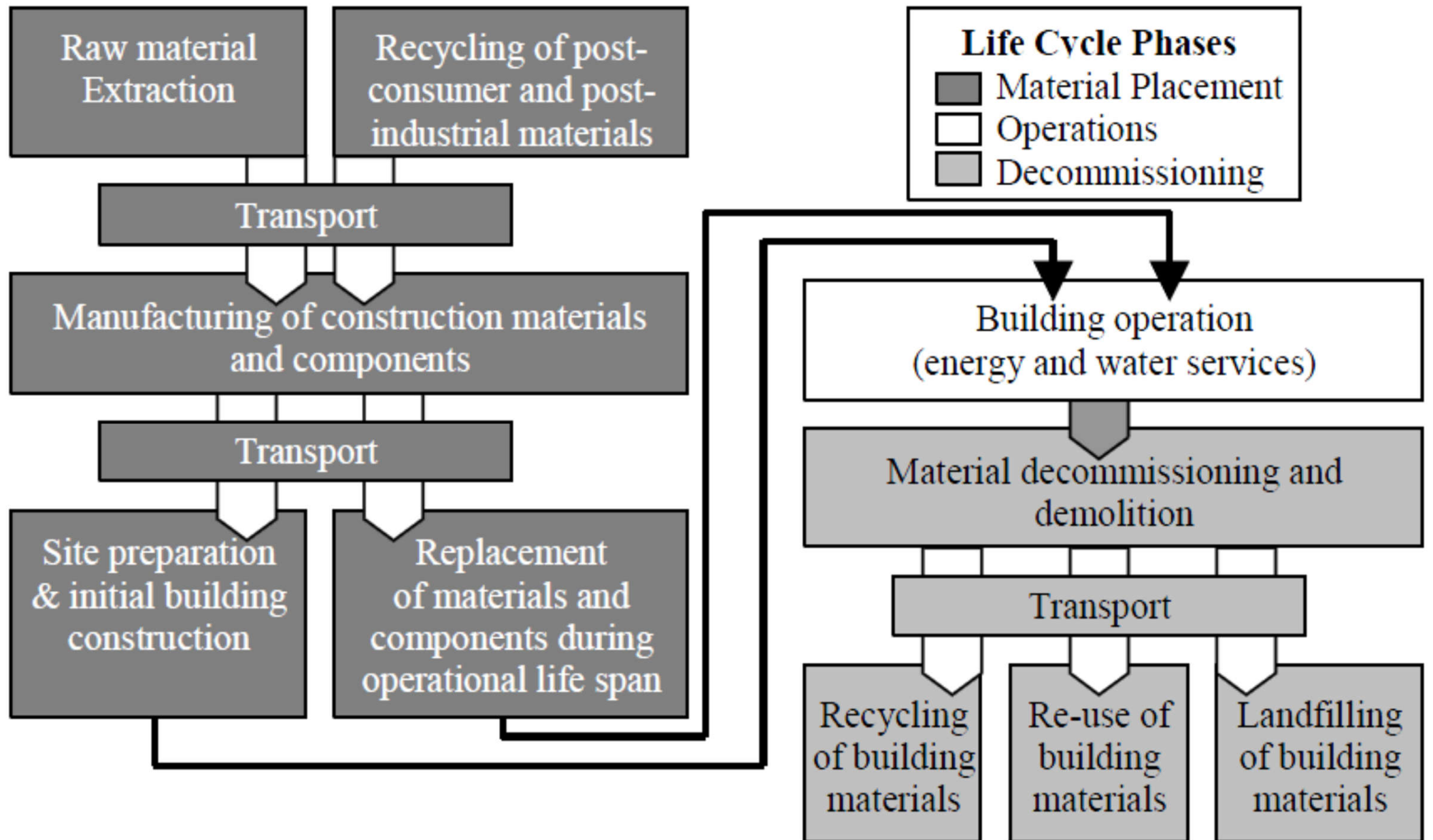
- **Source:** Fertilisers, waste water, transport and energy
- **Effect:** Eutrophication (Damage to plants and fish)



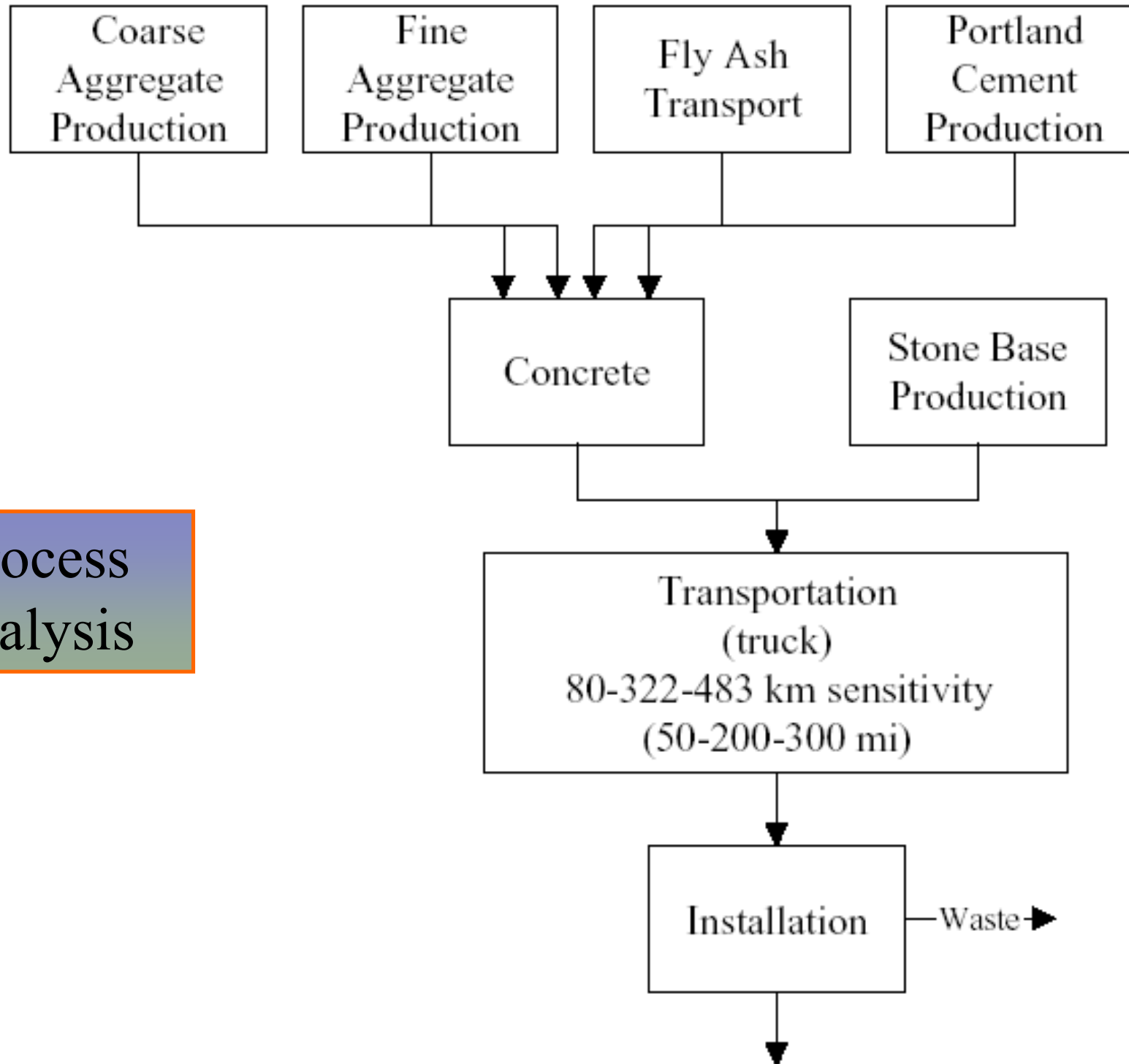
Persistent toxicity

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

# Life cycle phase diagram

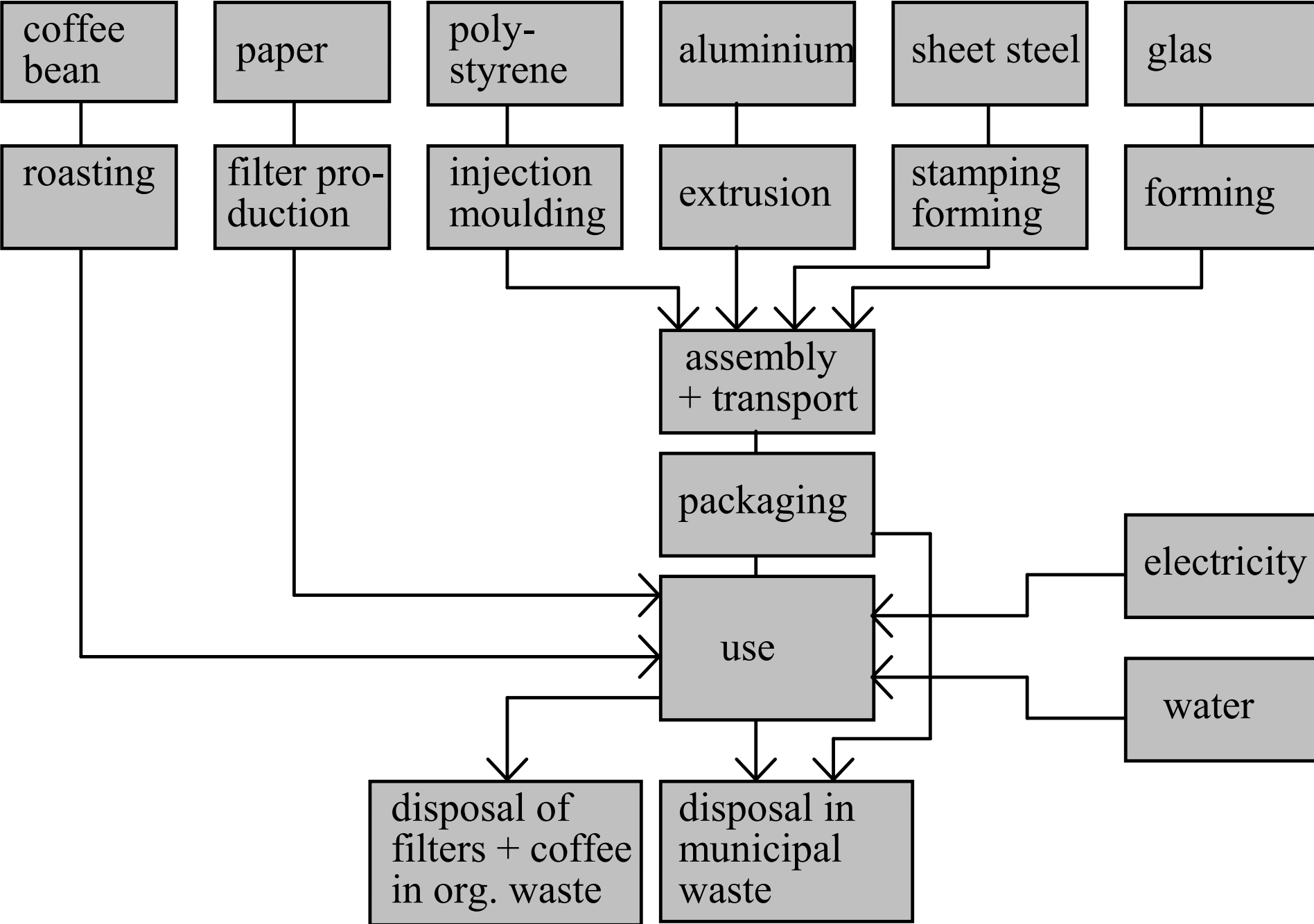


# LCA example – concrete paving flow chart



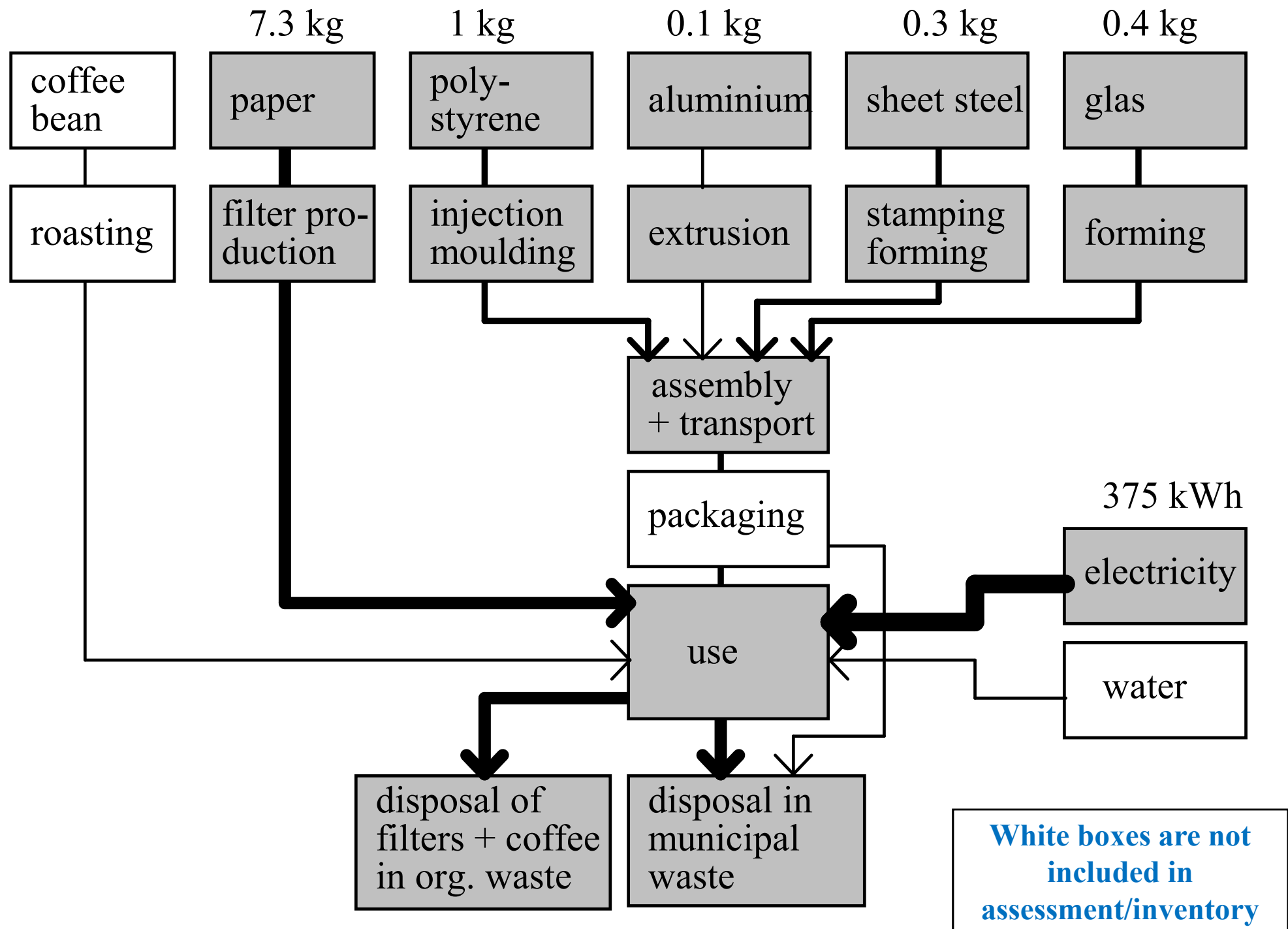
Process  
analysis

# Example: Simplified process tree for a coffee machine's life-cycle



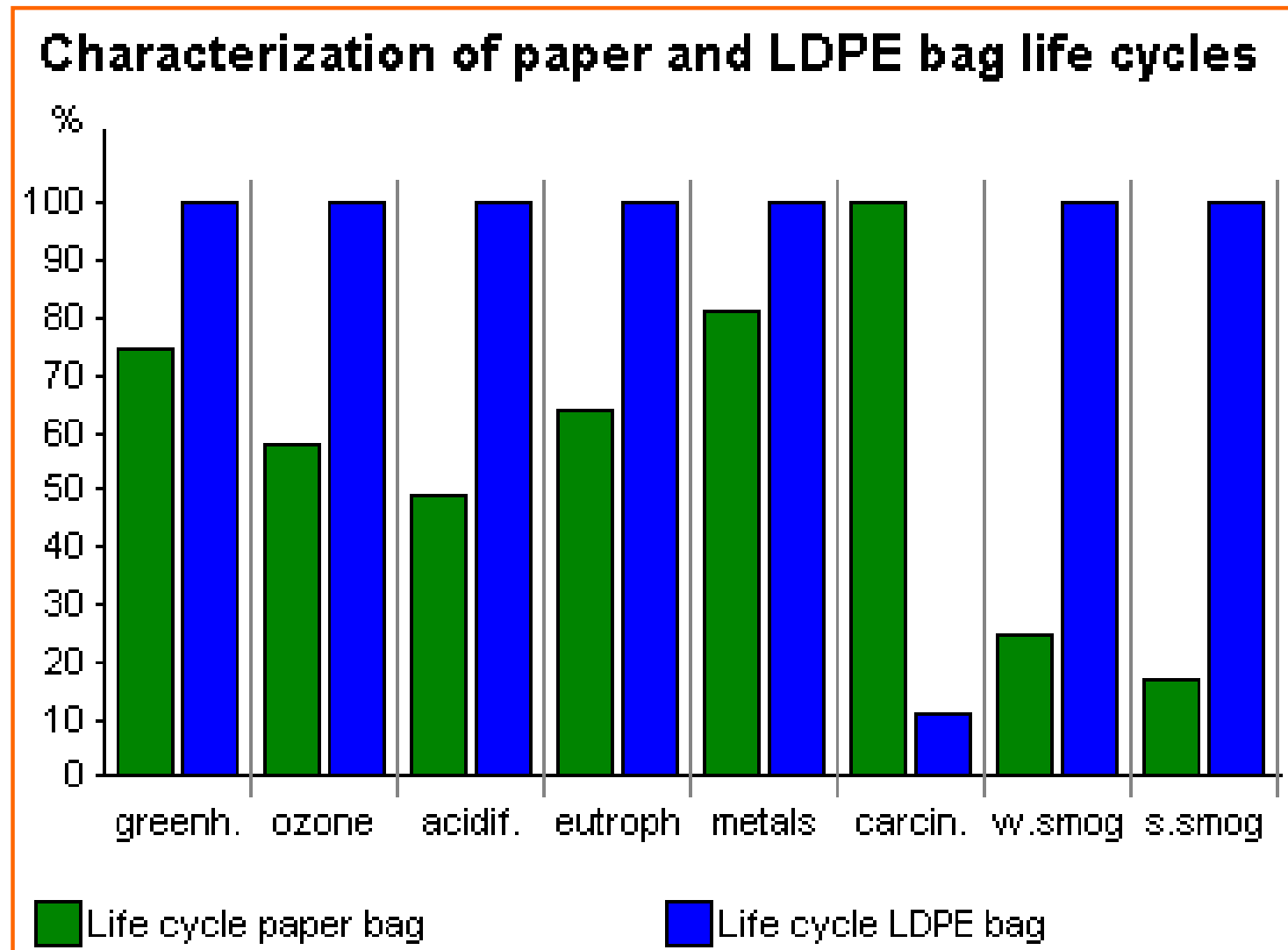
(Source: Systems Realization Laboratory, Georgia Institute of Technology)

# Example: Coffee machine life-cycle inventory



(Source: Systems Realization Laboratory, Georgia Institute of Technology)

## Example: Plastic versus paper bag classification

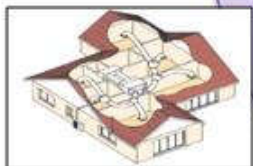
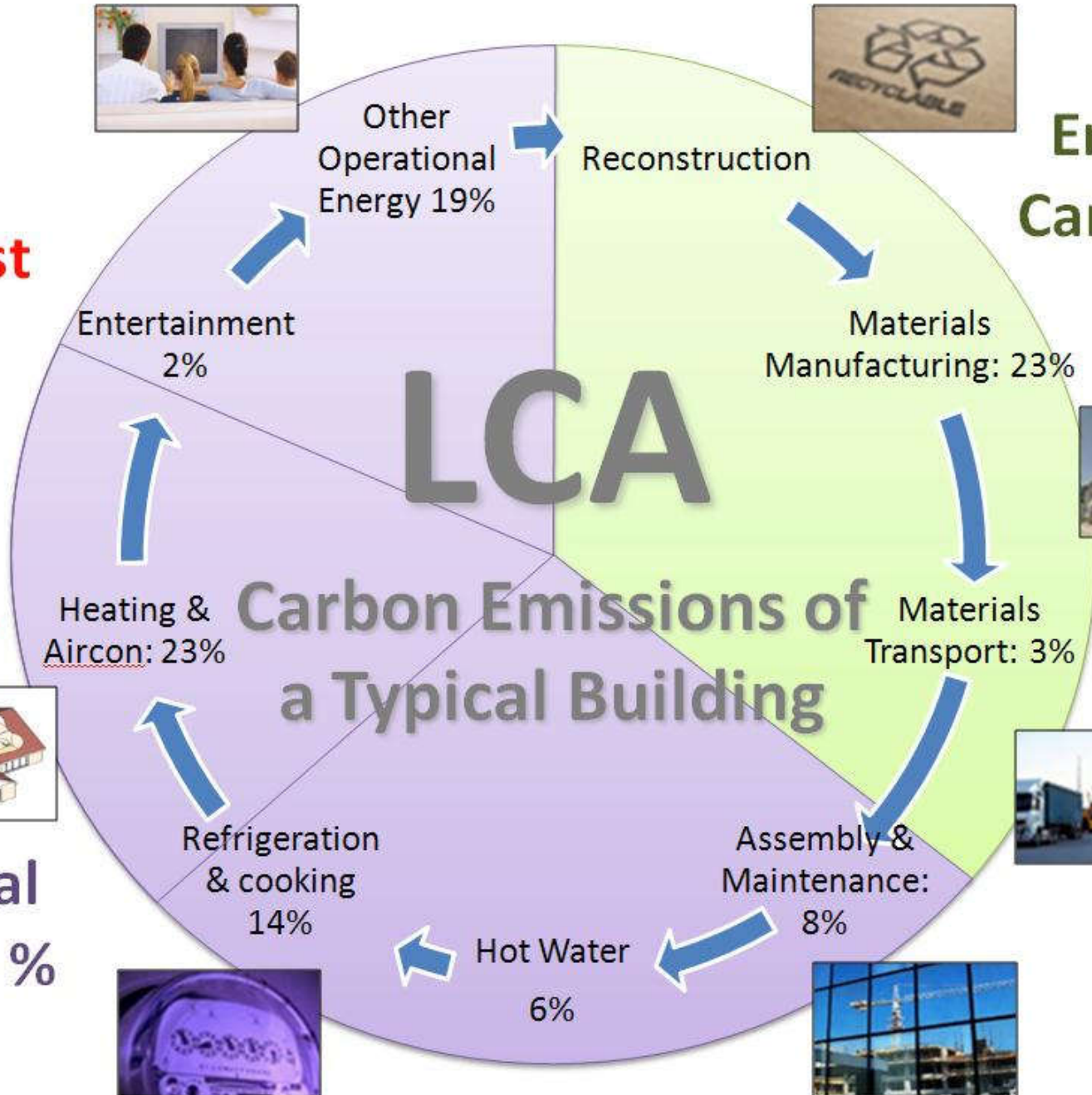


- The paper bag causes more winter smog and acidification, but scores better on the other environmental effects.
- The classification does not reveal which is the better bag. What is missing is the mutual weighting of the effects.

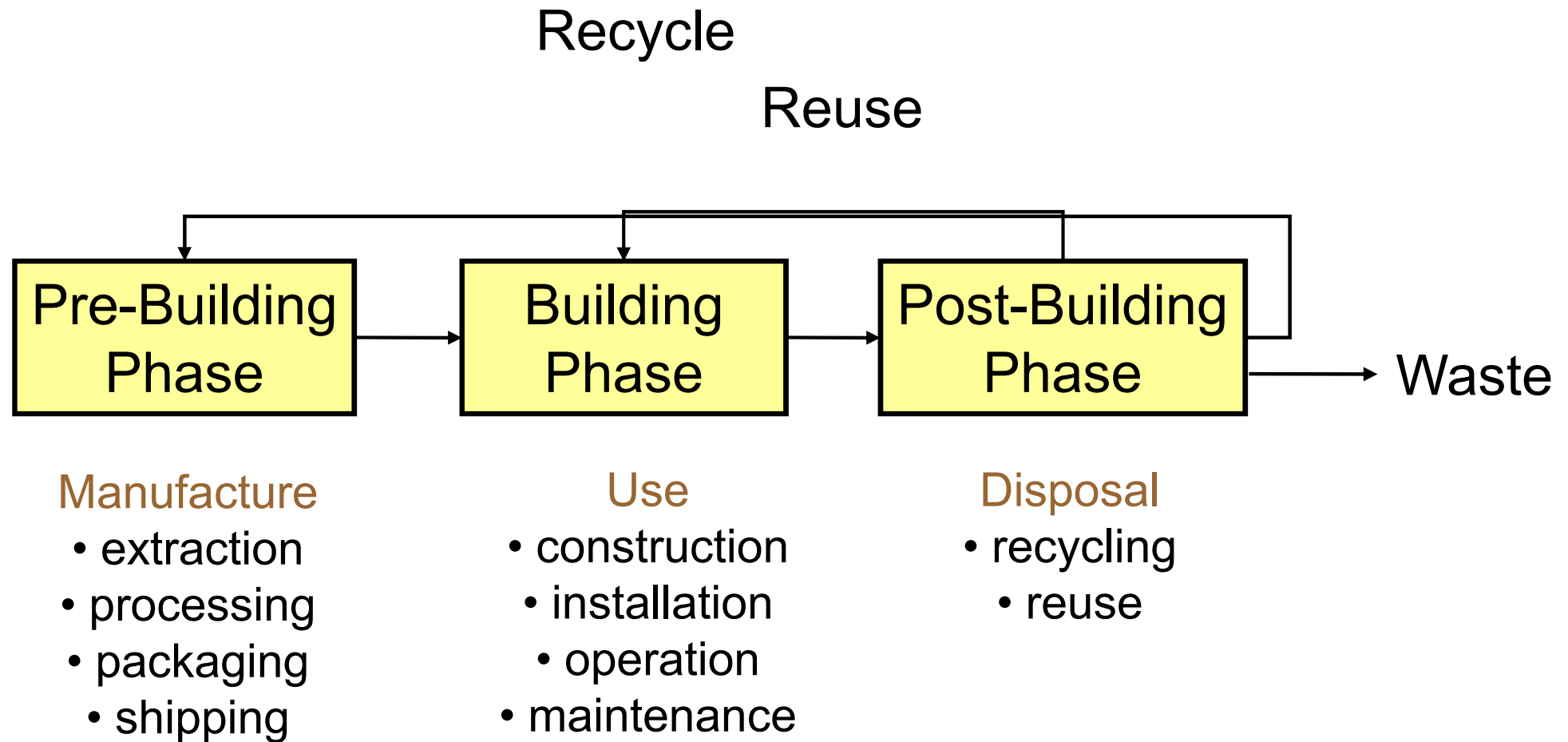
**Energy efficiency standards focus on just 24% of the total CO<sub>2</sub>**

**Operational Carbon: 65 %**

**Embodied Carbon: 35%**

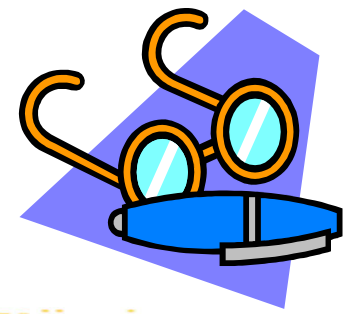


# Three phases of building material life cycle





# Evaluation methods

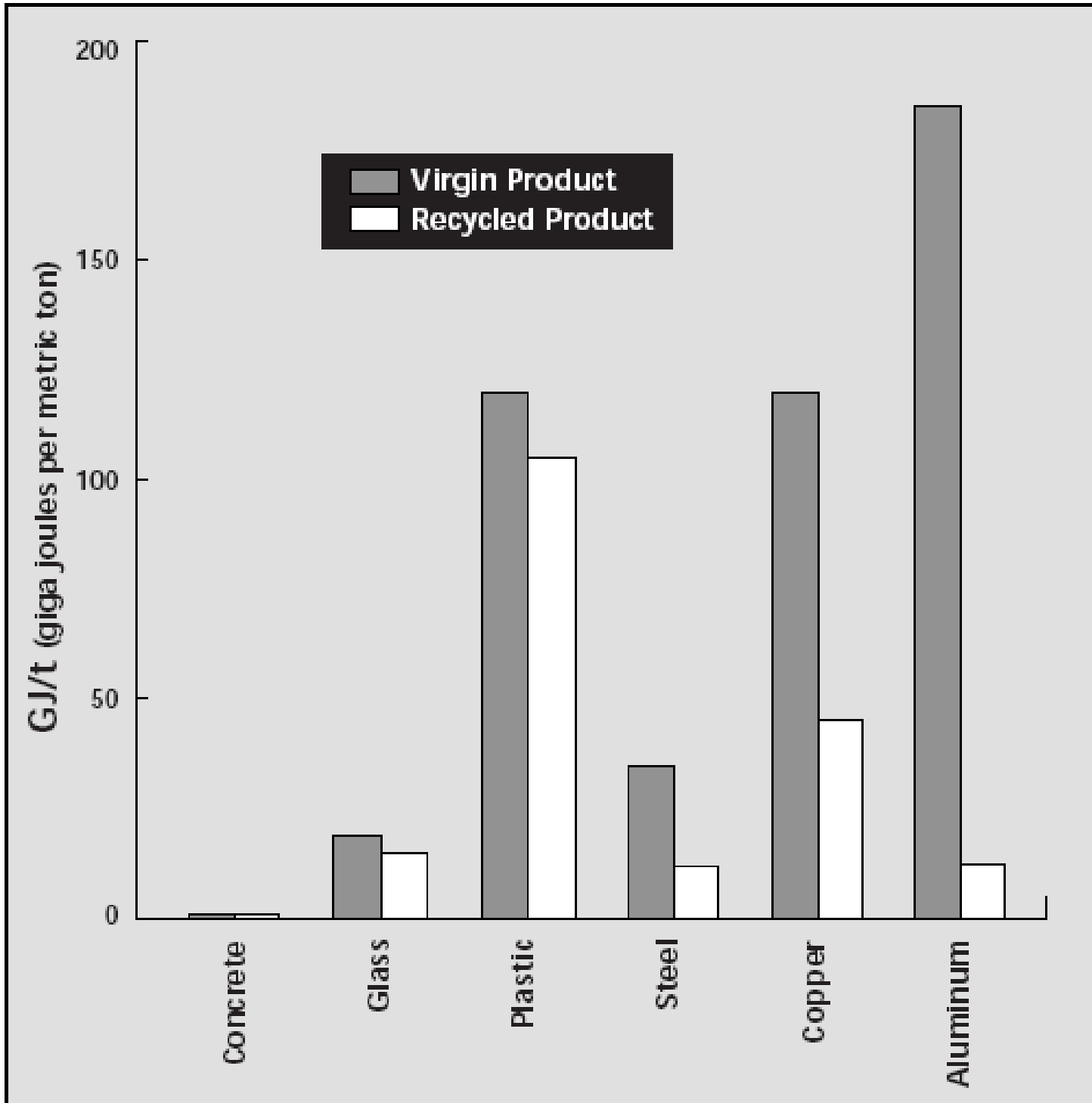


- Pre-building phase
  - Materials acquisition & preparation
    - Land degradation & depletion of resources
  - Manufacturing & fabrication
    - Energy & water use
    - Fugitive emissions
    - Water pollution
  - Distribution & transport
    - Fuel use & air pollution

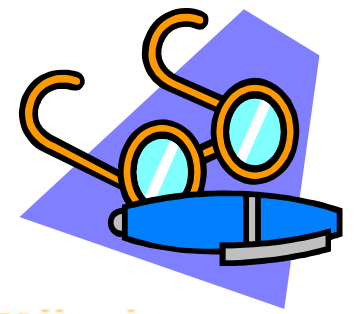
## Energy efficiency by mode of transport

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

# Embodied energy of virgin and recycled products



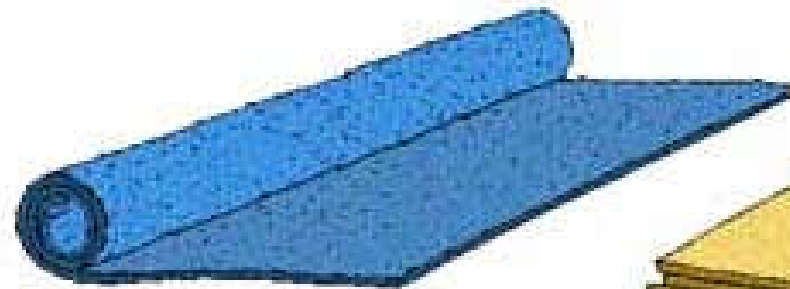
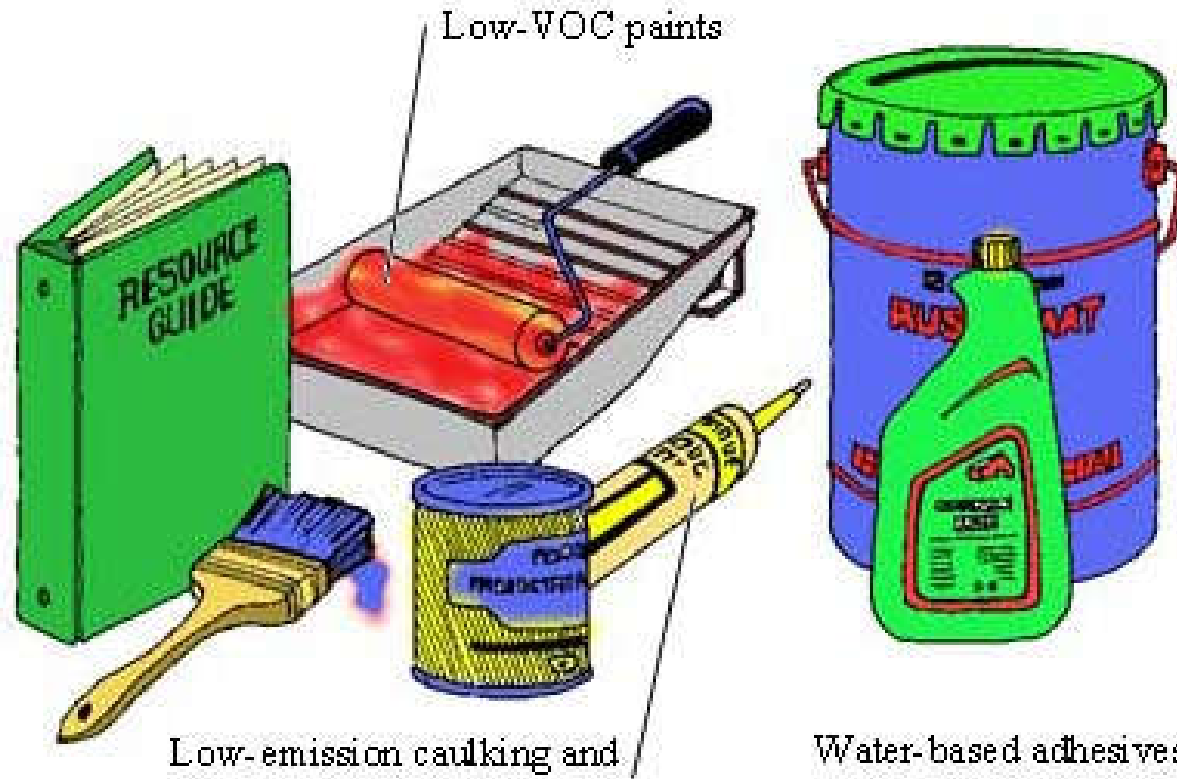
# Evaluation methods



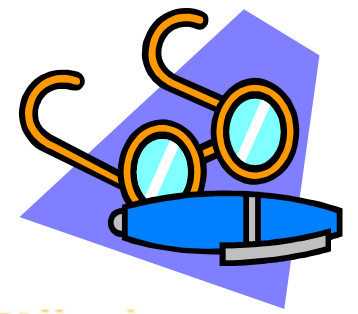
- Building phase

- 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

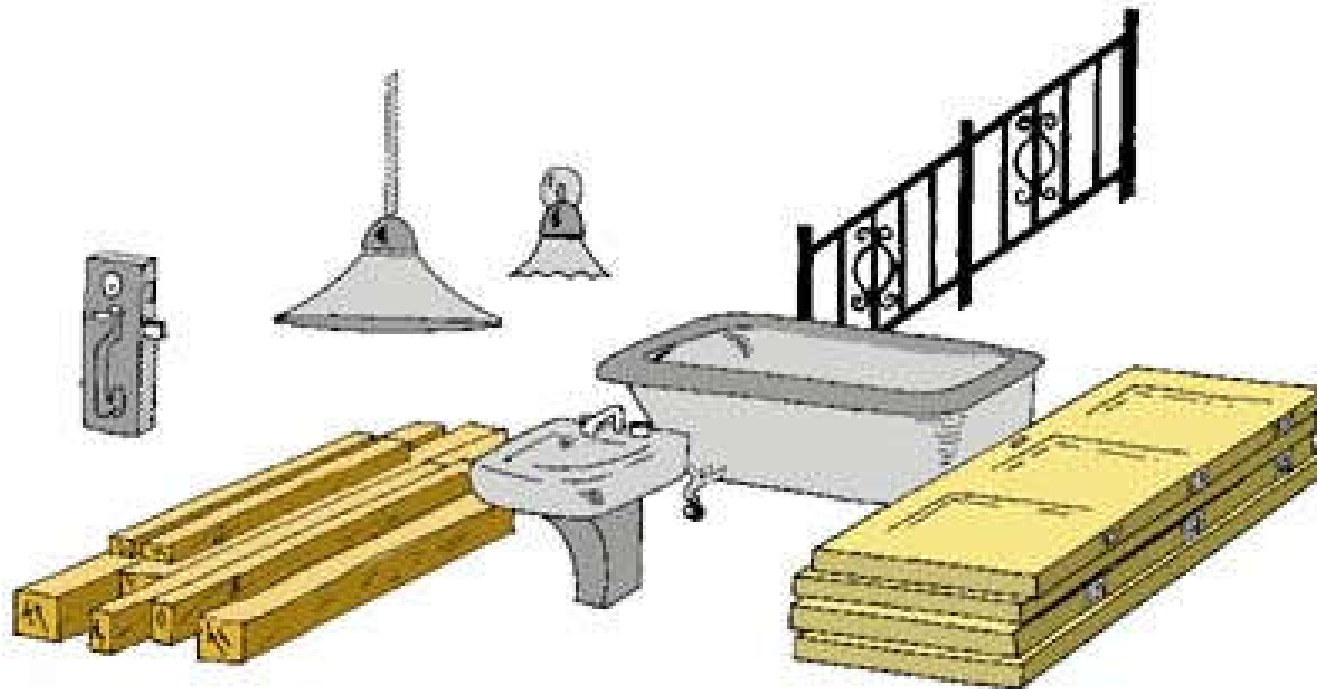
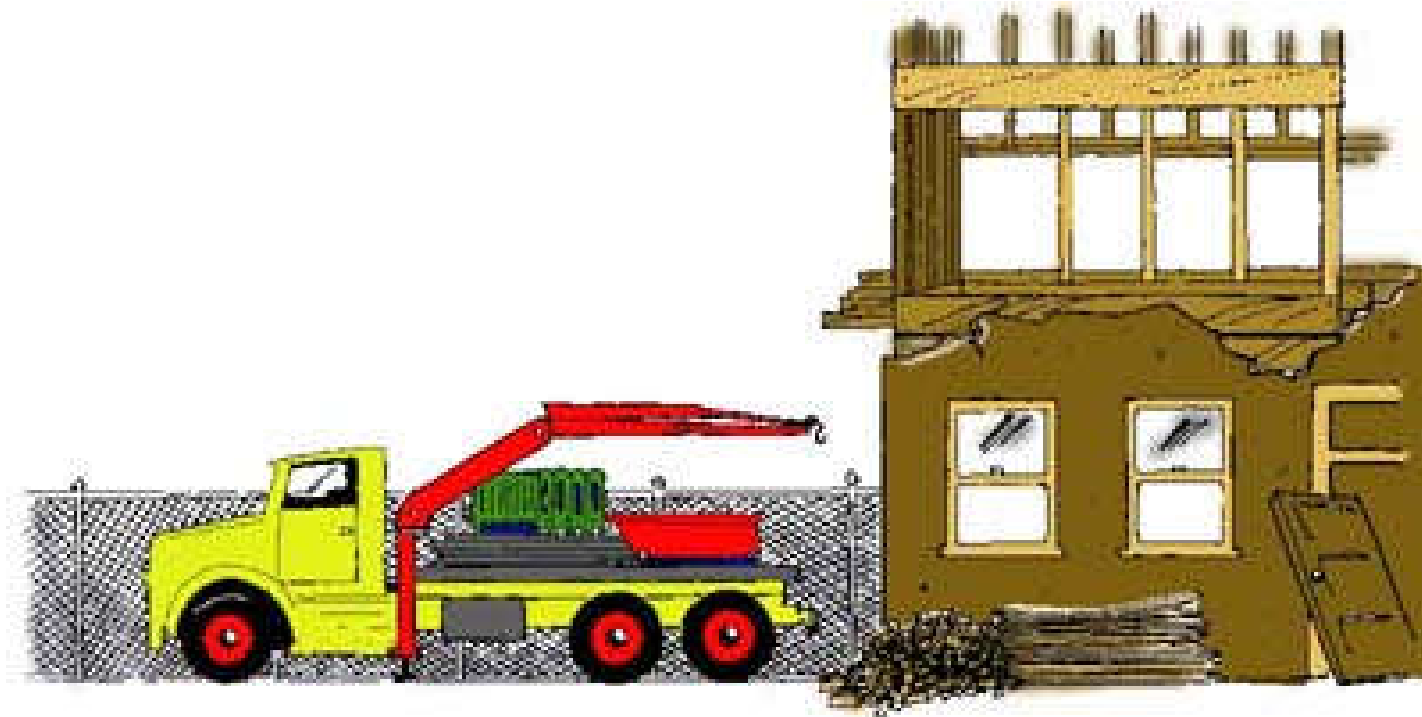


# Evaluation methods

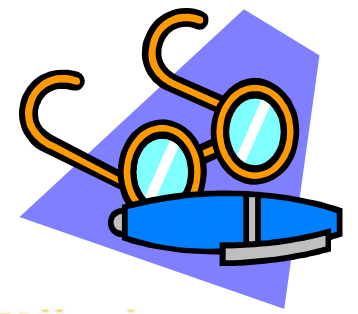


- Post-building phase
  - Demolition
    - Noise, air & water pollution during demolition
  - Disposal
    - Need for transportation, landfill, etc. for the waste
  - Reuse or recycling
    - Energy & water use
- “De-construction”
  - Building disassembly & materials salvage

# Separate recyclables from demolition and reuse salvaged materials



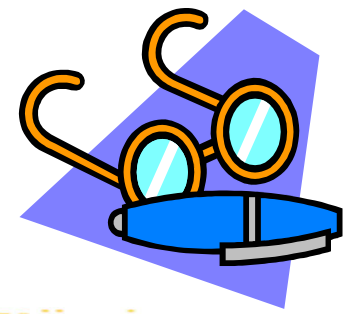
# Evaluation methods



- 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

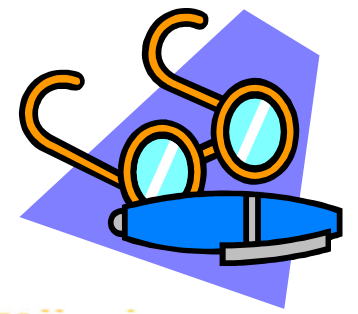


# Evaluation methods



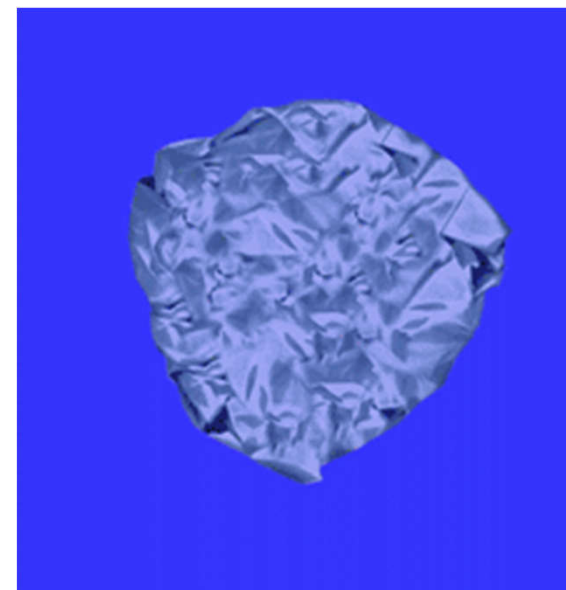
- Important considerations
  - Not just replace one material by another
  - Need to consider how the material is used
  - May require cultural change in design and in using the new materials
- Product to service shift
  - e.g. carpeting service (by Interface, Inc.)
  - Supplier to reuse or recycle the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

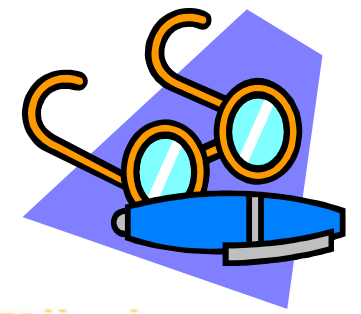
Purchase price & transportation costs of materials

+

Cost of storage, transport & disposal of waste

+

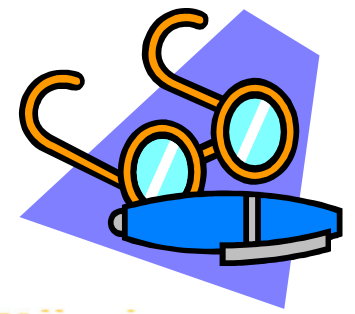
Loss of income from not salvaging waste materials



# Evaluation methods

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

# Evaluation methods



- LCA tools by Athena Sustainable Materials Institute <http://www.athenaSMI.ca/>

- Impact Estimator (for buildings)



**Athena**  
**Impact Estimator**  
for Buildings

- Evaluate whole buildings and assemblies based on LCA methodology



**Athena**  
**EcoCalculator**  
for Commercial Assemblies



**Athena**  
**EcoCalculator**  
for Residential Assemblies

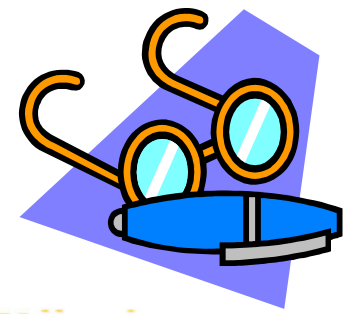
- EcoCalculator (for assemblies)

- Provides instant LCA results for more than 400 common building assemblies

- LCA inventory databases

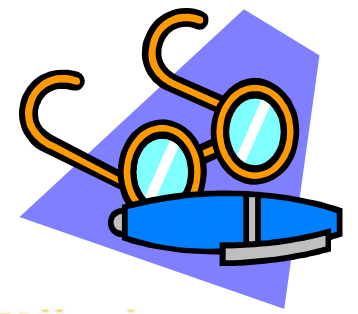
- Such as structural products and envelope products

# Evaluation methods



- Impact Estimator's summary measures format:
  - Embodied primary energy use (consumption)
  - Acidification potential
  - Global warming potential
  - Human health respiratory effects potential
  - Ozone depletion potential
  - Smog potential
  - Aquatic eutrophication potential
  - Weighted resource use

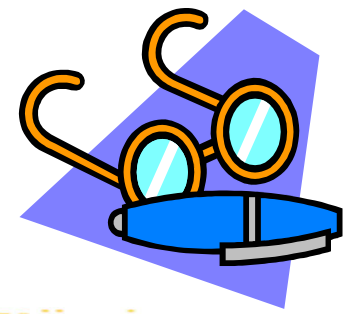
# Evaluation methods



- Impact Estimator's absolute values format:
  - Energy
  - Air emissions
  - Water emissions
  - Land emissions
  - Resource use
- Further information:
  - Impact Estimator for Buildings Tutorial
    - <https://calculatelca.com/resources/watch-tutorials/>



# Evaluation methods

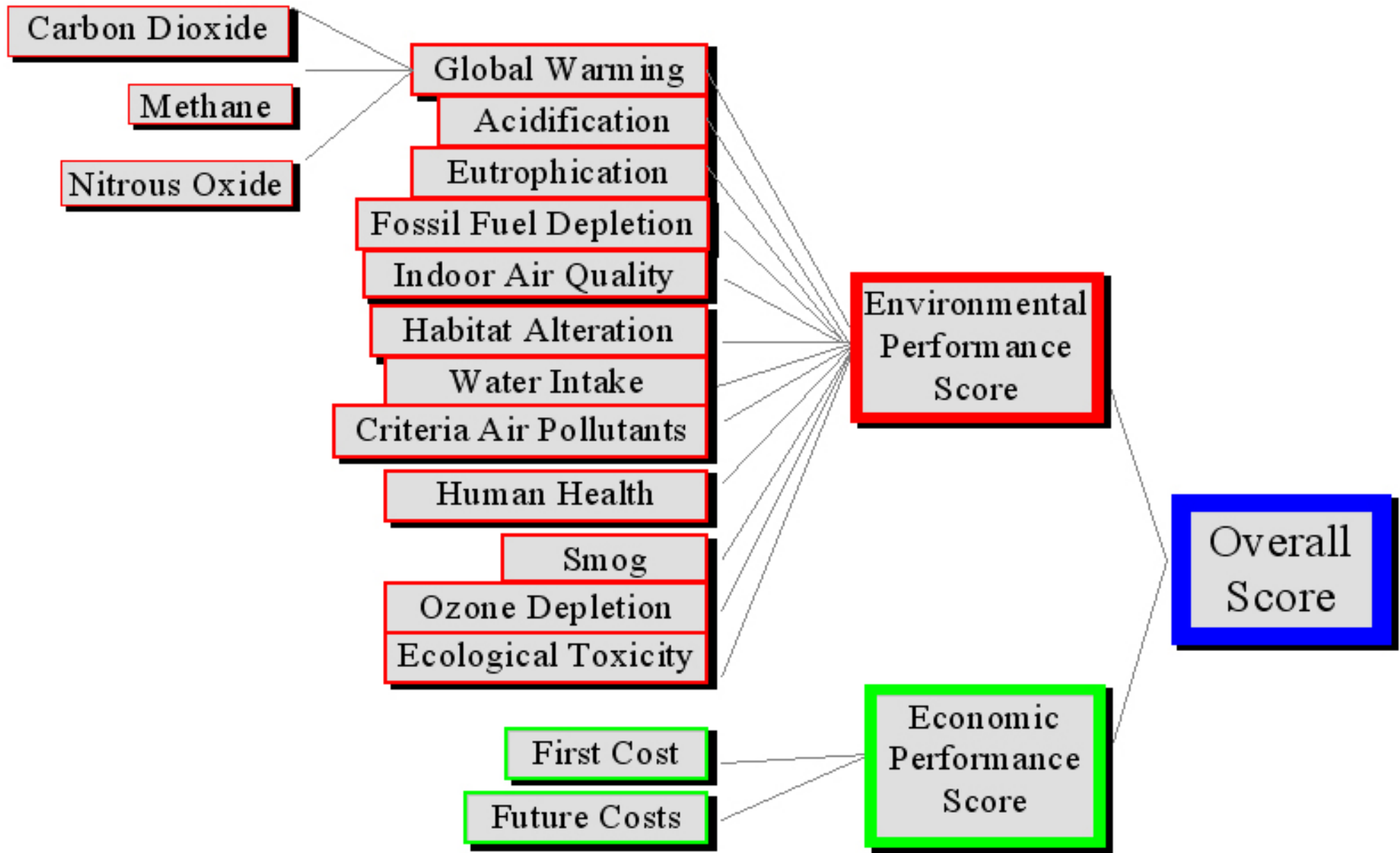


- BEES (Building for Environmental and Economic Sustainability) (USA)

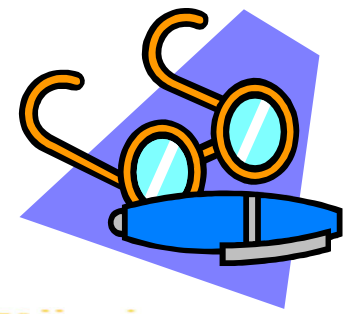


- <https://www.nist.gov/services-resources/software/bees>
- Developed by Building and Fire Research Laboratory of the National Institute of Standards and Technology (NIST)
- For measuring the life-cycle environmental and economic performance of building products
- BEES Online version is available now

# BEES (Building for Environmental and Economic Sustainability) Model



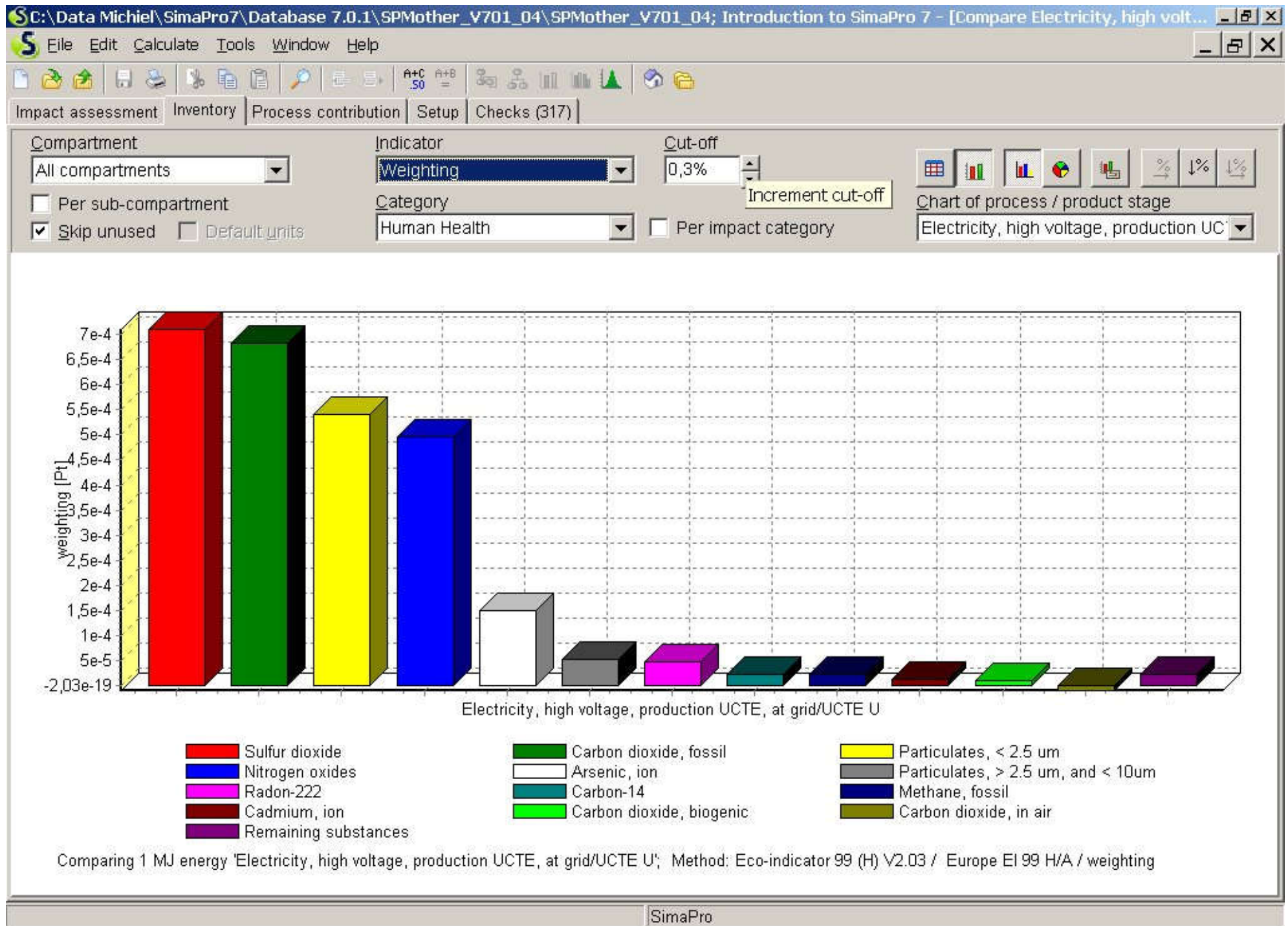
# Evaluation methods



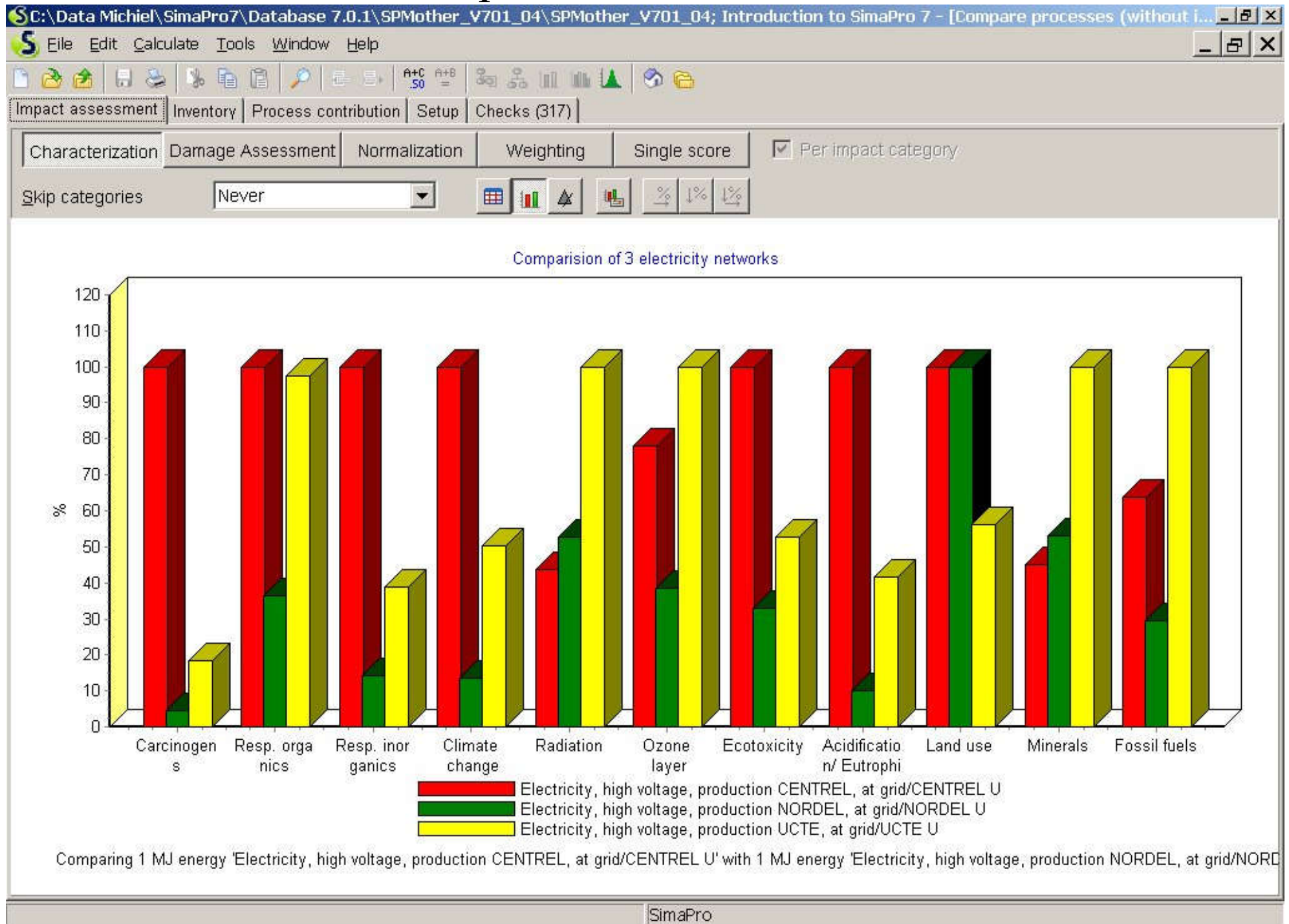
- SimaPro LCA software (by PRé Consultants)
  - <https://simapro.com/>
  - <http://www.pre.nl/simapro.html>
  - Tool to collect, analyze and monitor the environmental performance of products, processes and services
  - Follow the ISO 14040 series recommendations
  - SimaPro inventory databases



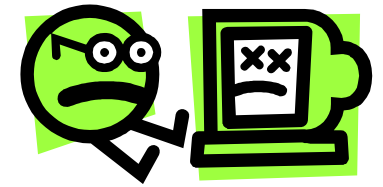
# Features of SimaPro



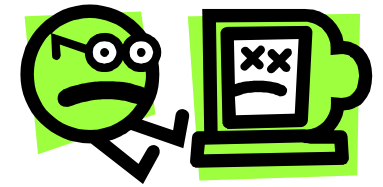
# Compare models in SimaPro



# Limitations of LCA

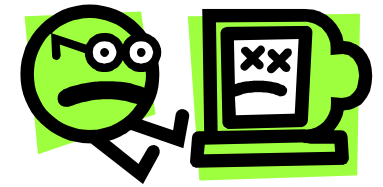


- Difficulties in LCA
  - Data quality and quantity is often not sufficient for a comprehensive LCA
  - A possible consequence of discrepancies in the data is that two independent studies analysing the same products may generate very different results. Ostensibly comparable LCA's may therefore be incomparable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



# Limitations of LCA

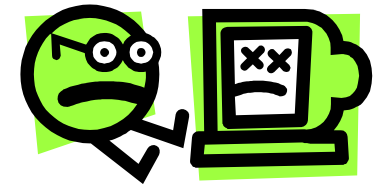
- LCA has attracted some criticisms
  - A lack of standardised information
  - Excessive detail that may be difficult to follow
  - Confusing the issues of human health with those of the environment (human- and eco-toxicity)
  - Weightings are lacking transparency and being subjective
    - It does not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



# Limitations of LCA

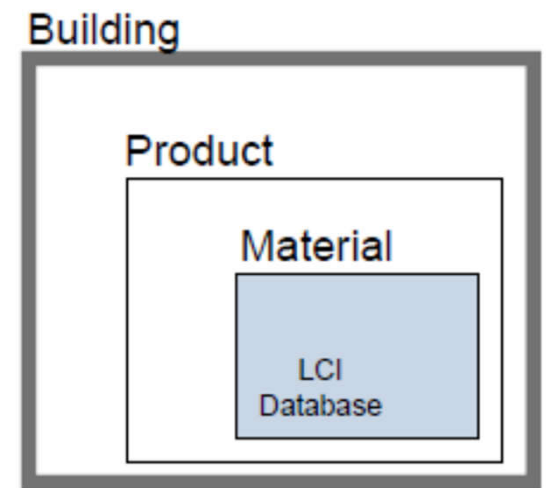
- Problems of LCA:
  - The cost is high, since collecting appropriate data is time consuming
  - Where there are gaps in the data, assumptions have to be made
  - It only provides a snapshot view based on data at the time of collection
  - It does not integrate environmental impact with the social and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

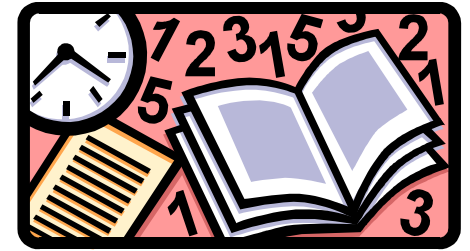




# Limitations of LCA

- LCA as a source of strategic insight for quantifying impacts and see if we can improve
- Must ensure the LCA methodology used is understood and clear (transparency)
- Options for incorporating LCA in green building design:
  - 1. Product or material level
  - 2. Assembly level
  - 3. Whole building level





# References

- AIA, 2010. *AIA Guide to Building Life Cycle Assessment in Practice*, American Institute of Architects (AIA), Washington, DC.  
<https://www.aia.org/resources/7961-building-life-cycle-assessment-in-practice>
- LCA (Life Cycle Assessment) Training Kit Material  
<https://www.lifecycleinitiative.org/resources/training/lca-life-cycle-assessment-training-kit-material/>
- Life Cycle Assessment (LCA) – Complete Beginner's Guide <https://ecochain.com/knowledge/life-cycle-assessment-lca-guide/>