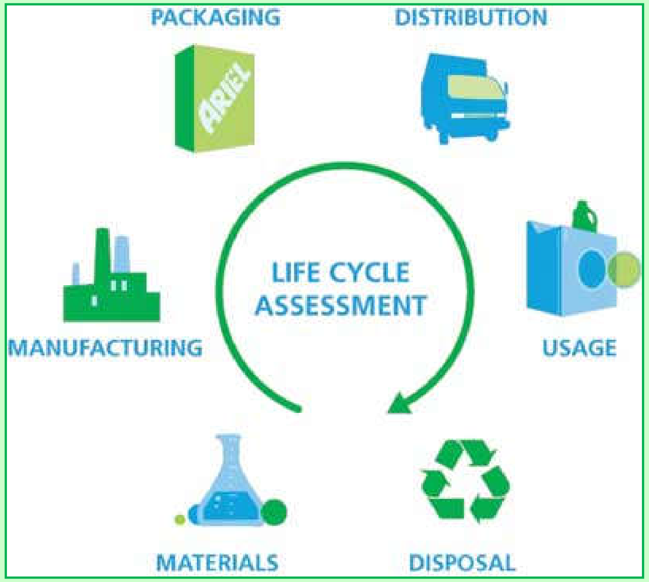
MEBS6020 Sustainable Building Design

http://ibse.hk/MEBS6020/



Energy and Environmental Design (II)

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- LCA process
- Examples of LCA
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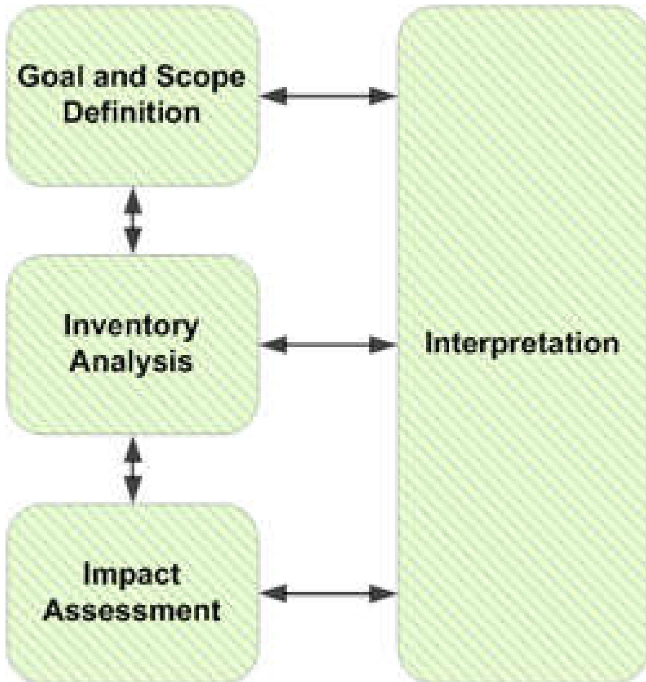
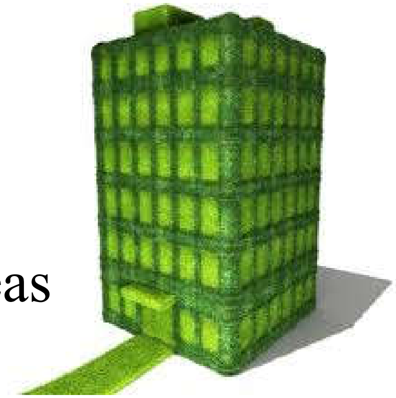
- Limitations of LCA



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

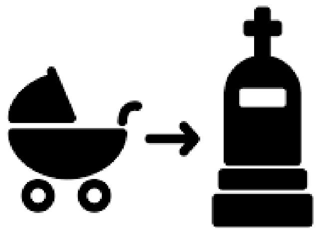
LCA = 生命週期評估

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



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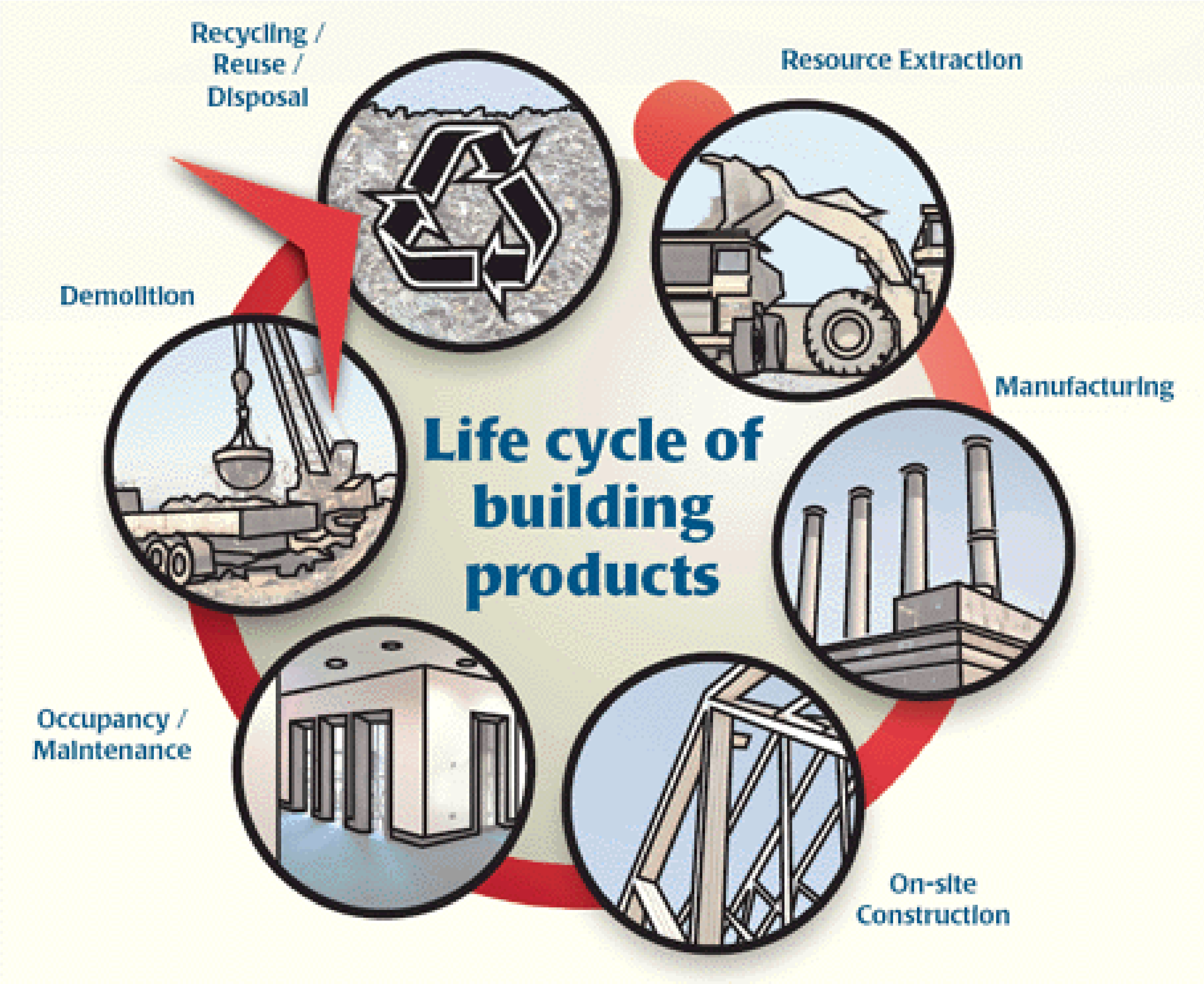
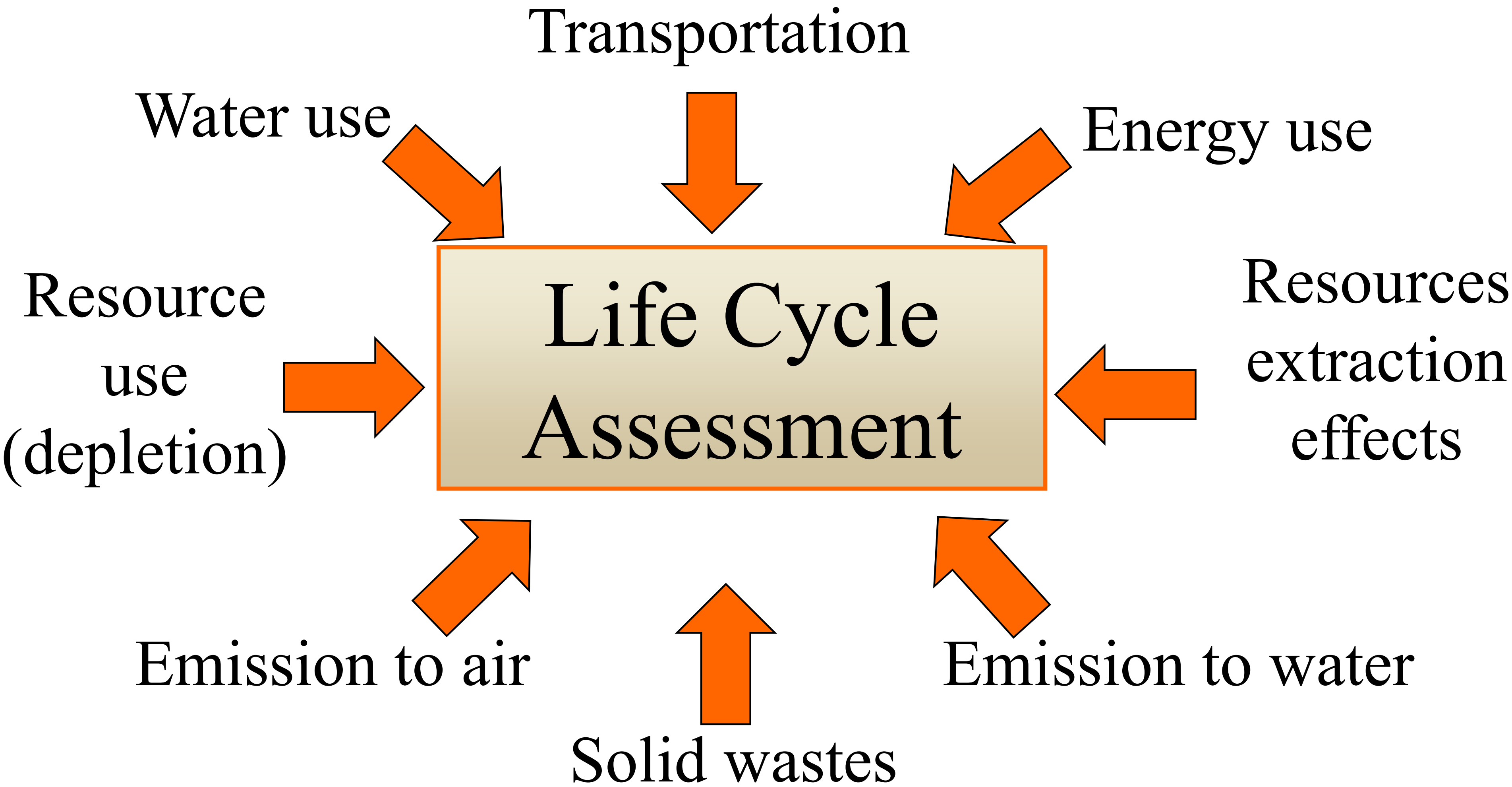
- Embodied effects include:
  - Resource use (raw materials, land, water, energy)
  - Emissions to air, water and land

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



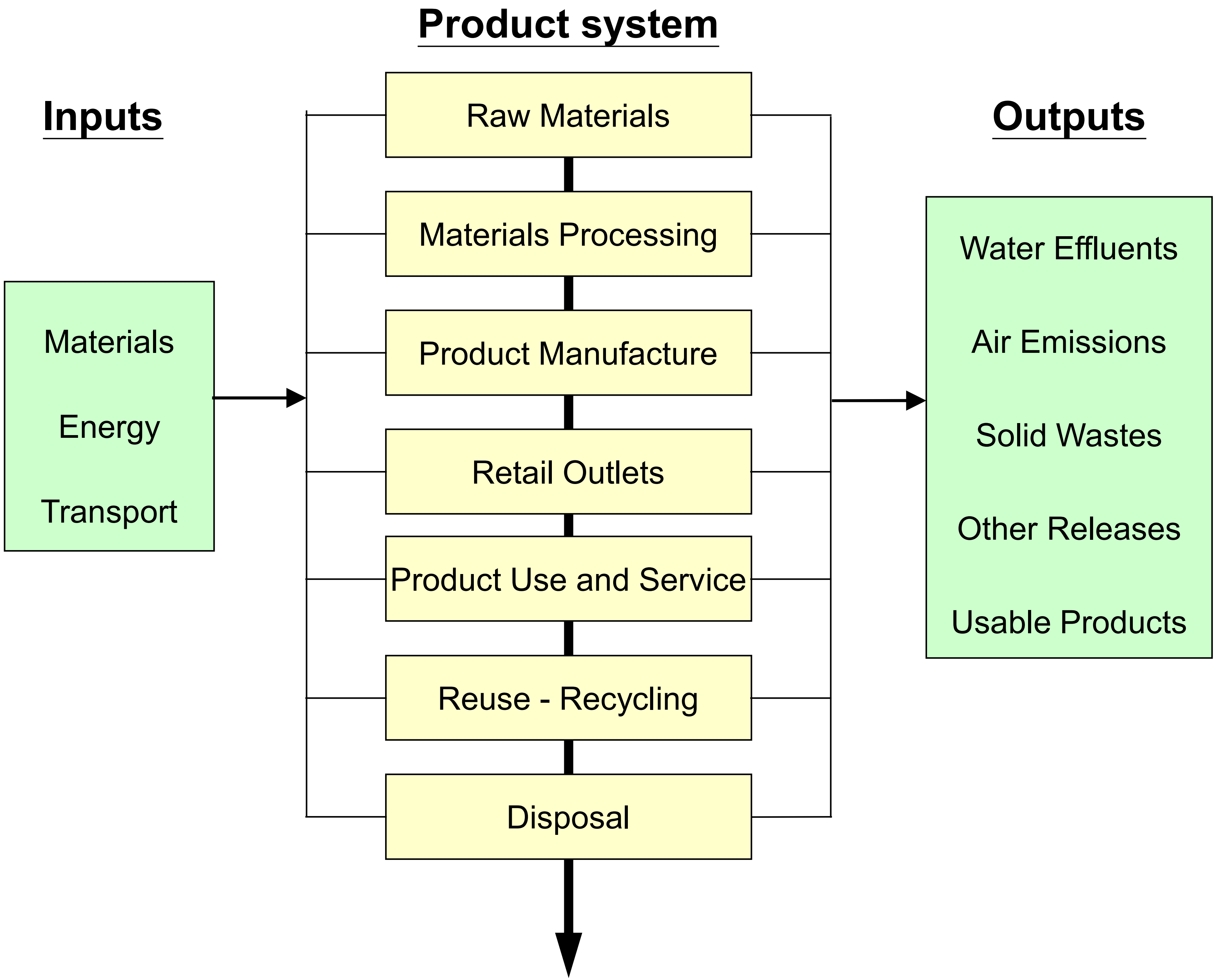
(Source: Athena Sustainable Materials Institute http://www.athenasmi.org)



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

(Source: Athena Sustainable Materials Institute http://www.athenasmi.org)

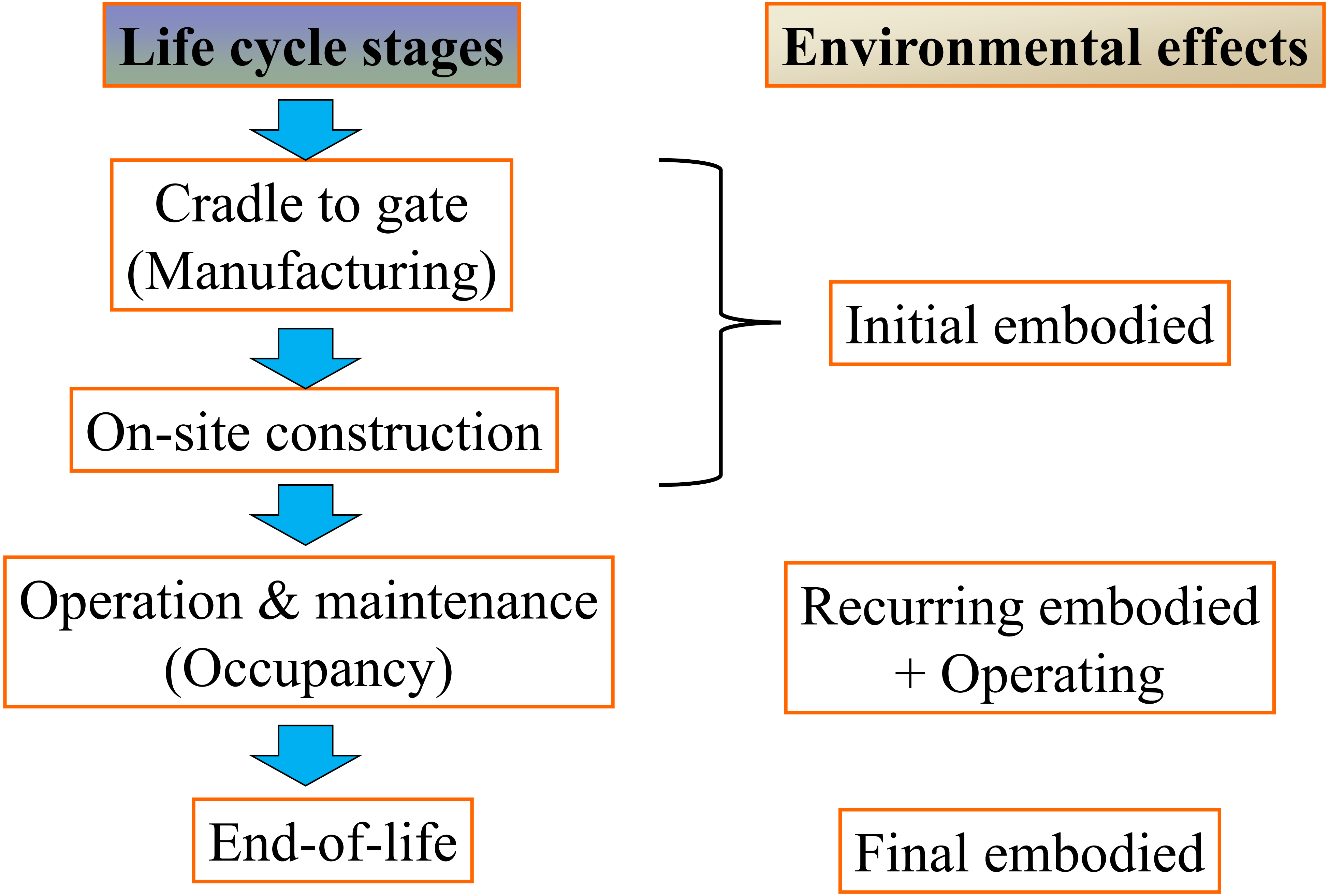
Areas covered by LCA



T-shirt example (cotton)

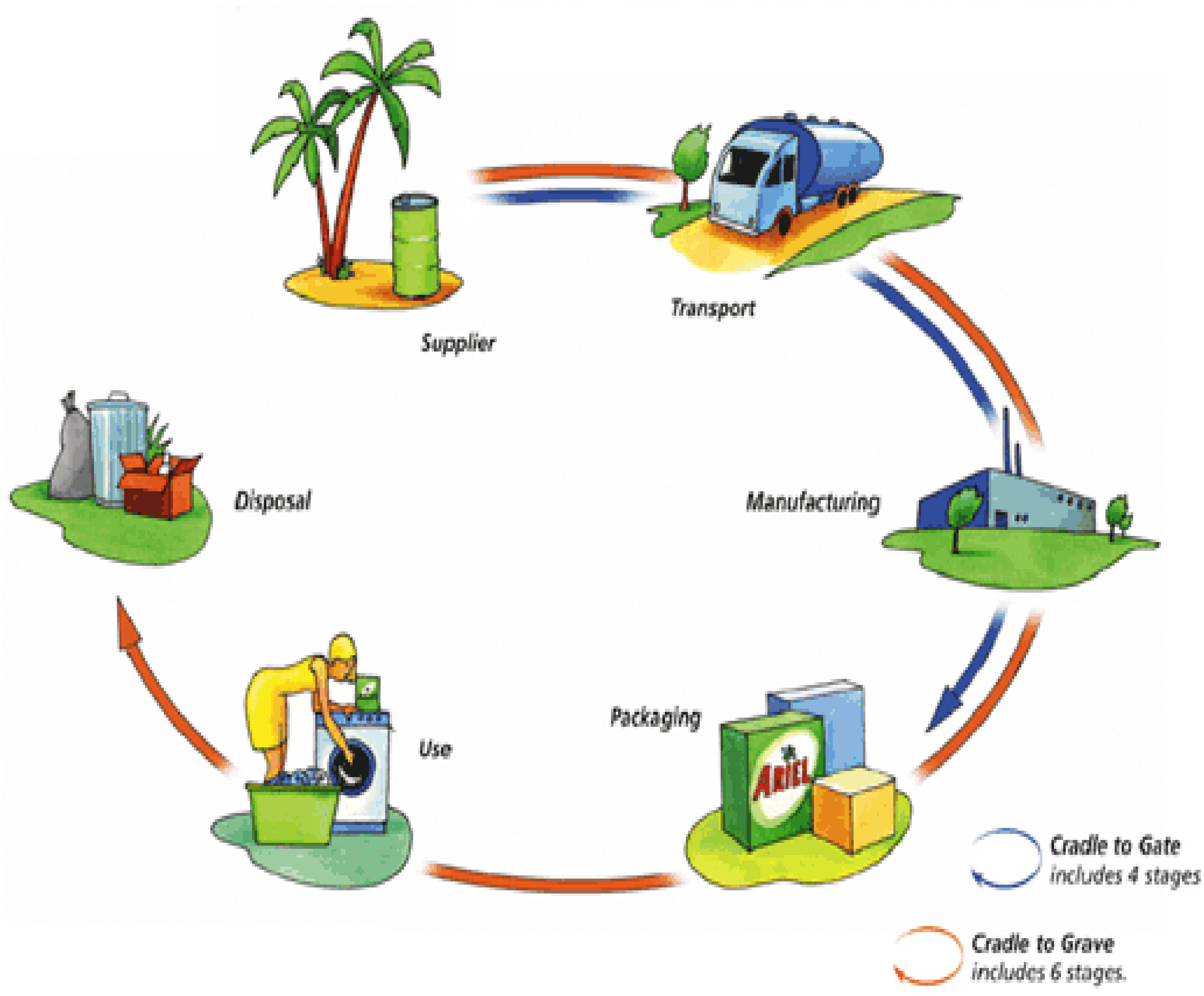
• Growing • Harvesting	Extraction of materials
• Spinning • Weaving/knitting	Processing of materials
• Bleaching, dyeing, washing and treatment • Cutting and sewing	Production
• Use - reuse	Use and maintenance
• Disposal - recycling	Disposal/end of life

Life cycle stages and effects



(Source: Athena Sustainable Materials Institute http://www.athenasmi.org)

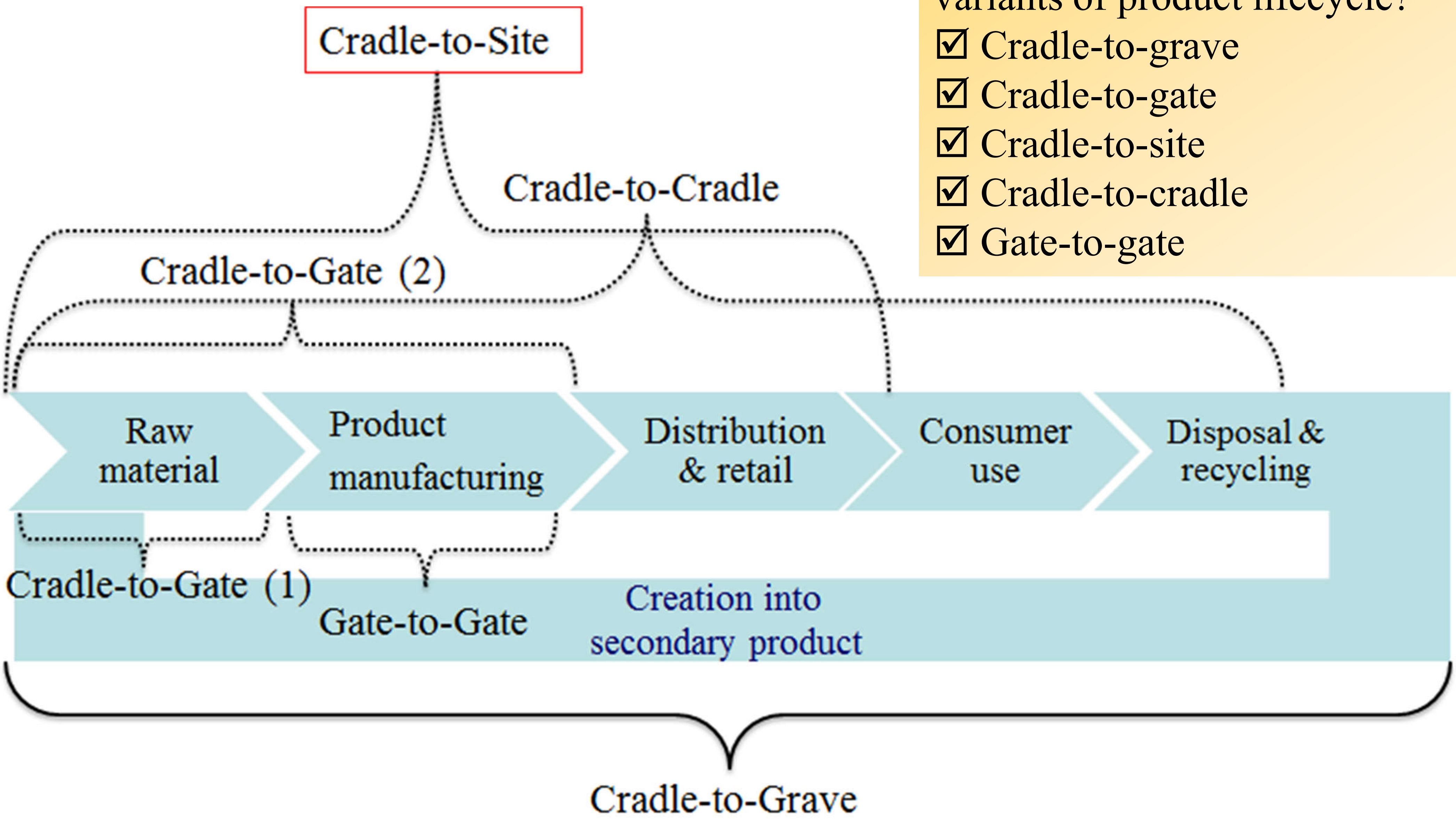
‘Cradle to Gate’ (4 stages) and ‘Cradle to Grave’ (6 stages)



Life cycle boundary and variants of LCA

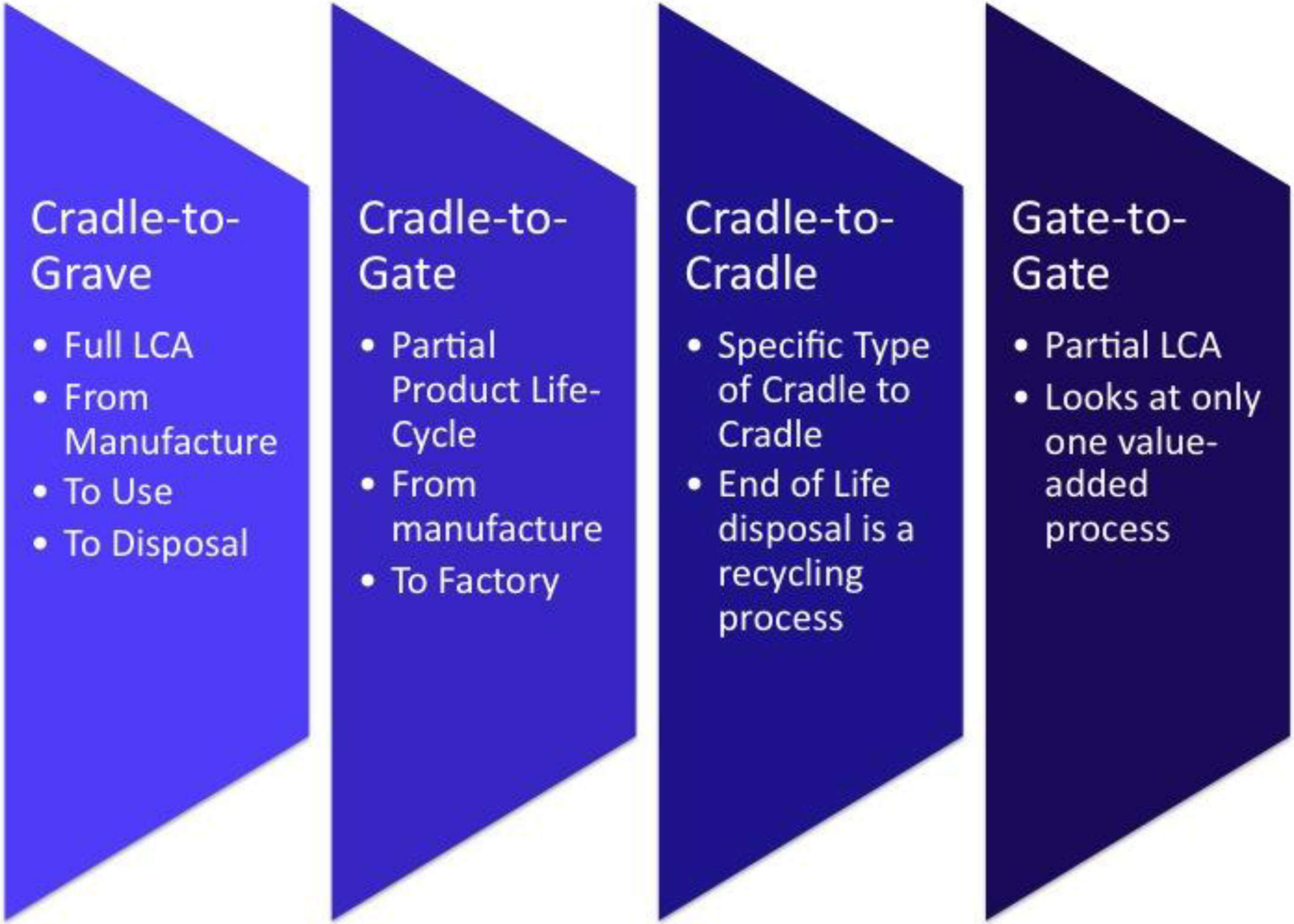
Do you know the other variants of product lifecycle?

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



(Image source: Life Cycle Boundary http://cejcheng.people.ust.hk/ec/methodologyLCB.html)

Different options of life cycle assessment



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

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

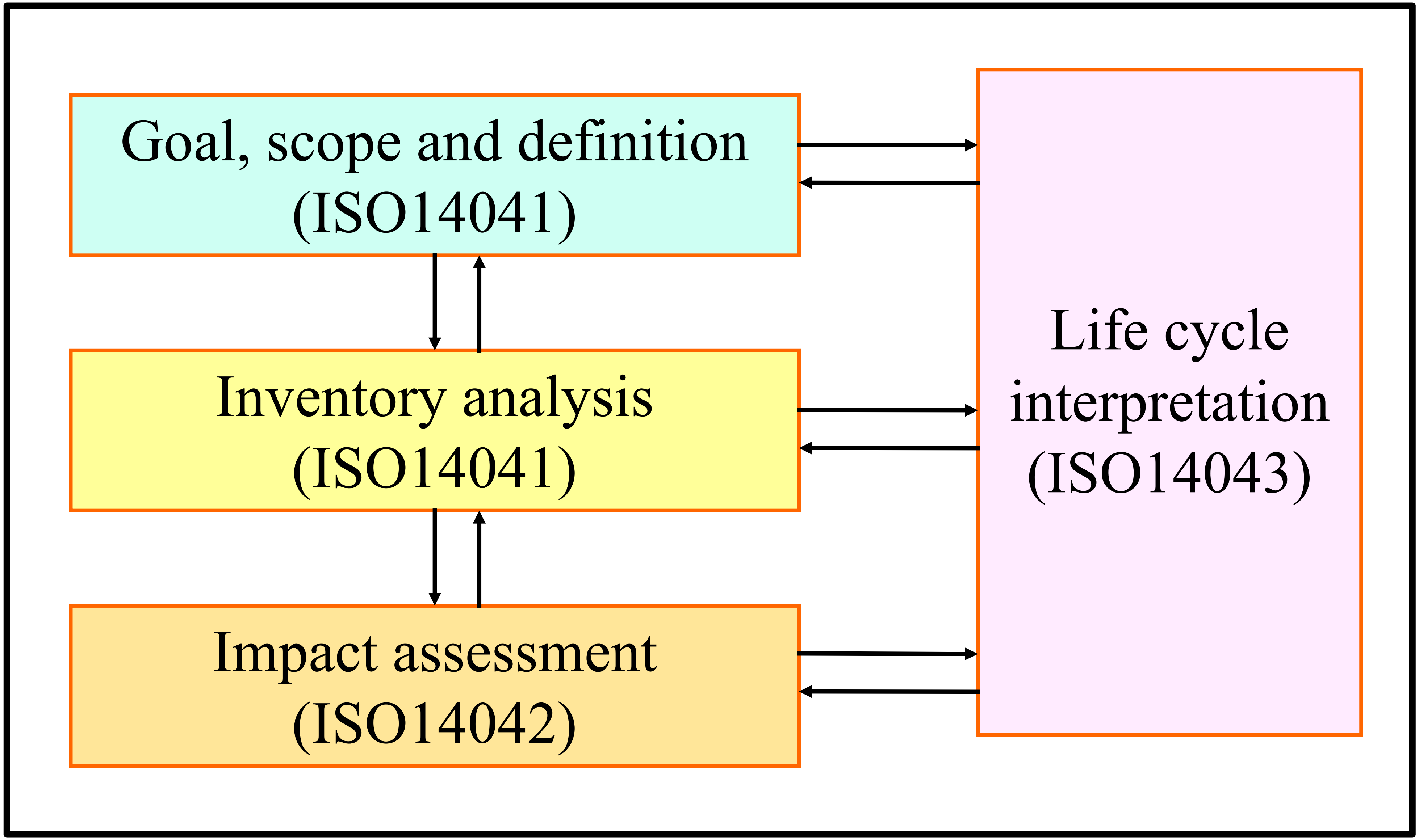
LCA process

- 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 (related ISO standard)



(Source: US-EPA & ISO)

LCA process

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

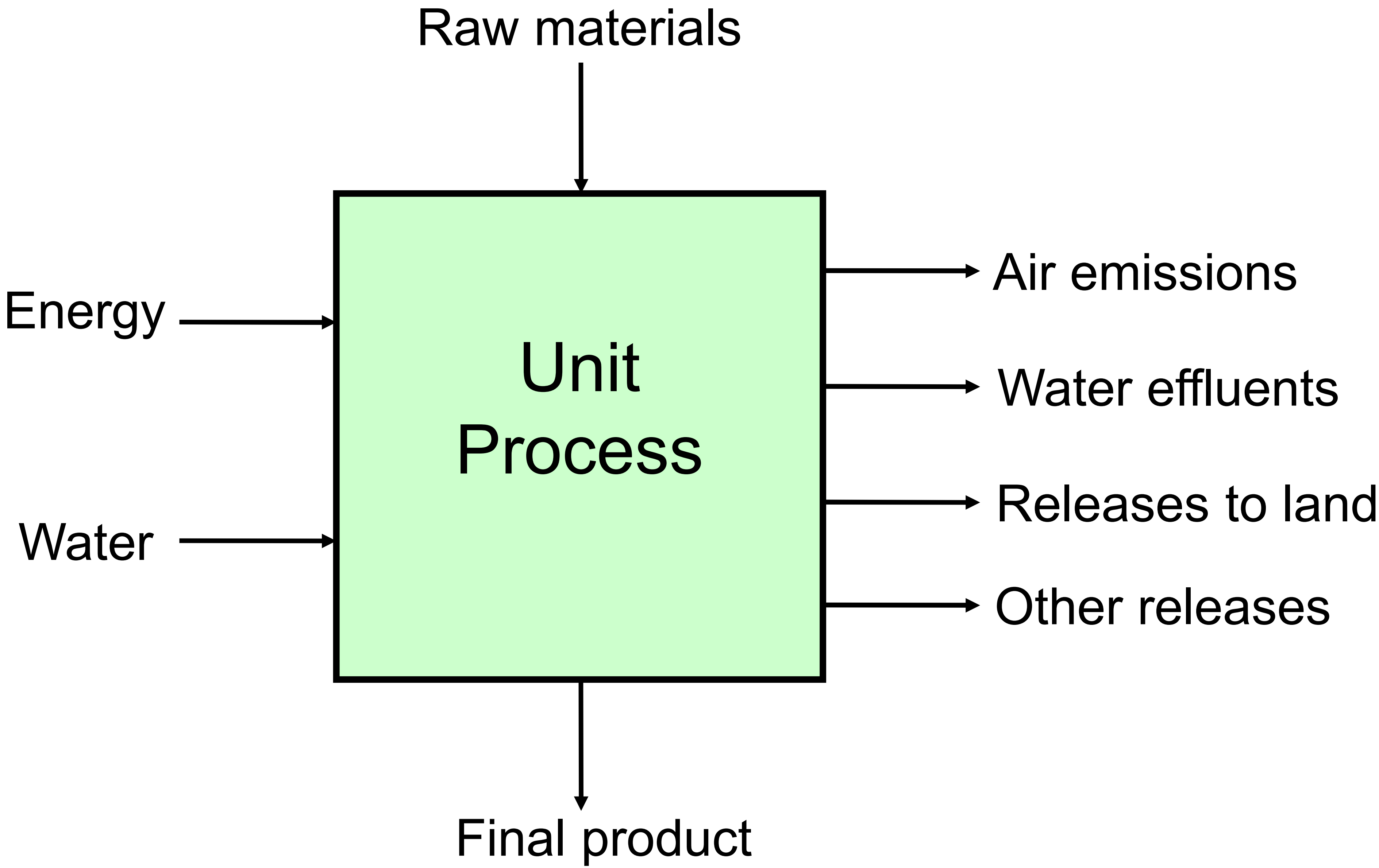
LCA process

- 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

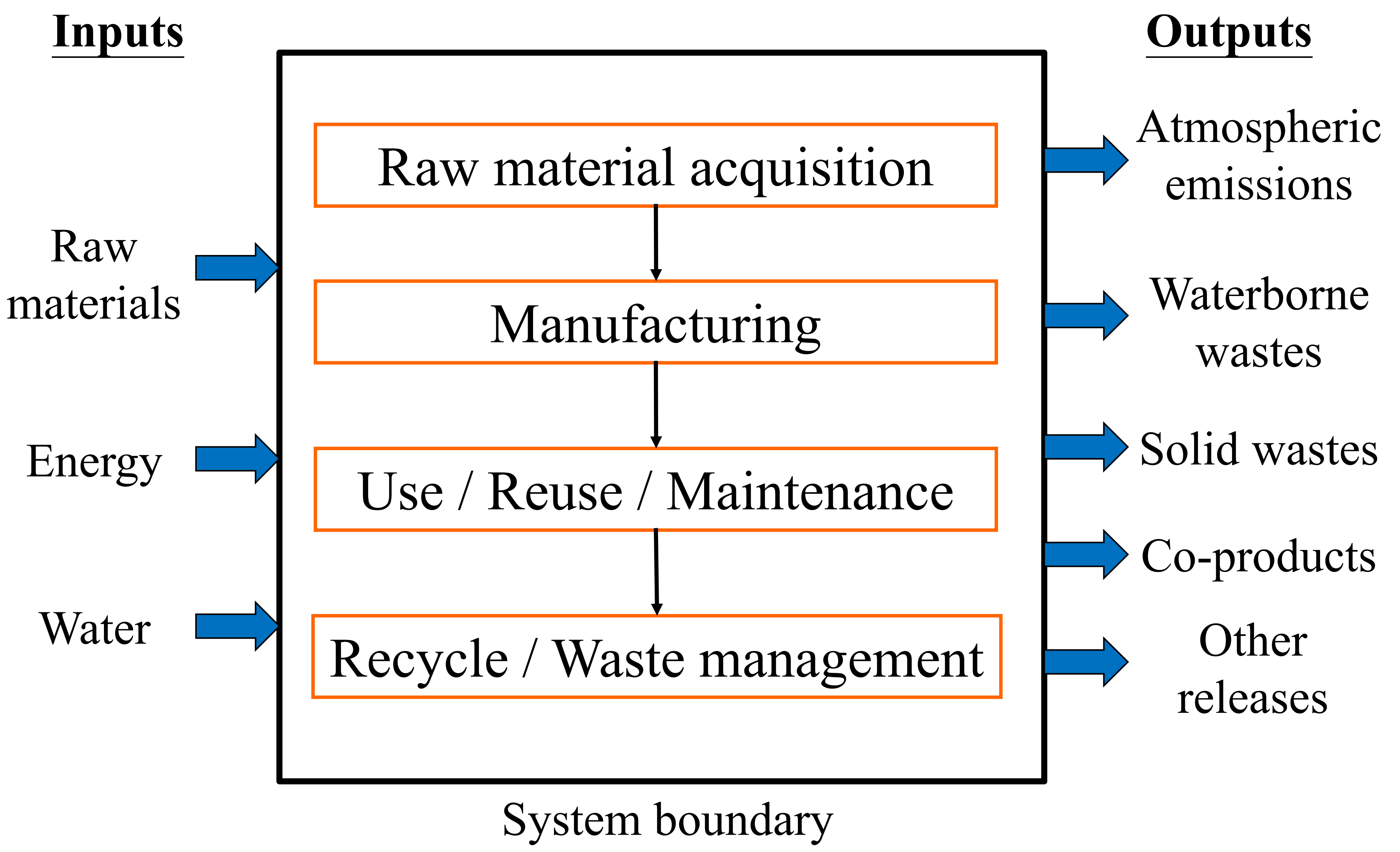
LCA process

- 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

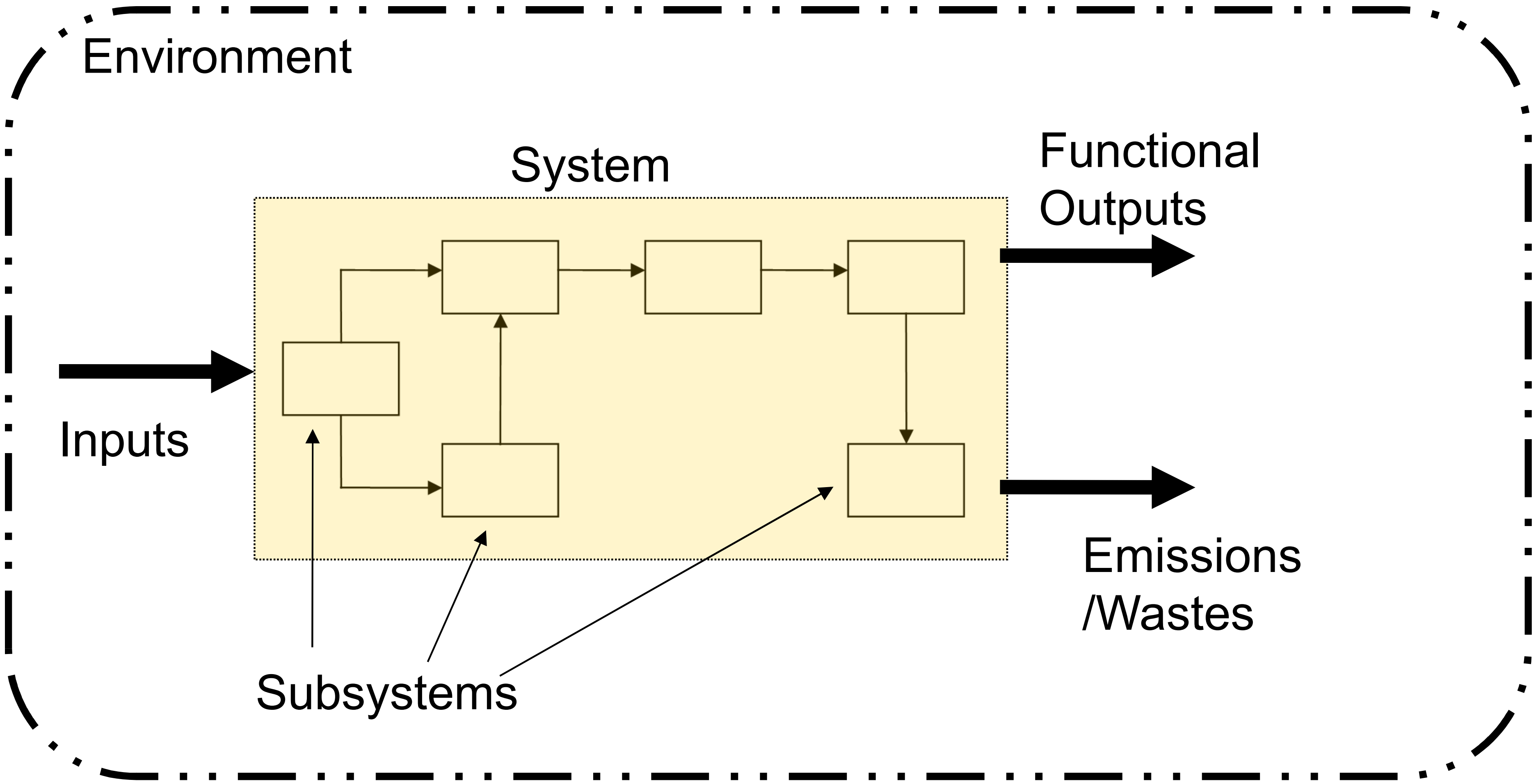


Life cycle stages and system boundary



(Source: US-EPA)

Life cycle inventory analysis

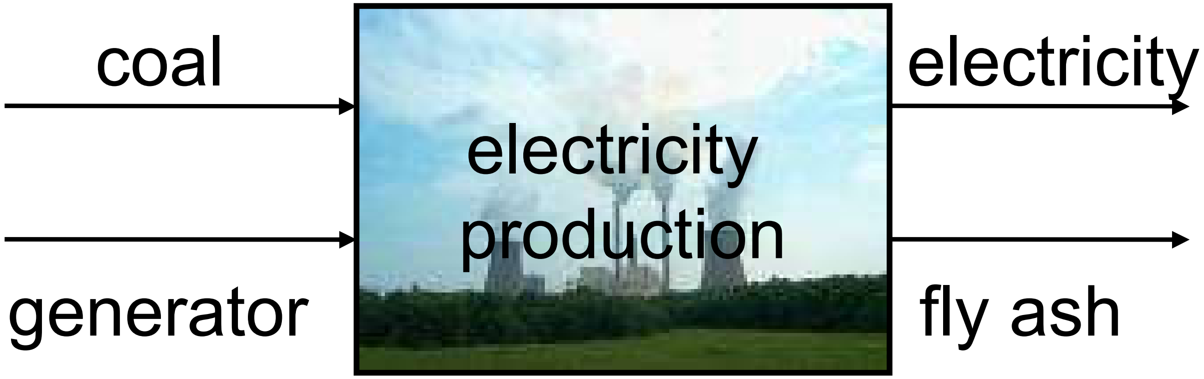


LCA process

- 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

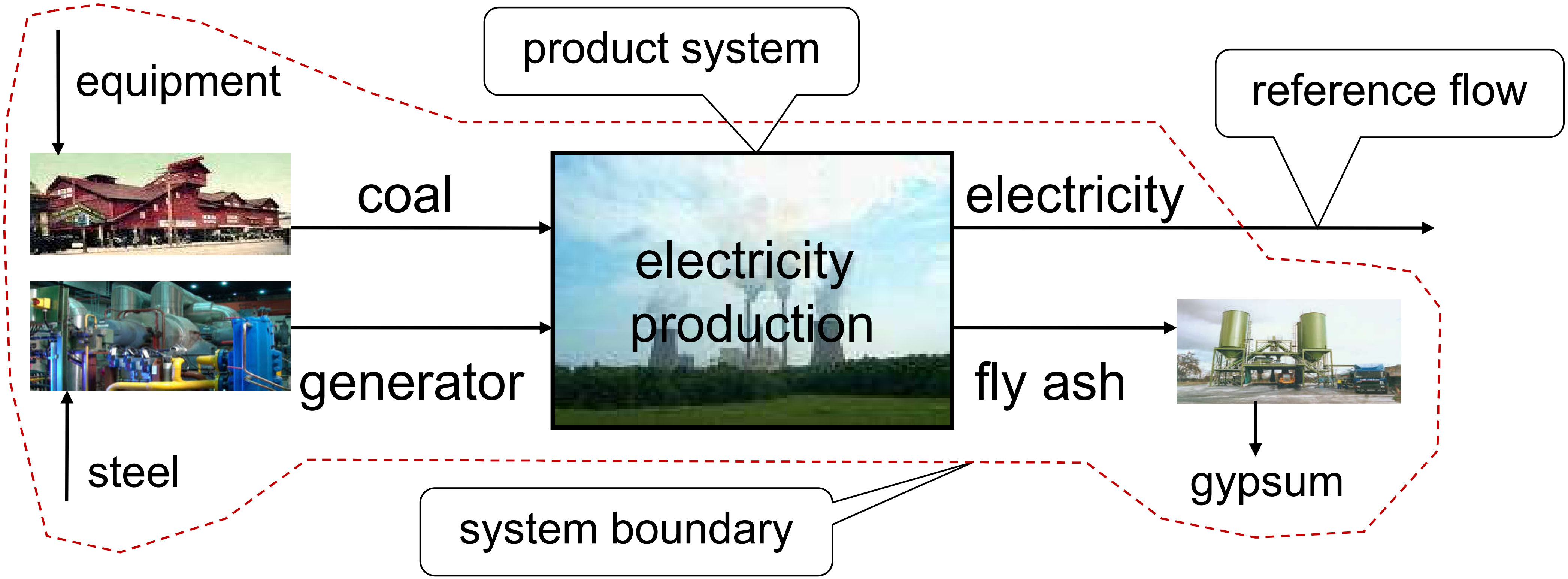
LCA process

- 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

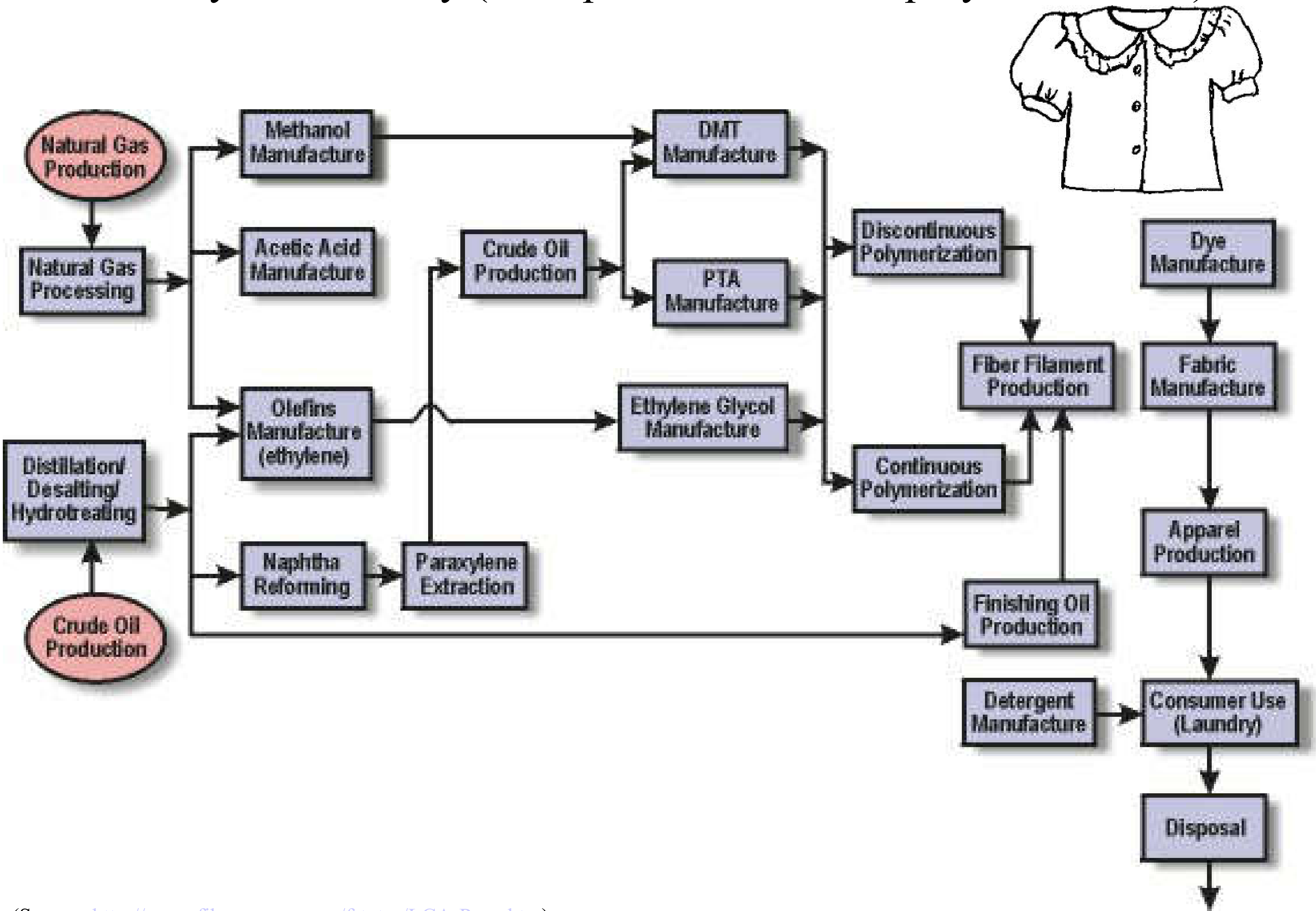


LCA process

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



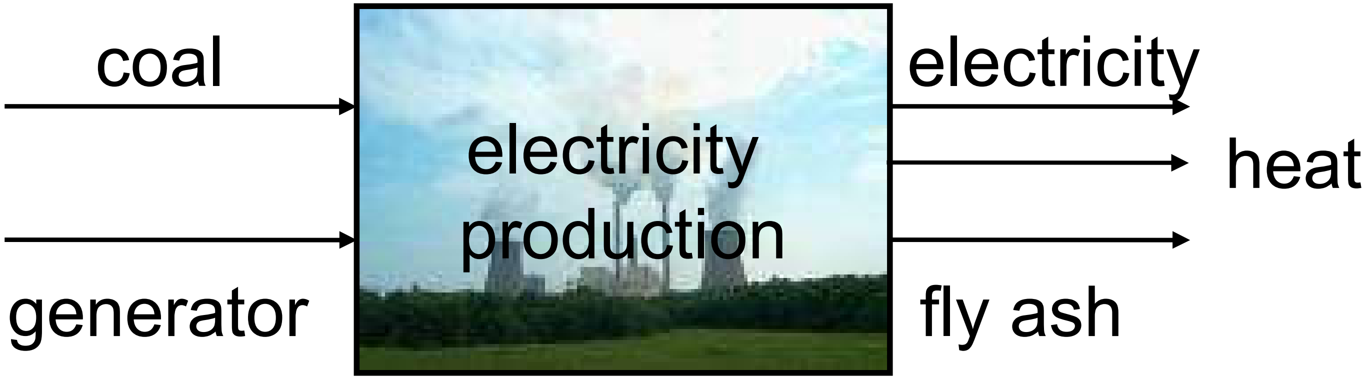
Life cycle inventory (example: woman's knit polyester blouse)



(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

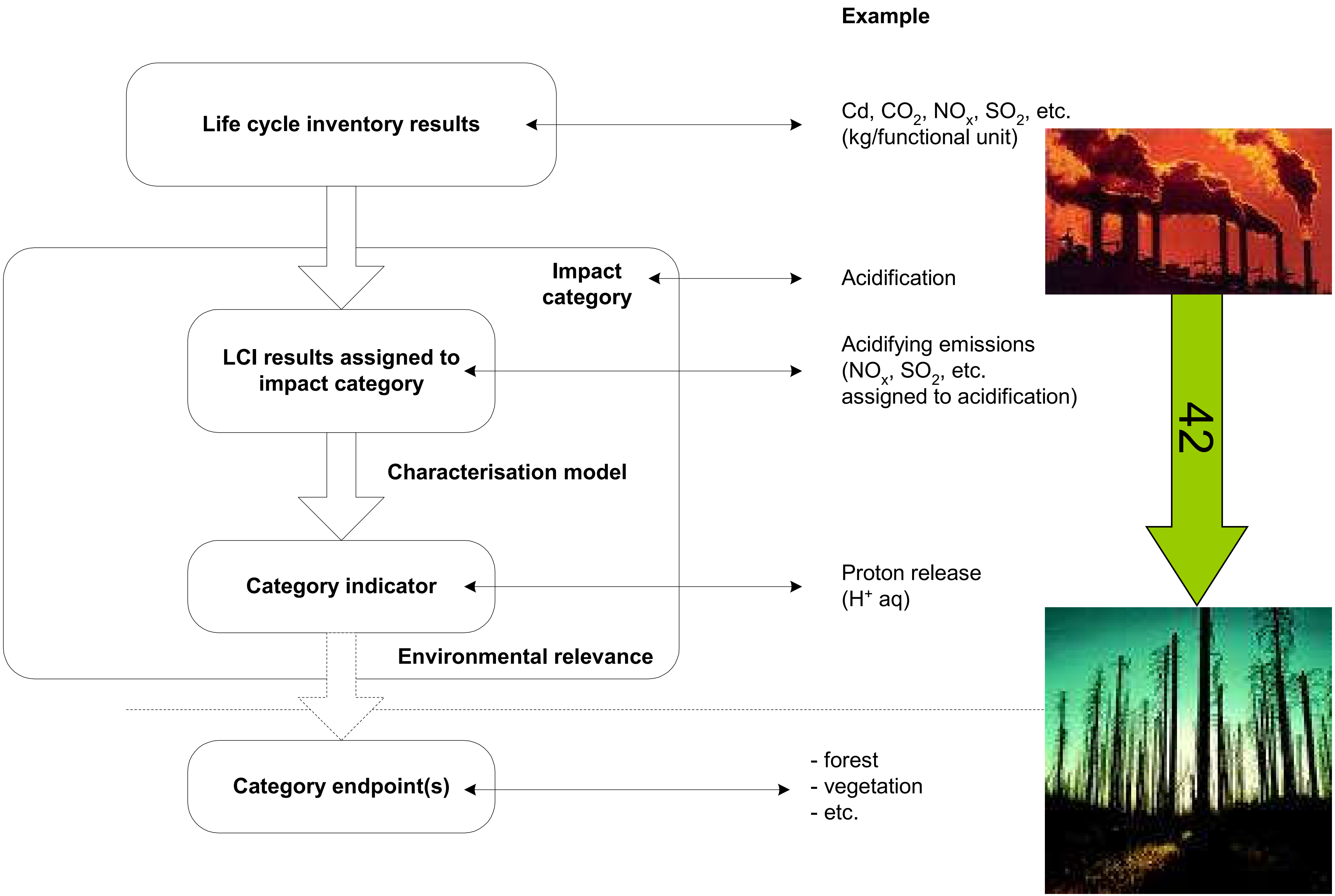
Elementary flow	Incandescent lamp	Fluorescent lamp
CO_2 to air	800000 kg	50000 kg
SO_2 to air	1000 kg	80 kg
Copper to water	3 g	20 g
Crude oil from earth	37000 kg	22000 kg
etc	…	…

(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)

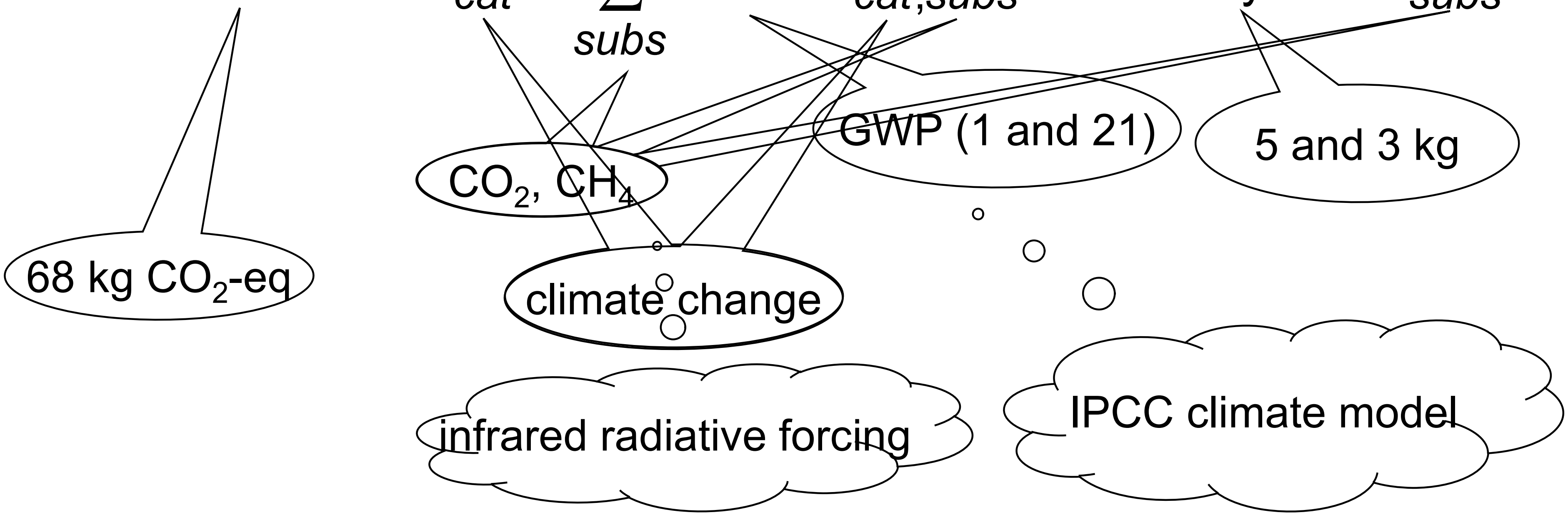
LCA process

- 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):

$$\text{IndicatorResult}_{cat} = \sum_{subs} \text{CharFact}_{cat,subs} \times \text{InventoryResult}_{subs}$$



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

impact category	category indicator	characterisation model	characterisation factor
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
...	...	...	...

(Source: UNEP LCA Training Kit)

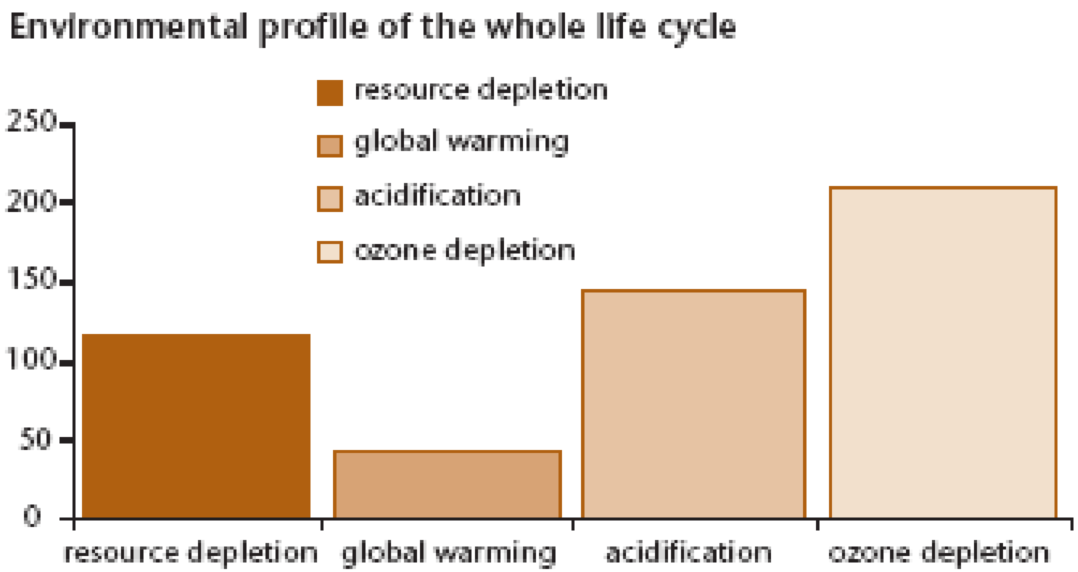
Example: Incandescent and fluorescent lamps – impact assessment

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)

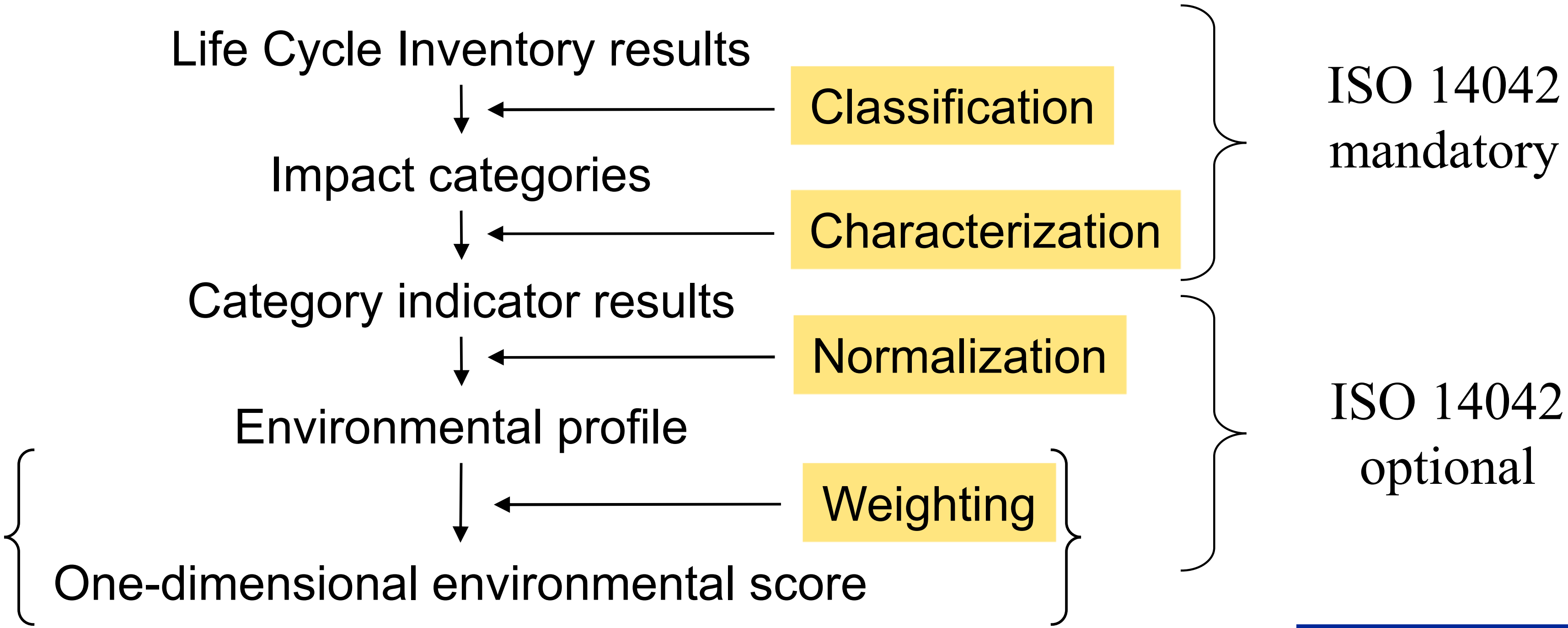
LCA process

- 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:

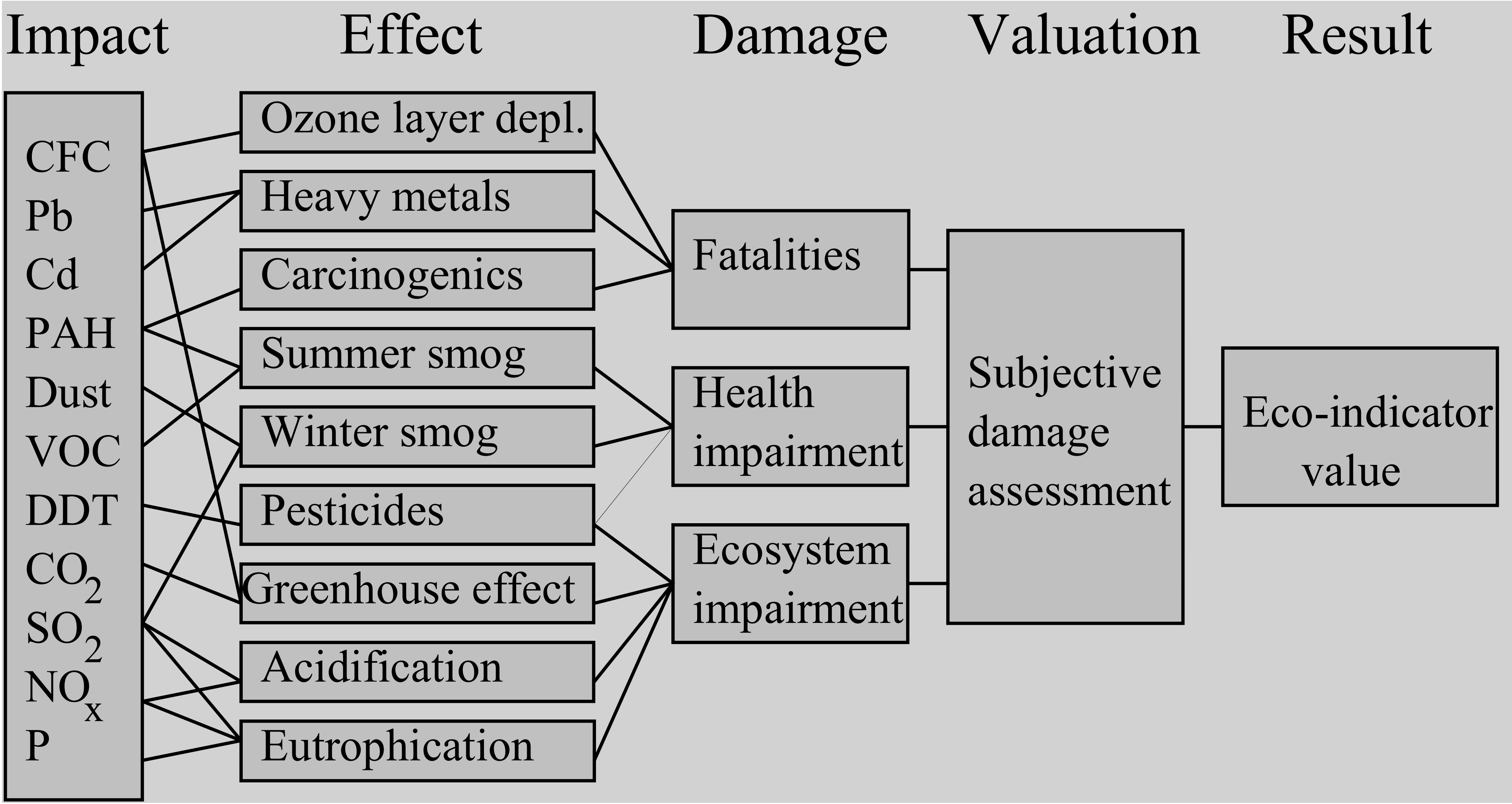
Weighed index	Incandescent lamp	Fluorescent lamp
Weighted index	8.5×10^{-10} yr	1.4×10^{-10} yr

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

LCA process

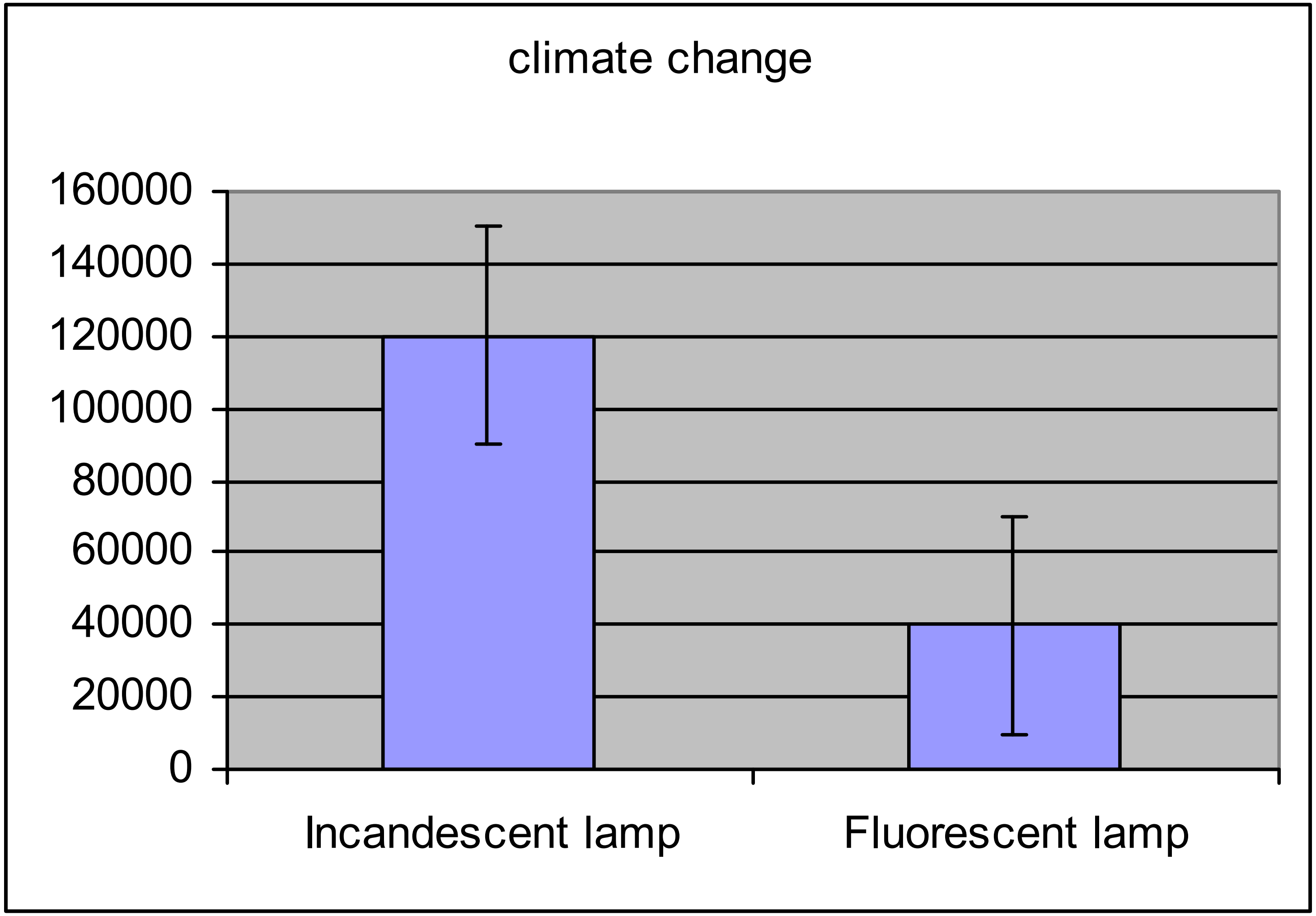
- 4) Life cycle interpretation (cont'd)
  - Identifies areas for improvement within a system
    - Reliant on the user noticing not only areas which have significant environmental effects but also those with smaller effects where changes could be made easily
  - Conclusions, recommendations, analysis,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



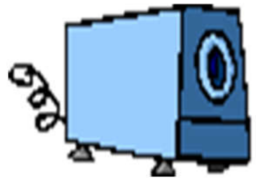
(Source: UNEP LCA Training Kit)

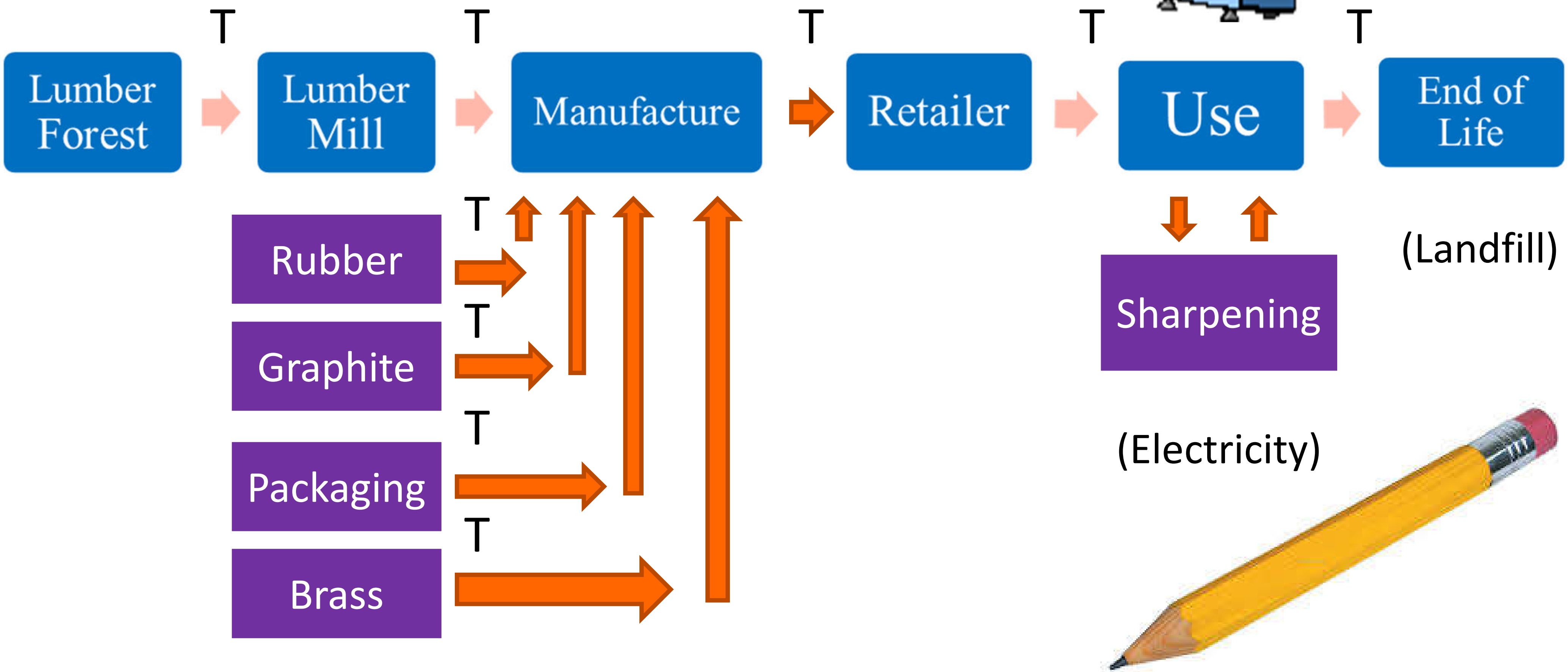
Example of life cycle assessment: Wooden Pencil vs. Mechanical Pencil

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

Rubber →(T) Manufacture

Graphite →(T) Manufacture

Packaging →(T) Manufacture

Spring →(T) Manufacture

(Landfill)

T = Transportation

(Source: Dr. Michael Lepech, Stanford University)

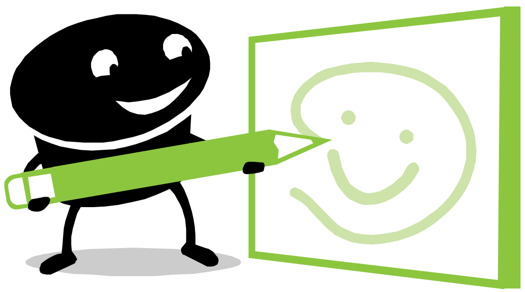
Function & Functional Unit

Function

- Service provided by a system
- What it does!

Functional Unit

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

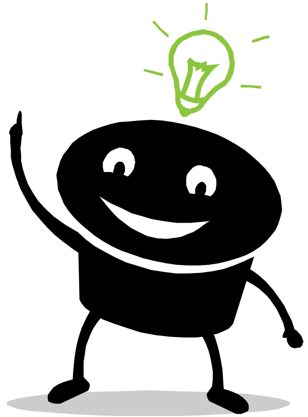


Example

Wooden Pencil vs. Mechanical Pencil

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

(Source: Dr. Michael Lepech, Stanford University)



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

(Source: Dr. Michael Lepech, Stanford University)

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:

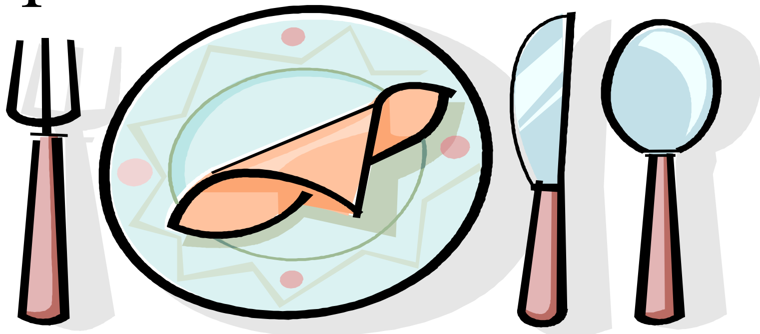
Covers all the areas outlined in the scope

(Source: Dr. Michael Lepech, Stanford University)

LCA in Action: Think About It!

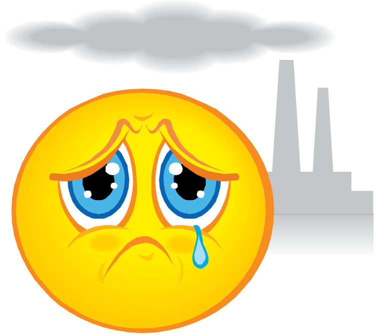
Paper Plate vs. China (Plate You Wash & Reuse)

- ✓ 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?

(Source: Dr. Michael Lepech, Stanford University)



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_2 , CH_4 , ozone, NO_2

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

(Source: Dr. Michael Lepech, Stanford University)

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!!

(Source: Dr. Michael Lepech, Stanford University)

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.

(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 (SOx, NOx, NH3)

Eutrofication

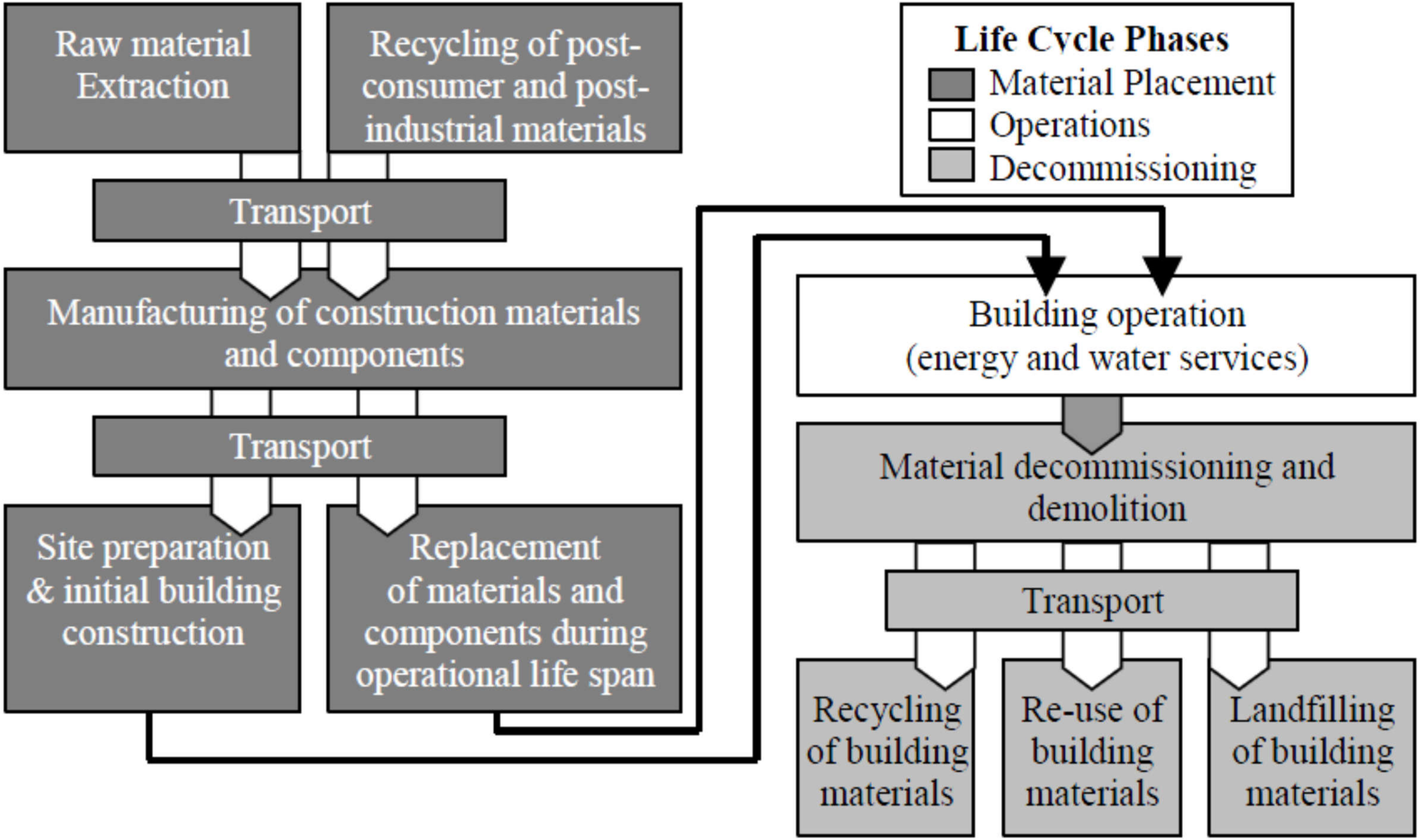
- **Source:** Fertilisers, waste water, transport and energy
- **Effect:** Eutrophication **(**Damage to plants and fish)

Persistent toxicity

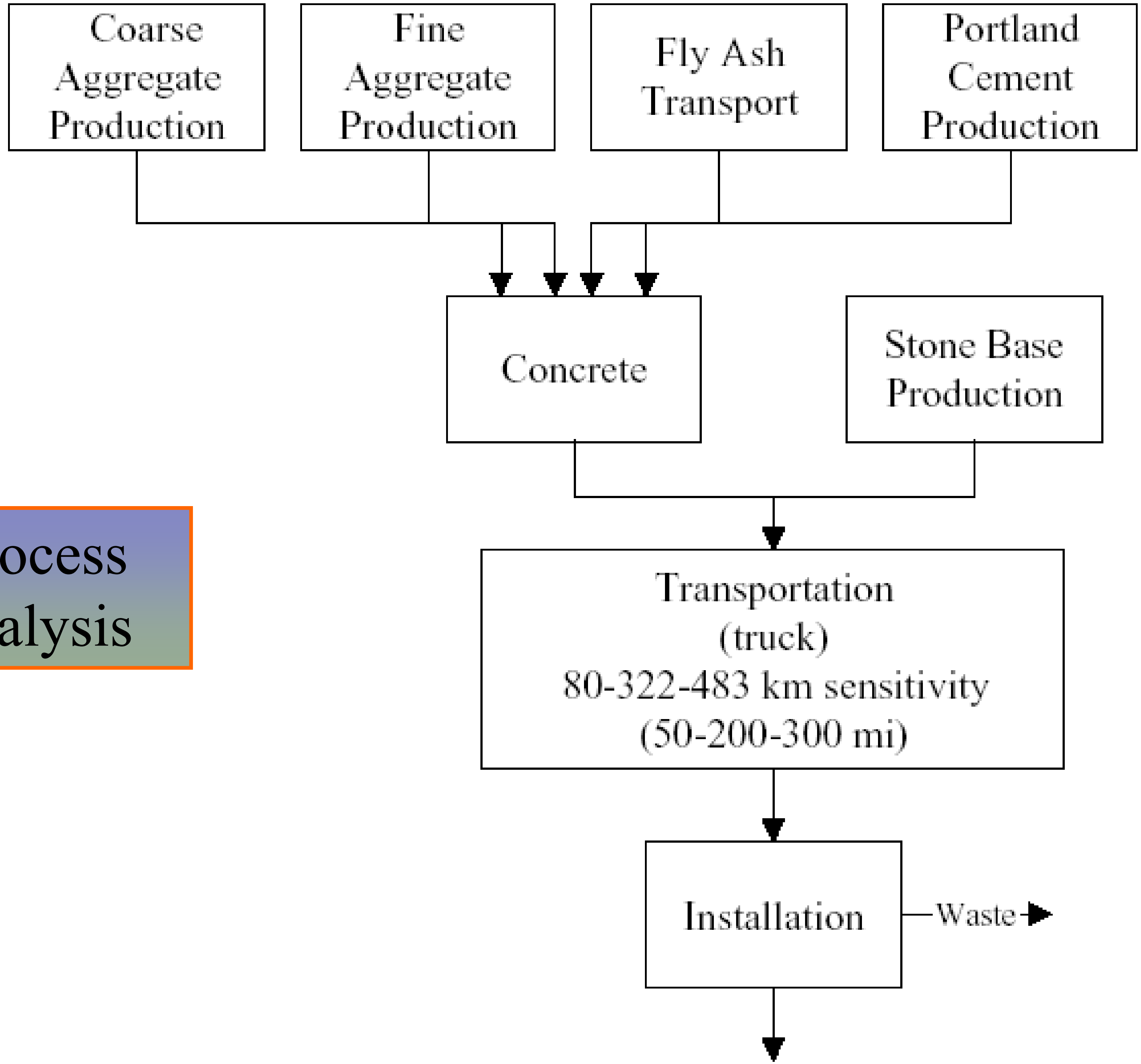
- **Source:** Waste water, incineration, industry, ships etc.
- **Effect:** Accumulation: Chronic damage to ecosystems and organisms

(Source: Loughborough University)

Life cycle phase diagram

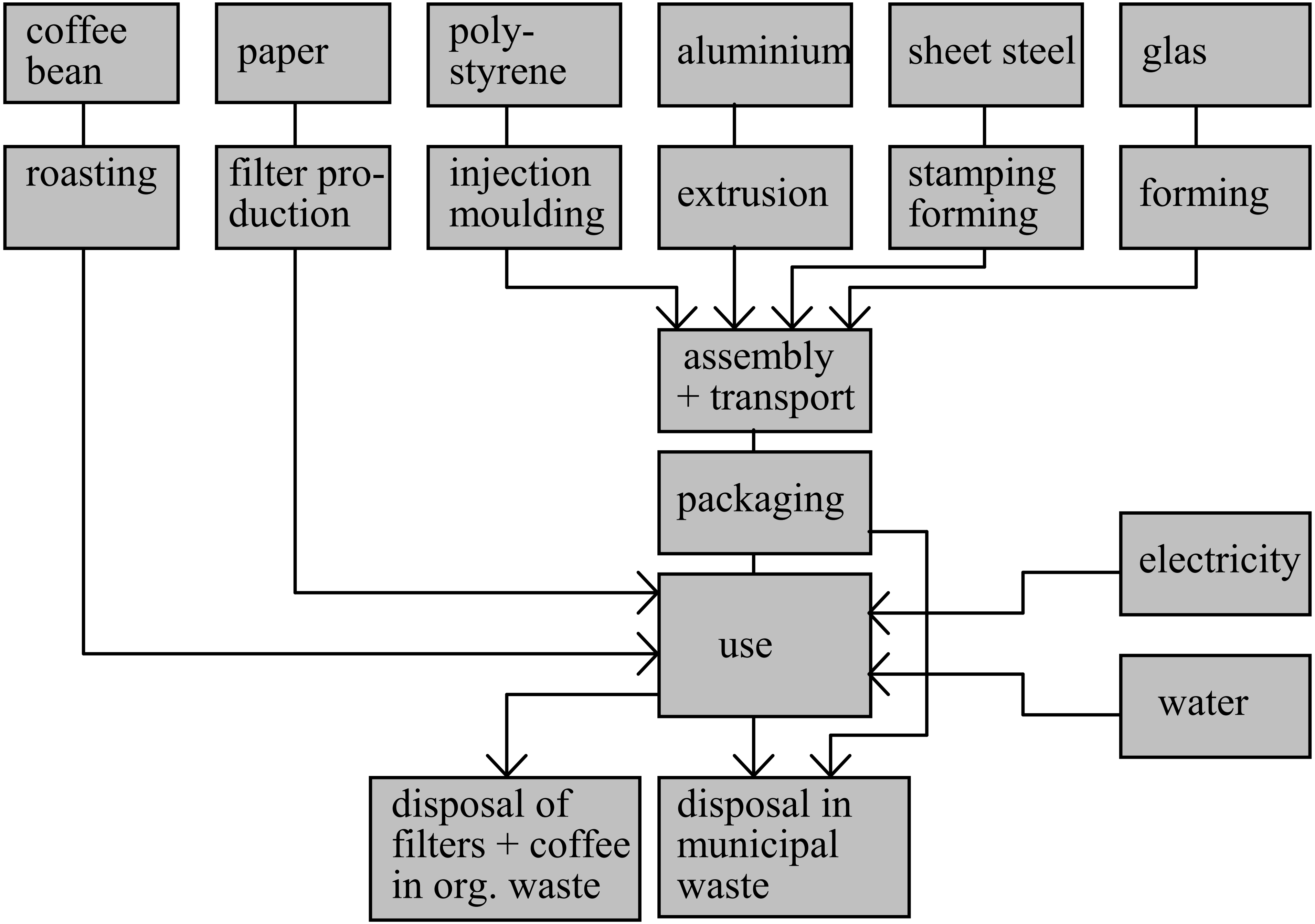


LCA example – concrete paving flow chart



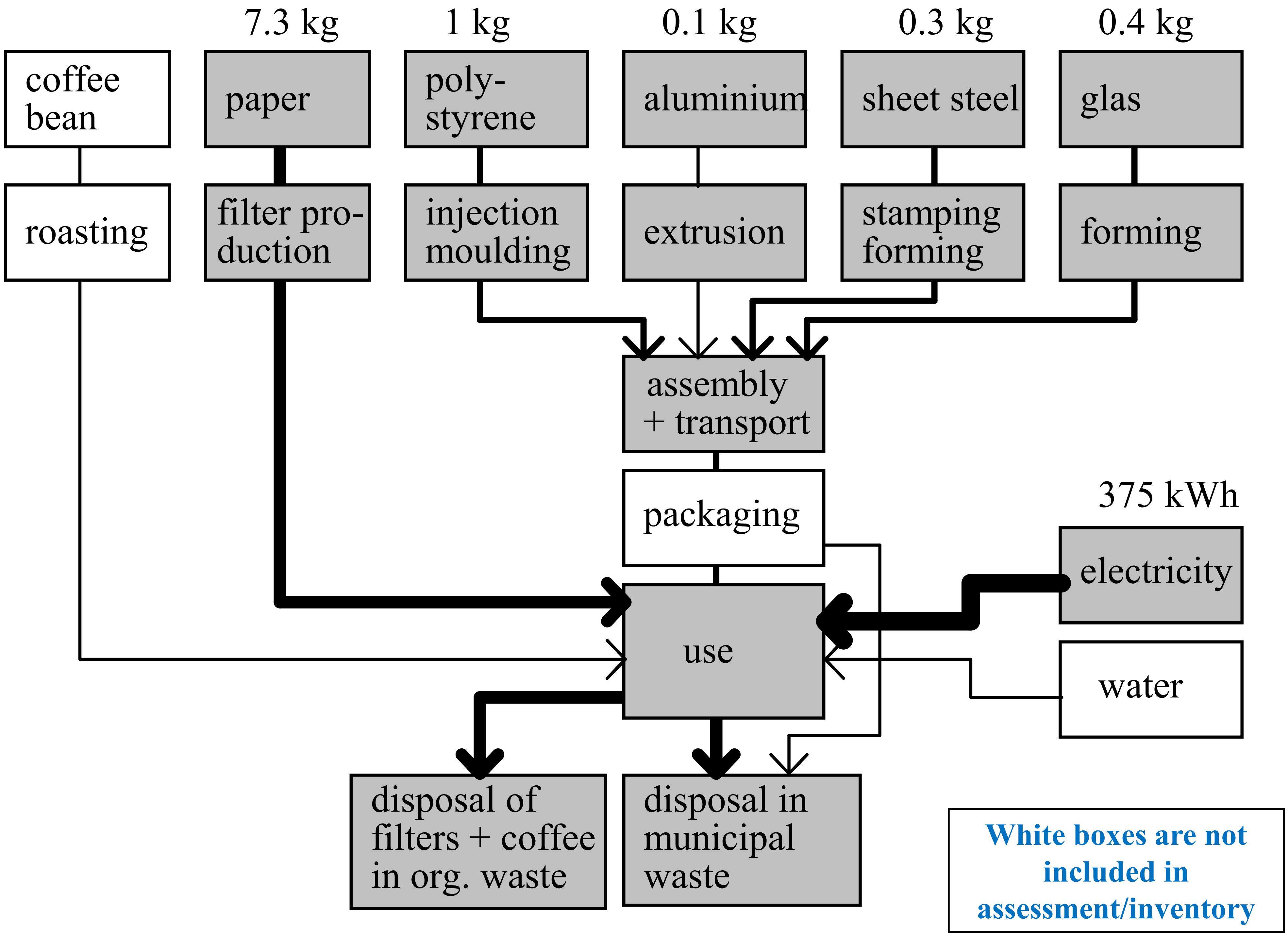
Process analysis

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



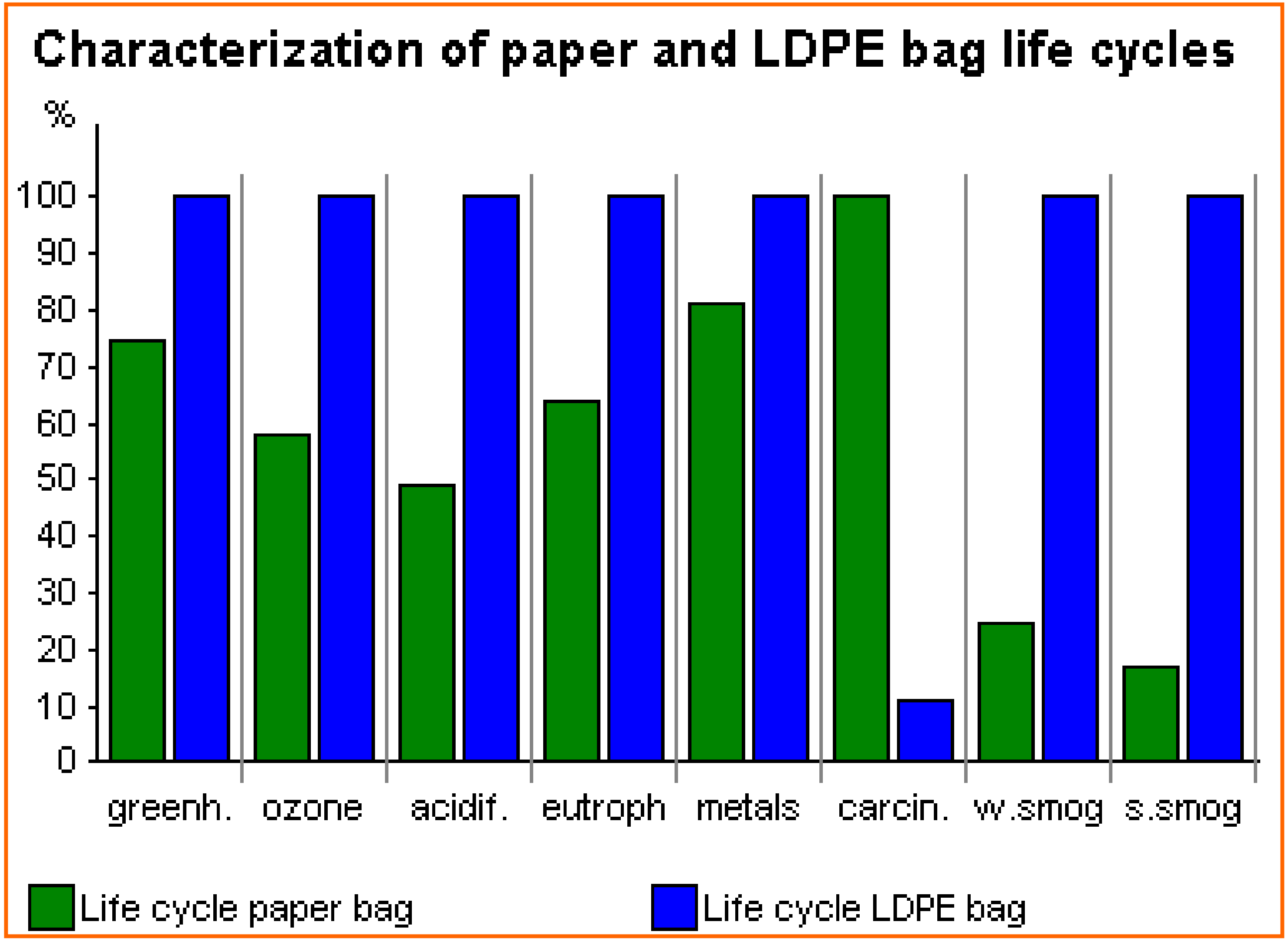
(Source: Systems Realization Laboratory, Georgia Institute of Technology)

Example: Coffee machine life-cycle inventory



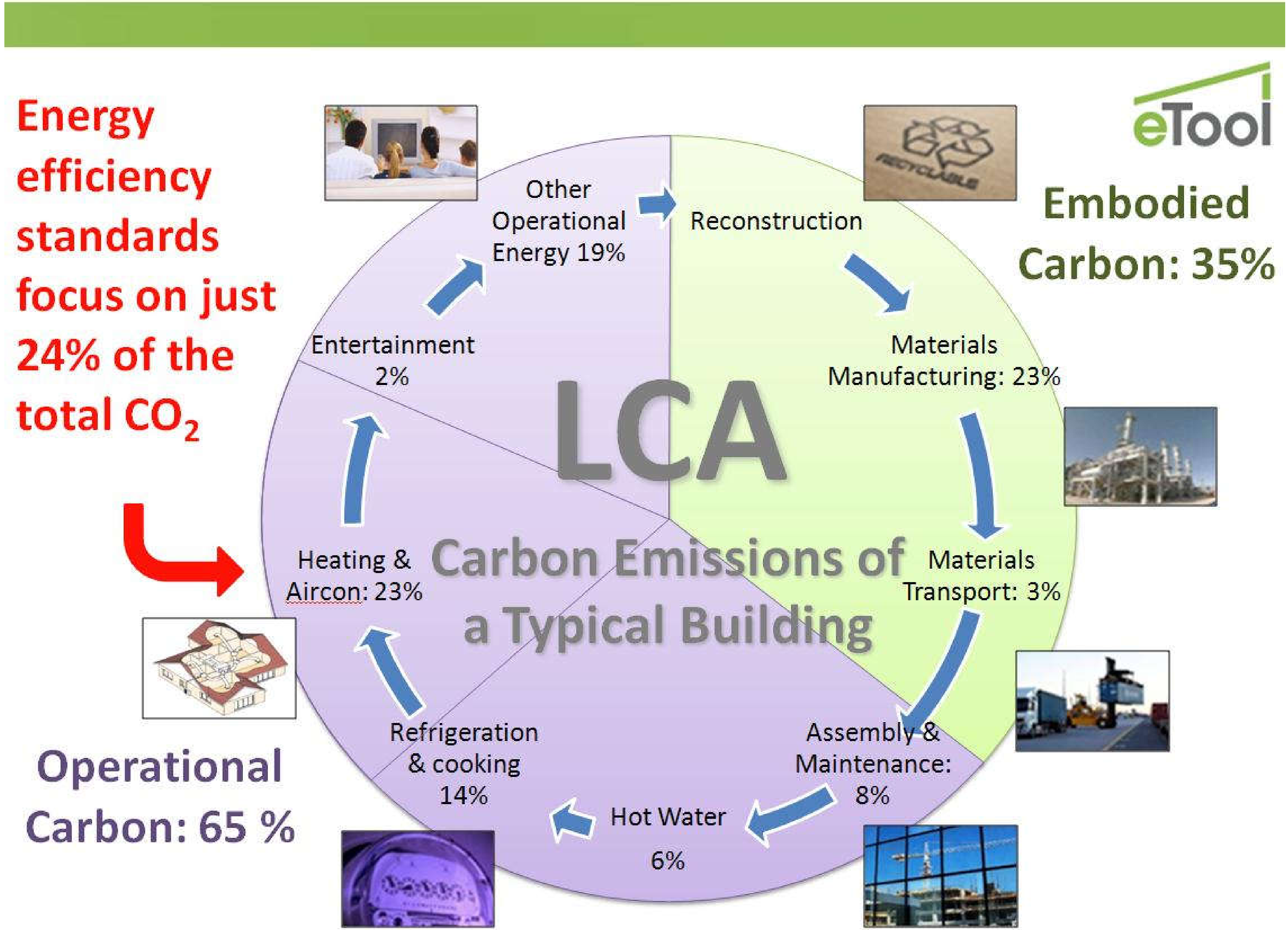
(Source: Systems Realization Laboratory, Georgia Institute of Technology)

Example: Plastic versus paper bag classification



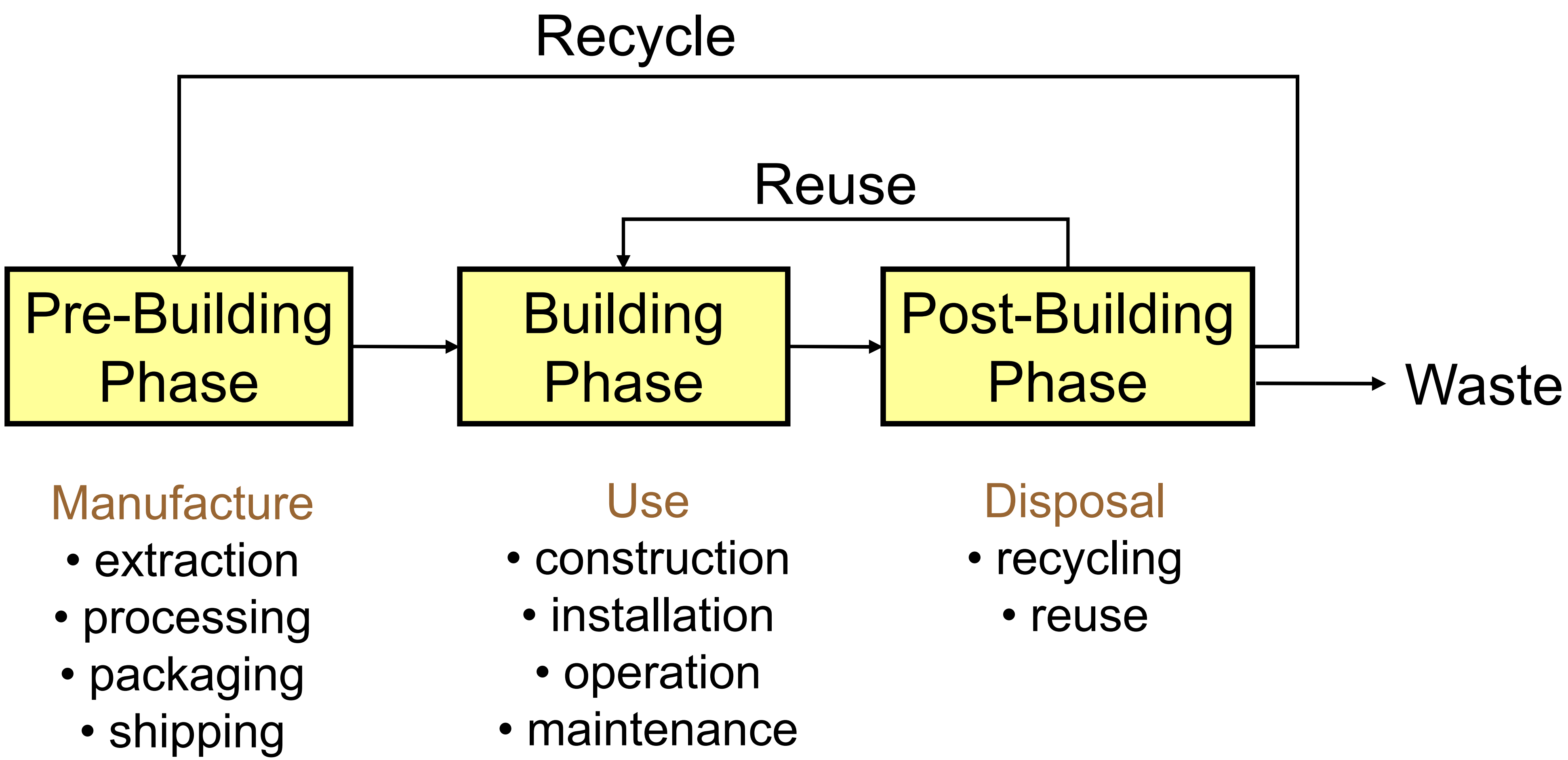
- The paper bag causes more winter smog and acidification, but scores better on the other environmental effects.
- The classification does not reveal which is the better bag. What is missing is the mutual weighting of the effects.

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



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

Three phases of building material life cycle



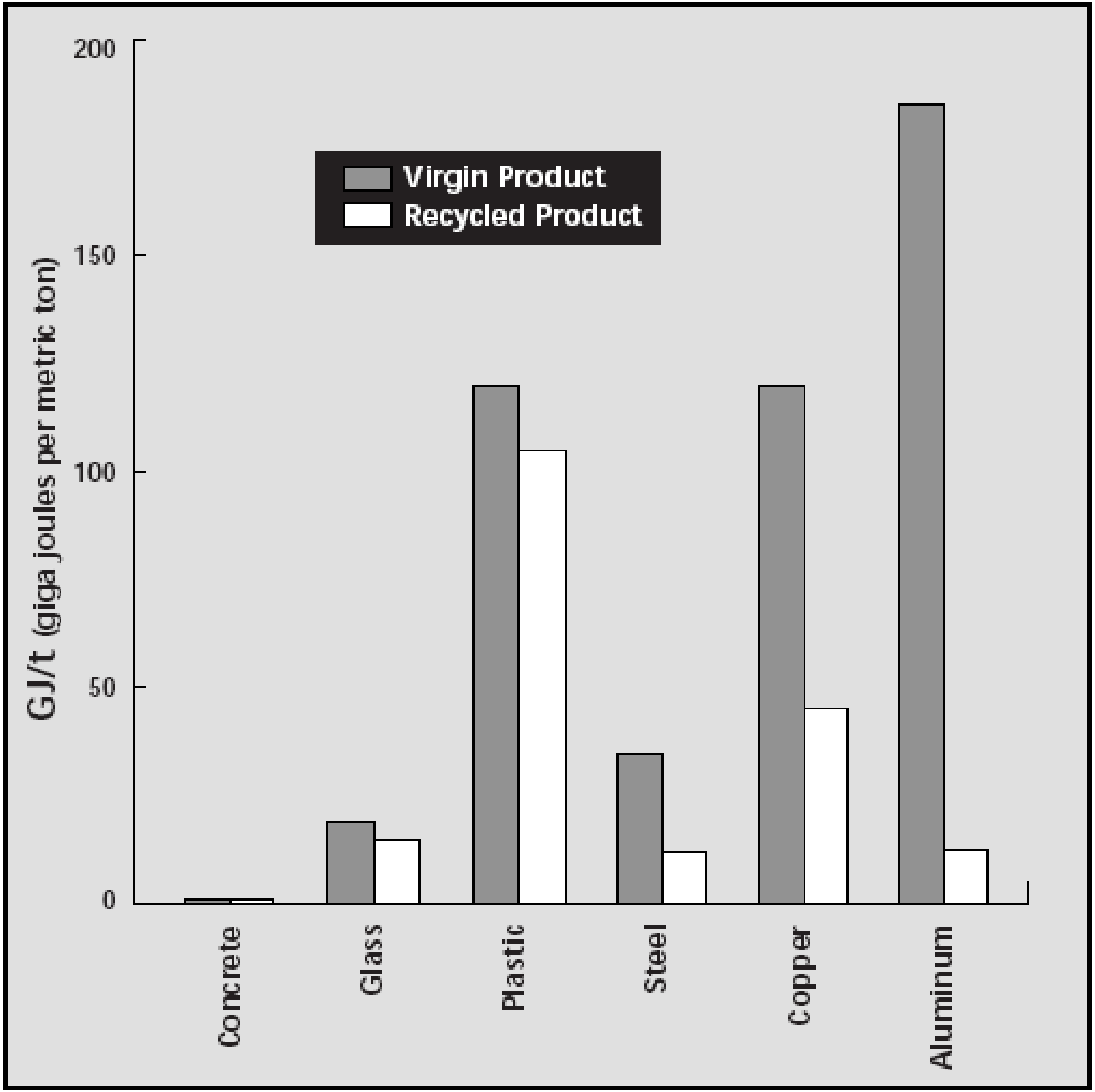
Evaluation methods

- 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

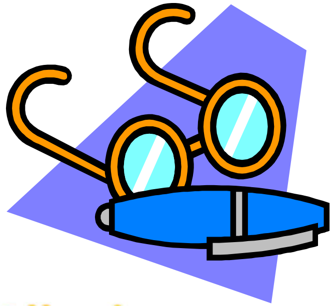
Energy efficiency by mode of transport

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

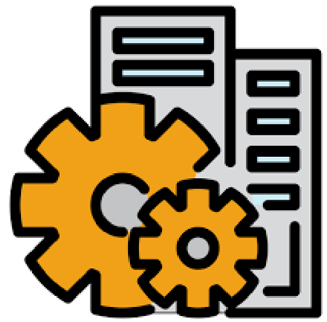
Embodied energy of virgin and recycled products



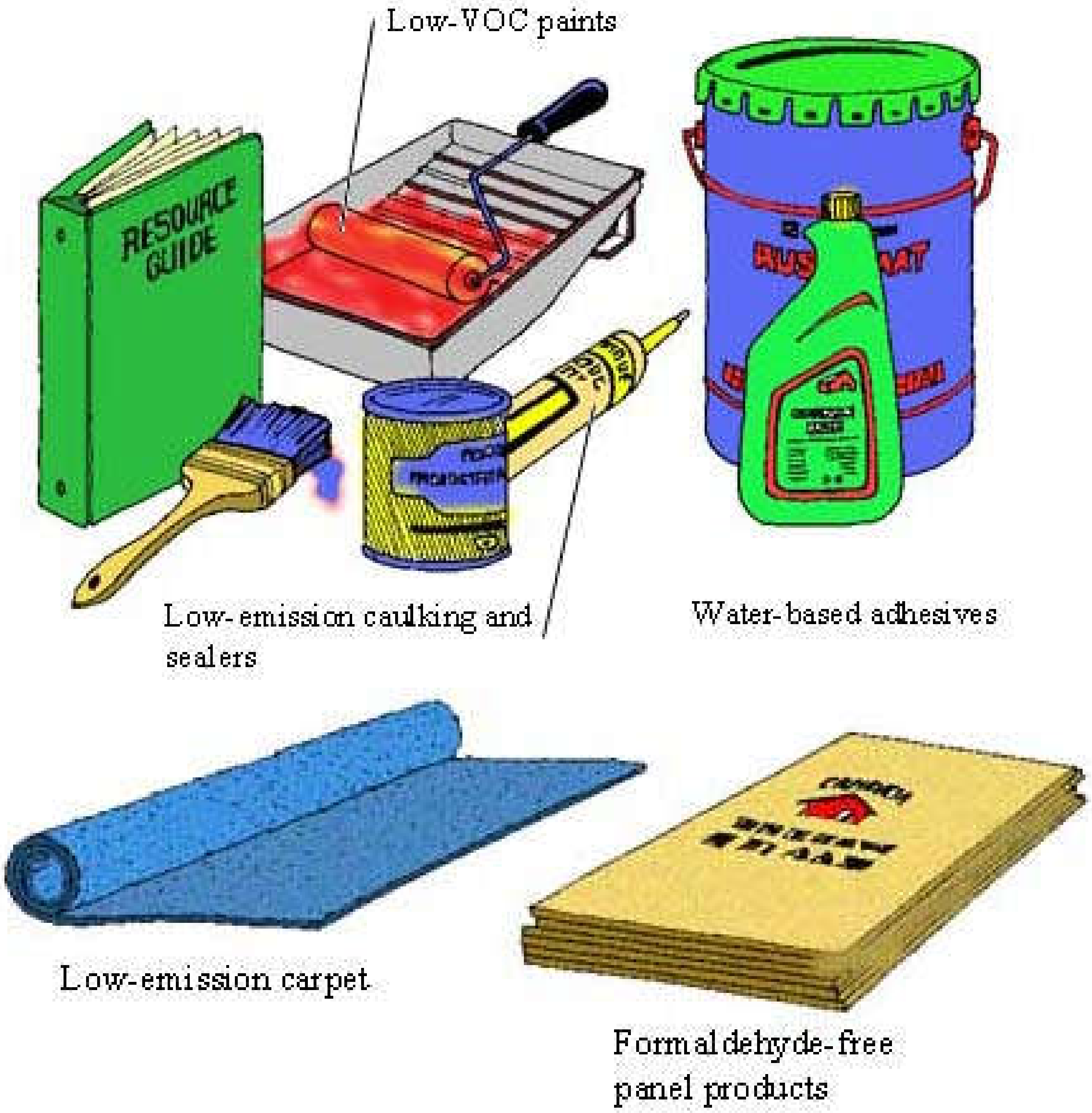
Evaluation methods



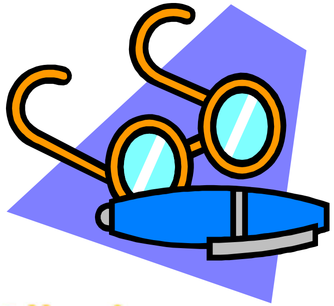
- Building phase
  - Construction & installation on site
    - Noise, waste & pollutants from construction site
  - Maintenance & repair
    - Energy & water use
    - Maintenance & operation requirements
  - Use & operation of the building
    - Effects on indoor air quality & occupants' health



Enhance indoor air quality and minimise health effects

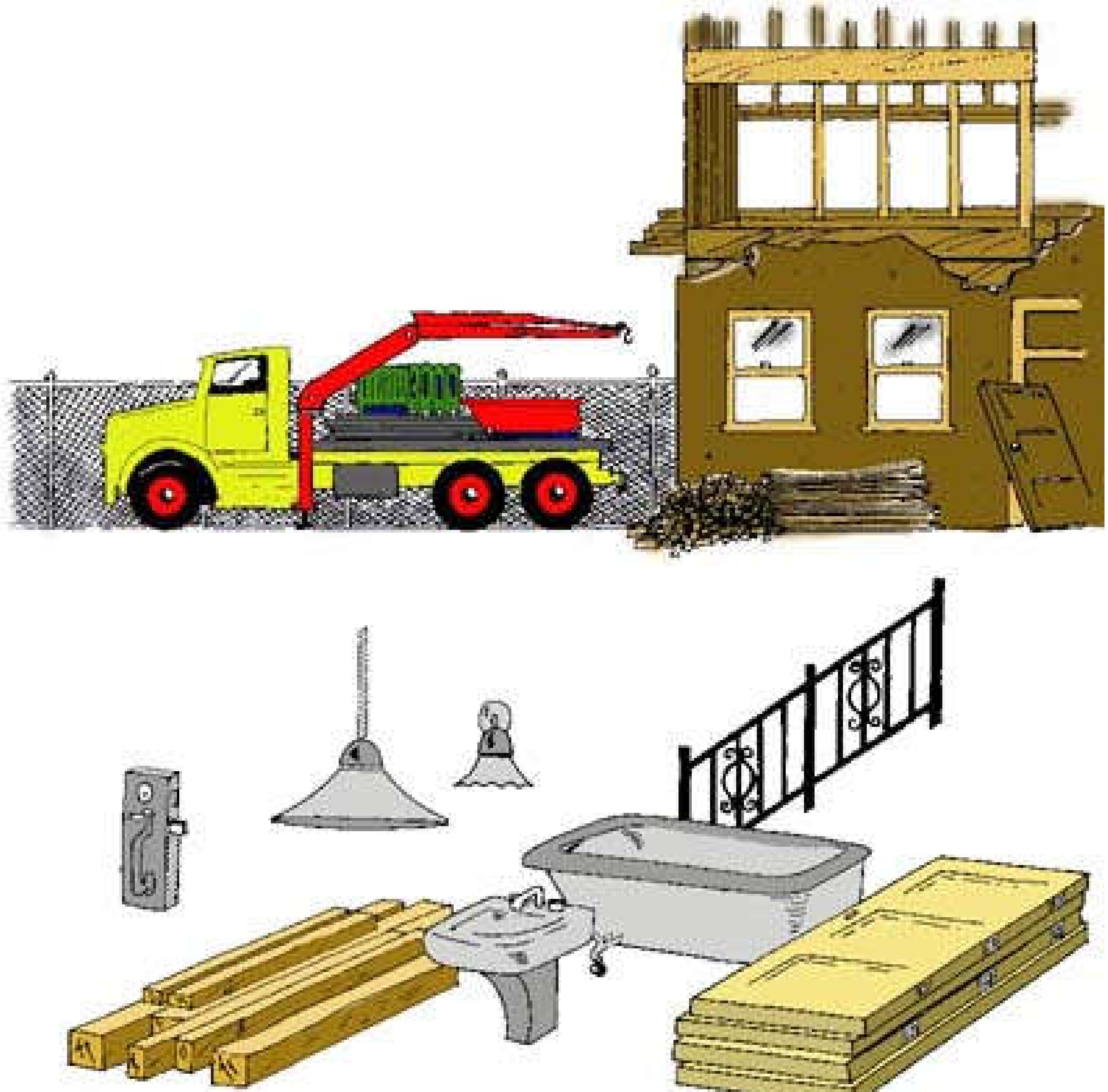


Evaluation methods

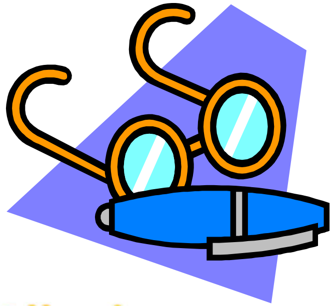


- Post-building phase
  - Demolition
    - Noise, air & water pollution during demolition
  - Disposal
    - Need for transportation, landfil, etc. for the waste
  - Reuse or recycling
    - Energy & water use
- "De-construction"
  - Building disassembly & materials salvage

Separate recyclables from demolition and reuse salvaged materials



Evaluation methods

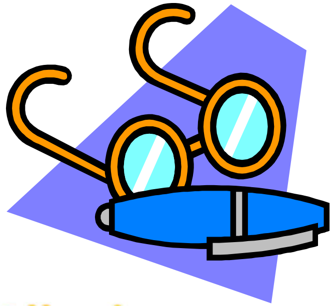


- Criteria in material selection:
  - Resource quantity (use less & more efficiently)
  - Reused materials (salvaged & reused)
  - Recycled content (post- & pre-consumer waste)
  - Renewable materials (e.g. sustainable forestry)
  - Local content and reduced transportation
  - Life-cycle cost & maintenance 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
  - Product as a Service (PaaS)
  - e.g. carpeting service (by Interface, Inc.)
  - Supplier to reuse or recycle the materials

Evaluation methods

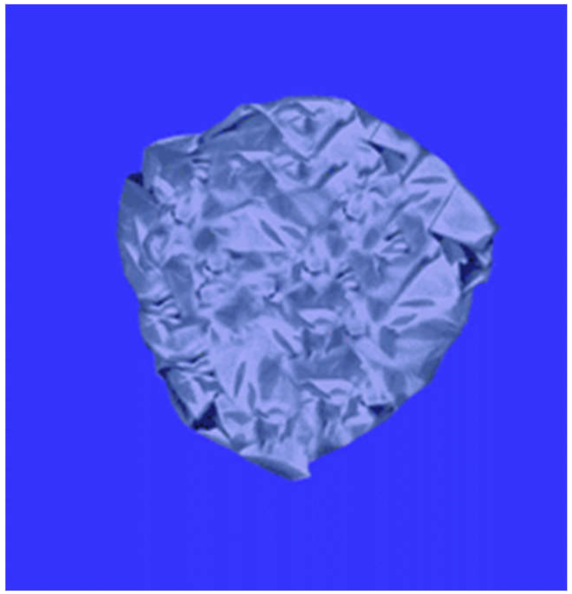


- Evaluate building materials
  - Collect as much information as possible
  - Make judgements & assumptions if needed
- Basic questions
  - What is in them?
  - How they are made?
  - Where they come from?
  - How they perform in the building?
  - What happens to them afterwards?

廢物 - 在錯了地方資源

“Waste - a resource in the wrong place”

-- An old Chinese proverb.



The True Cost of Waste

Purchase price & transportation costs of materials

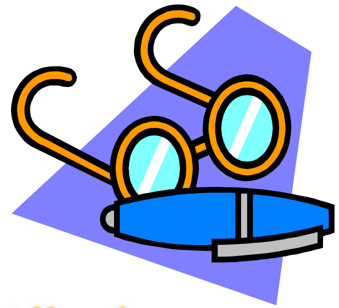
+

Cost of storage, transport & disposal of waste

+

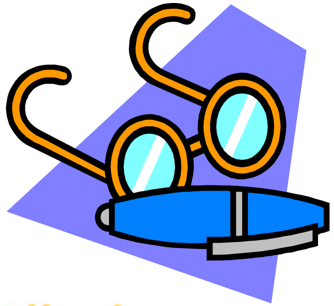
Loss of income from not salvaging waste materials

Evaluation methods



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

Evaluation methods



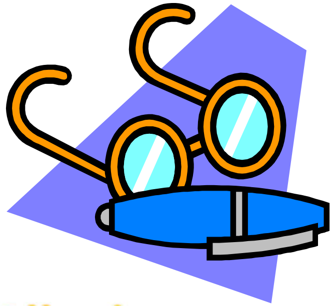
- LCA tools by Athena Sustainable Materials I nstitute http://www.athenaSMI.ca/
  - Impact Estimator (for buildings)
    - Evaluate whole buildings and assemblies based on LCA methodology
  - EcoCalculator (for assemblies)
    - Provides instant LCA results for more than 400 common building assemblies
  - LCA inventory databases
    - Such as structural products and envelope products

Athena Impact Estimator for Buildings

Athena EcoCalculator for Commercial Assemblies

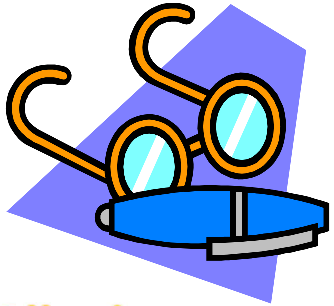
Athena EcoCalculator for Residential Assemblies

Evaluation methods



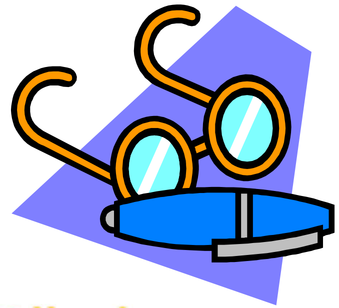
- Impact Estimator’s summary measures format:
  - Embodied primary energy use (consumption)
  - Acidification potential
  - Global warming potential
  - Human health respiratory effects potential
  - Ozone depletion potential
  - Smog potential
  - Aquatic eutrophication potential
  - Weighted resource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

Evaluation methods



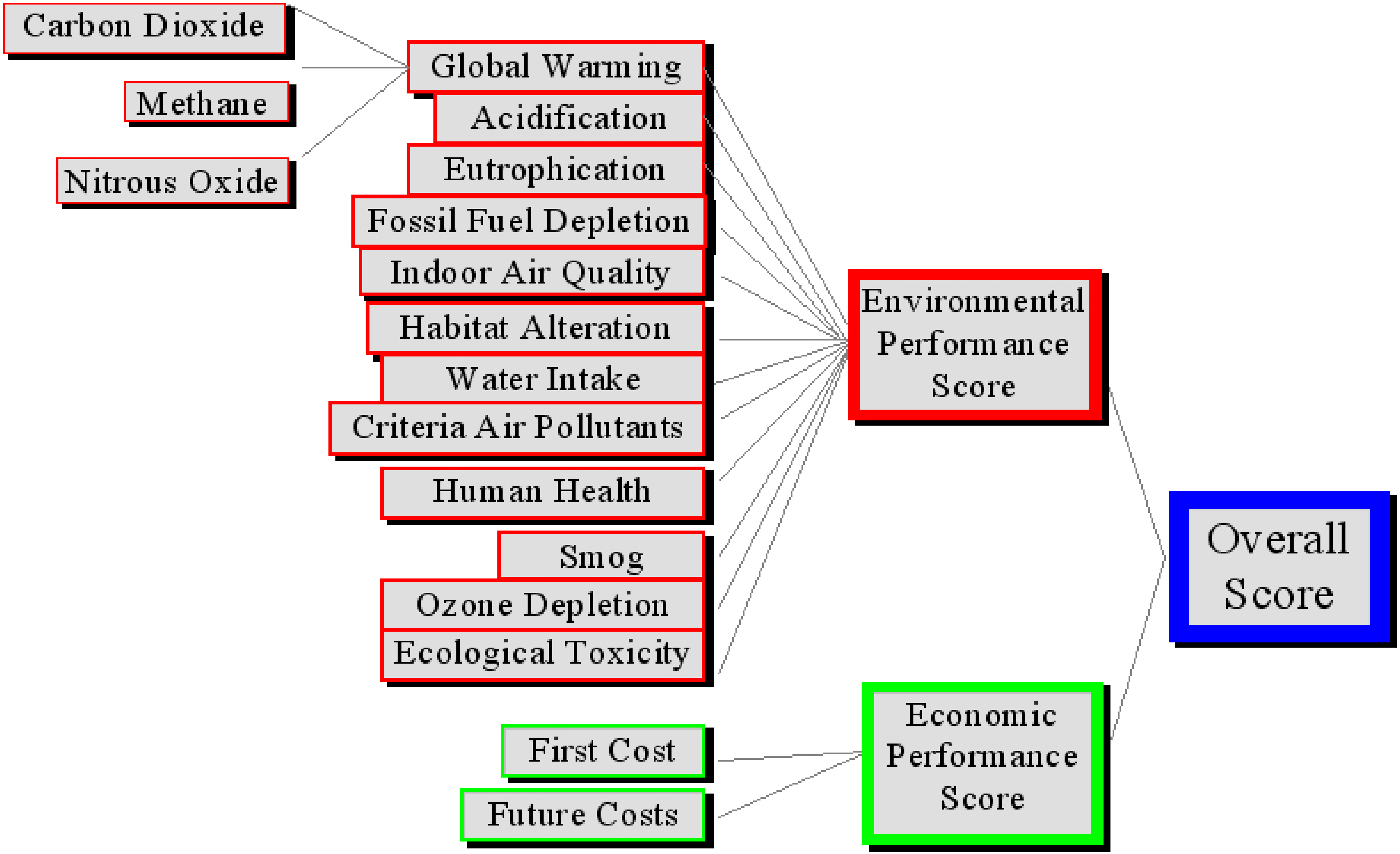
- Impact Estimator's absolute values format:
  - Energy
  - Air emissions
  - Water emissions
  - Land emissions
  - Resource use
- Further information:
  - Impact Estimator for Buildings Tutorial
    - https://calculatelca.com/resources/watch-tutorials/

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

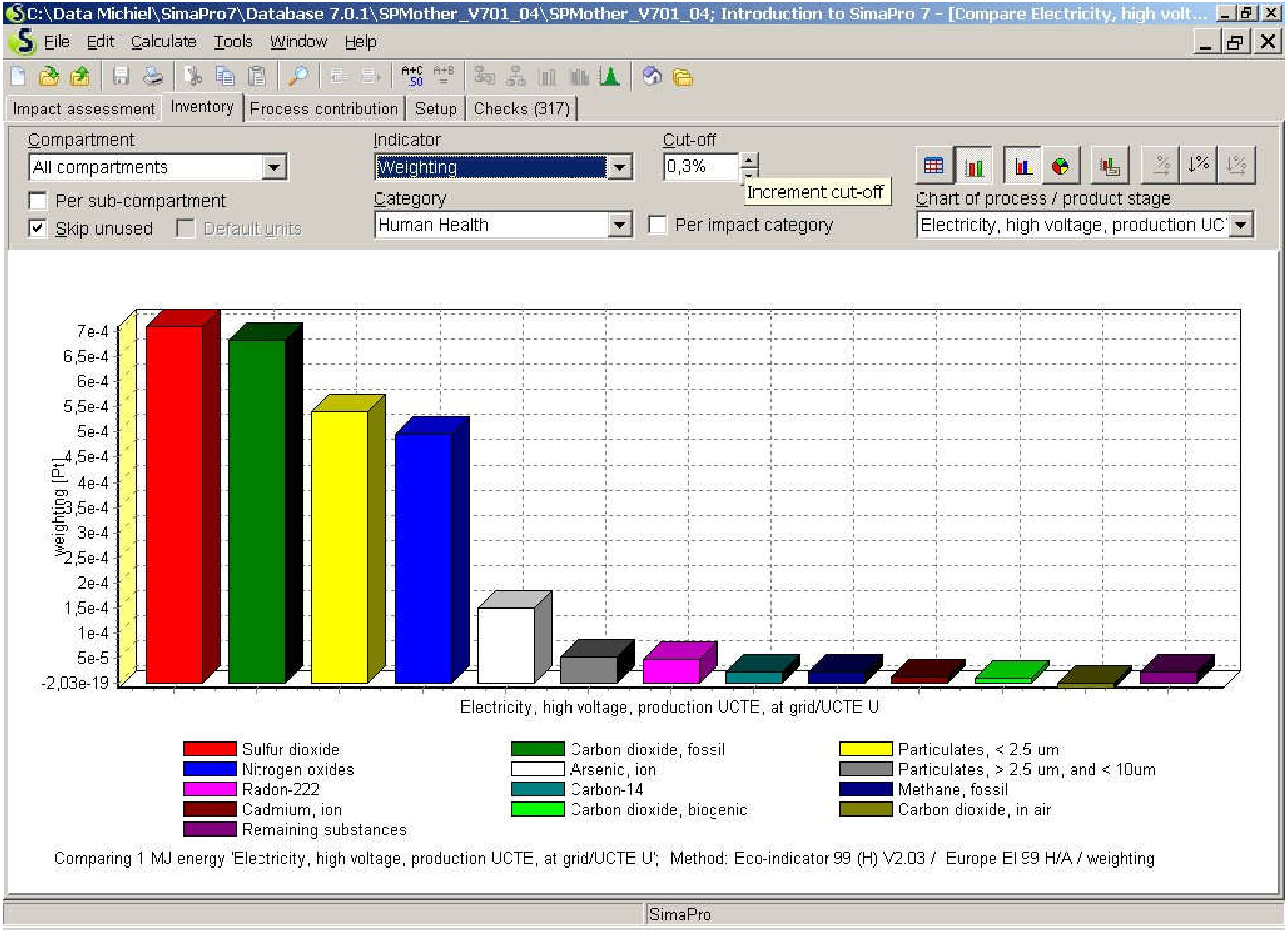


(Source: https://www.nist.gov/services-resources/software/bees)

Evaluation methods

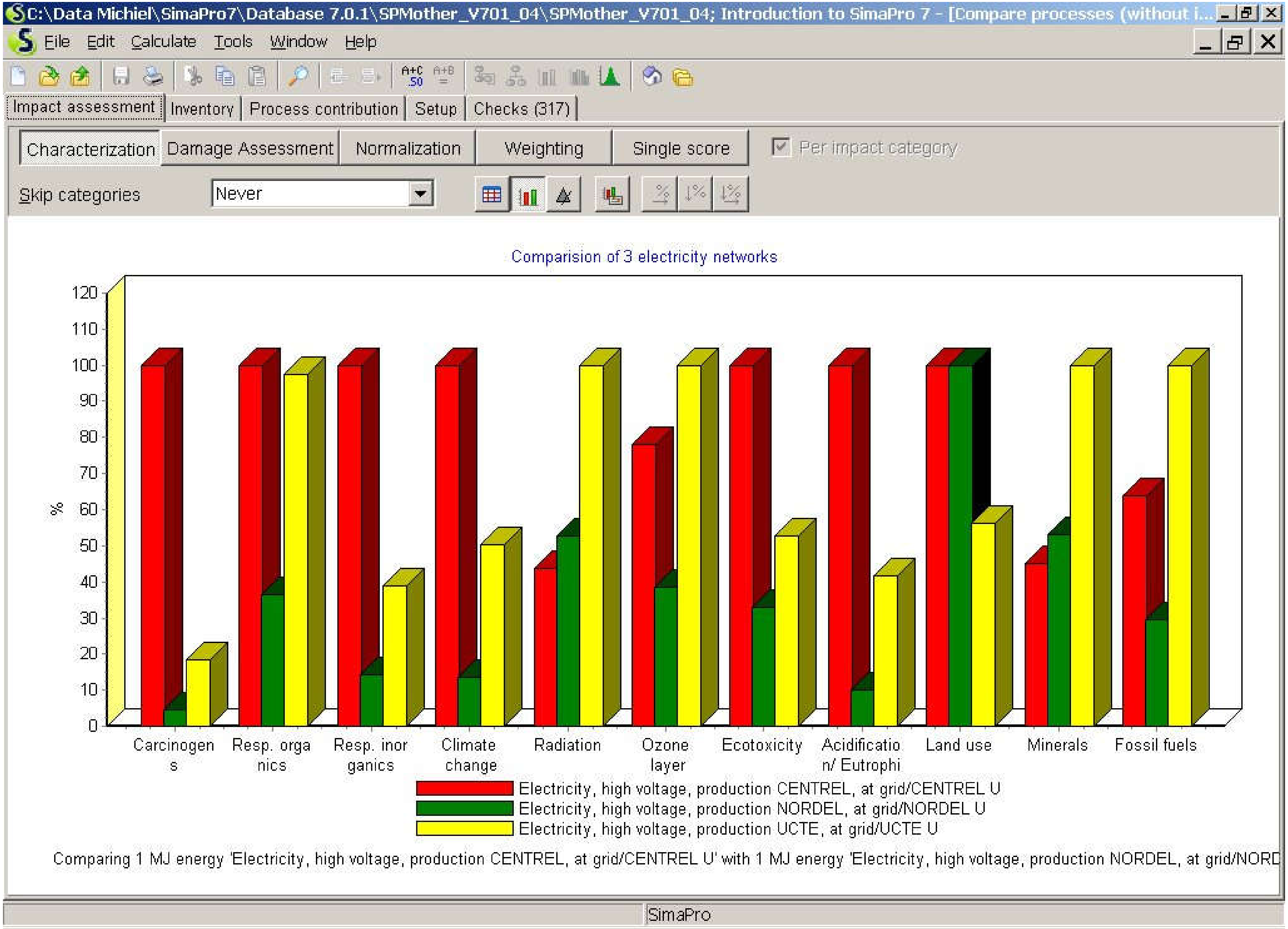
- SimaPro LCA software (by PRé Consultants)
  - https://simapro.com/
  - http://www.pre.nl/simapro.html
  - Tool to collect, analyze and monitor the environmental performance of products, processes and services
  - Follow the ISO 14040 series recommendations
  - SimaPro inventory databases

Features of SimaPro



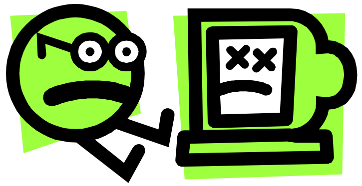
(Source: www.pre.nl/simapro/)

Compare models in SimaPro



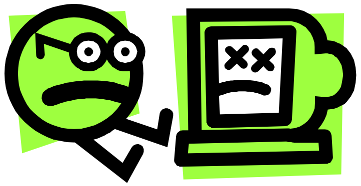
(Source: www.pre.nl/simapro/)

Limitations of LCA



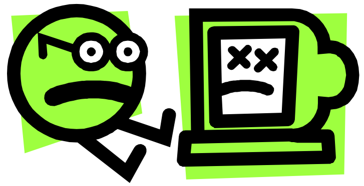
- Difficulties in LCA
  - Data quality and quantity is often not sufficient for a comprehensive LCA
  - A possible consequence of discrepancies in the data is that two independent studies analysing the same products may generate very different results. Ostensibly comparable LCA’s may therefore be incomparable
  - 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



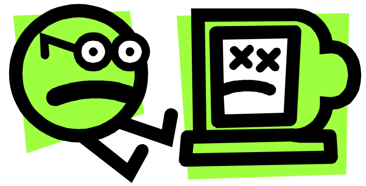
- LCA has attracted some criticisms
  - A lack of standardised information
  - Excessive detail that may be difficult to follow
  - Confusing the issues of human health with those of the environment (human- and eco-toxicity)
  - Weightings are lacking transparency and being subjective
    - It does not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

Limitations of LCA

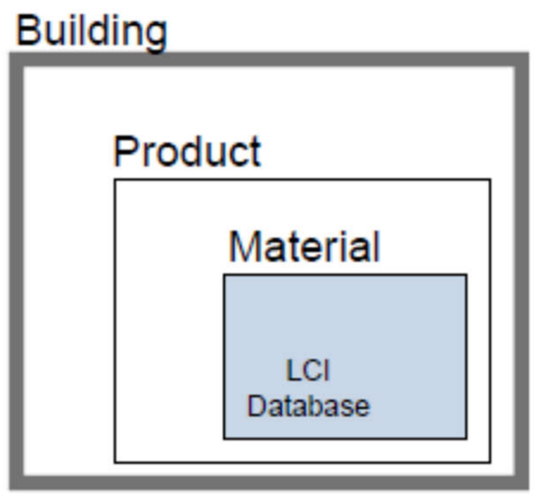


- Problems of LCA:
  - The cost is high, since collecting appropriate data is time consuming
  - Where there are gaps in the data, assumptions have to be made
  - It only provides a snapshot view based on data at the time of collection
  - It does not integrate environmental impact with the social and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

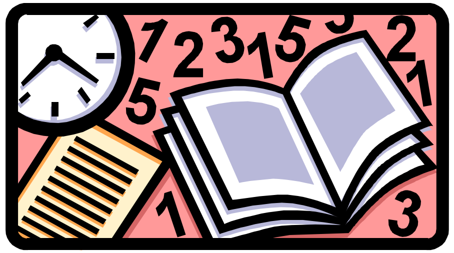
Limitations of LCA



- 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/