POLITECNICO DI MILANO

School of Industrial and Information Engineering
Course 096125 (095857)
Introduction to Green and Sustainable Chemistry

Life-cycle of Products, Processes and Activities.

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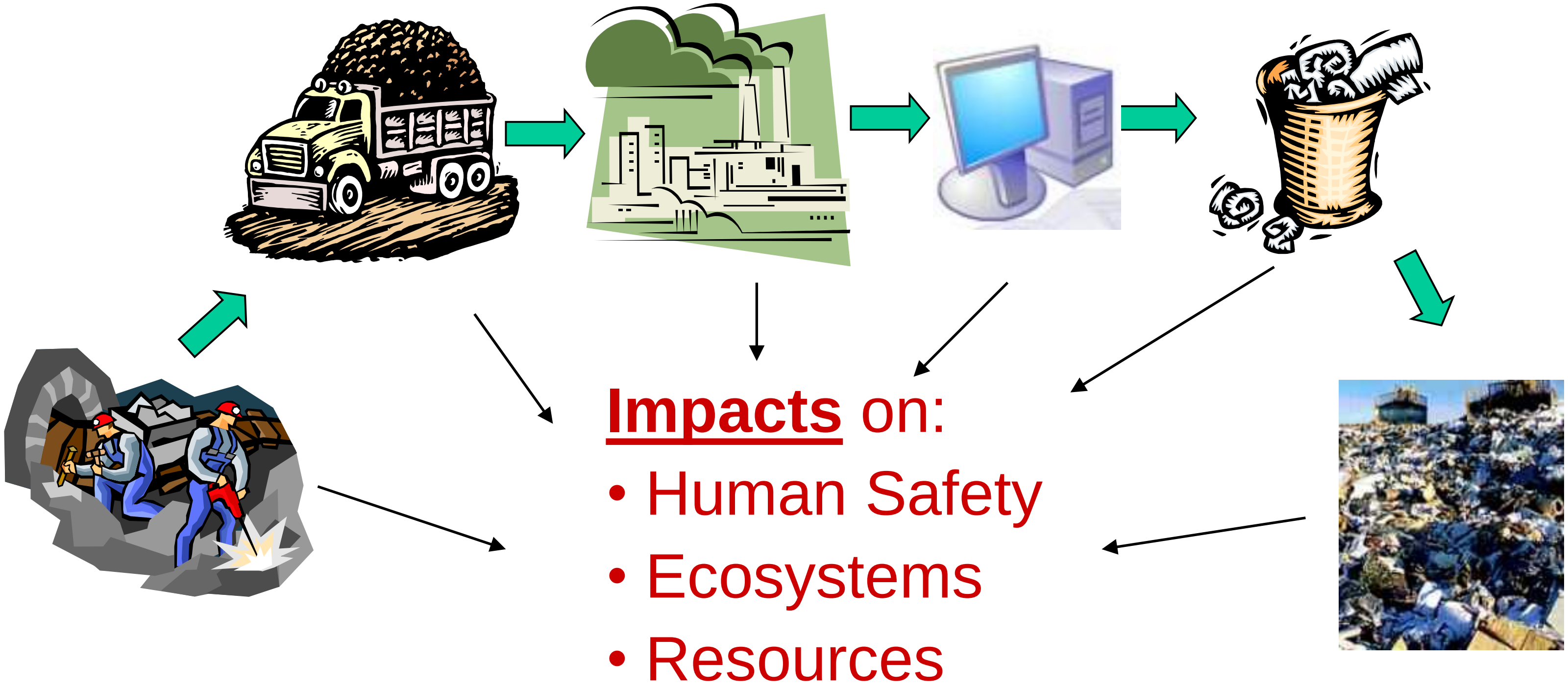
Life-cycle Assessment (LCA).

”From cradle to grave”

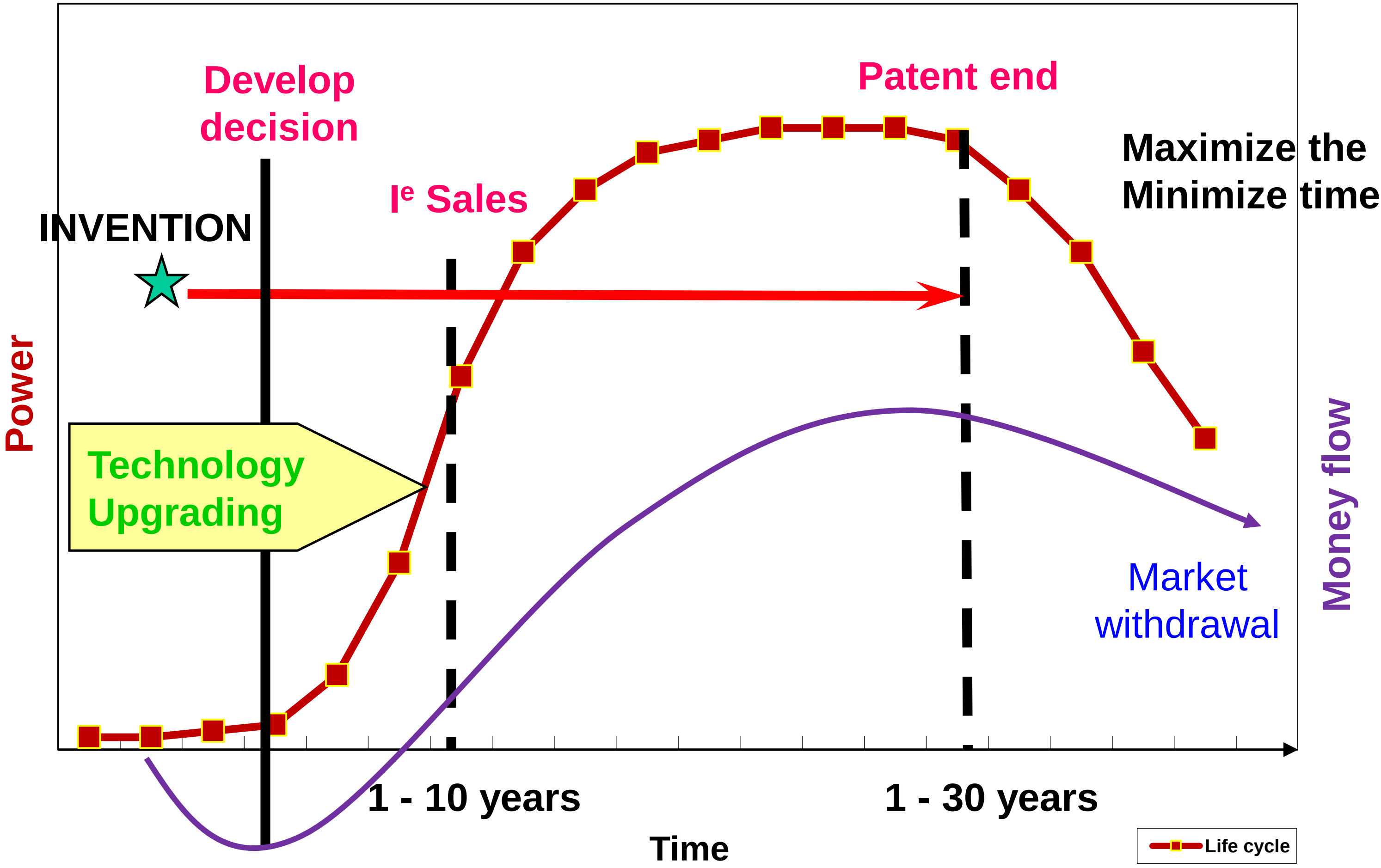


Impacts on:

- Human Safety
- Ecosystems
- Resources

Business Life Cycle.

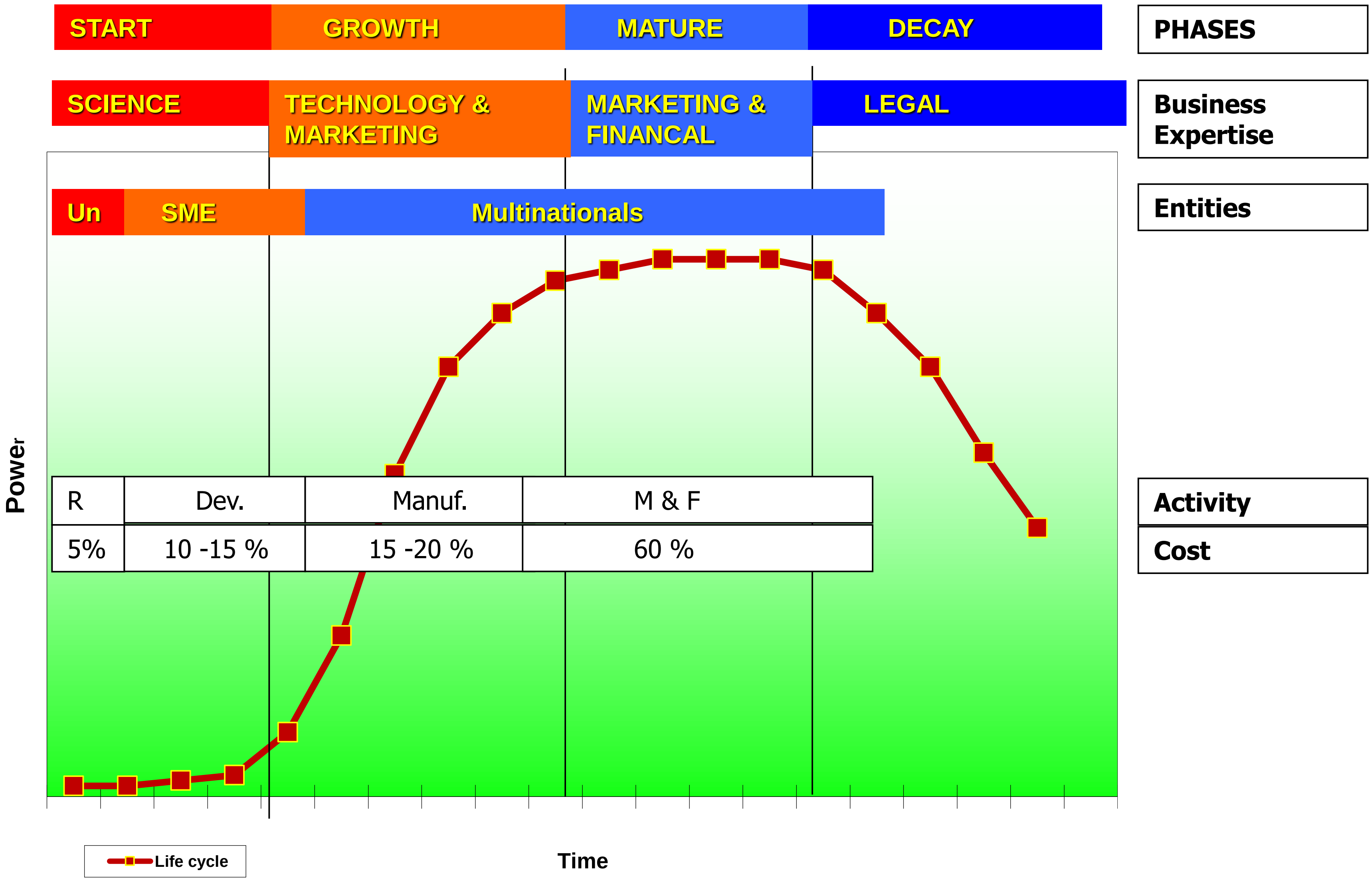
START	GROWTH	MATURE	DECAY	PHASES



Maximize the product value
Minimize time to market

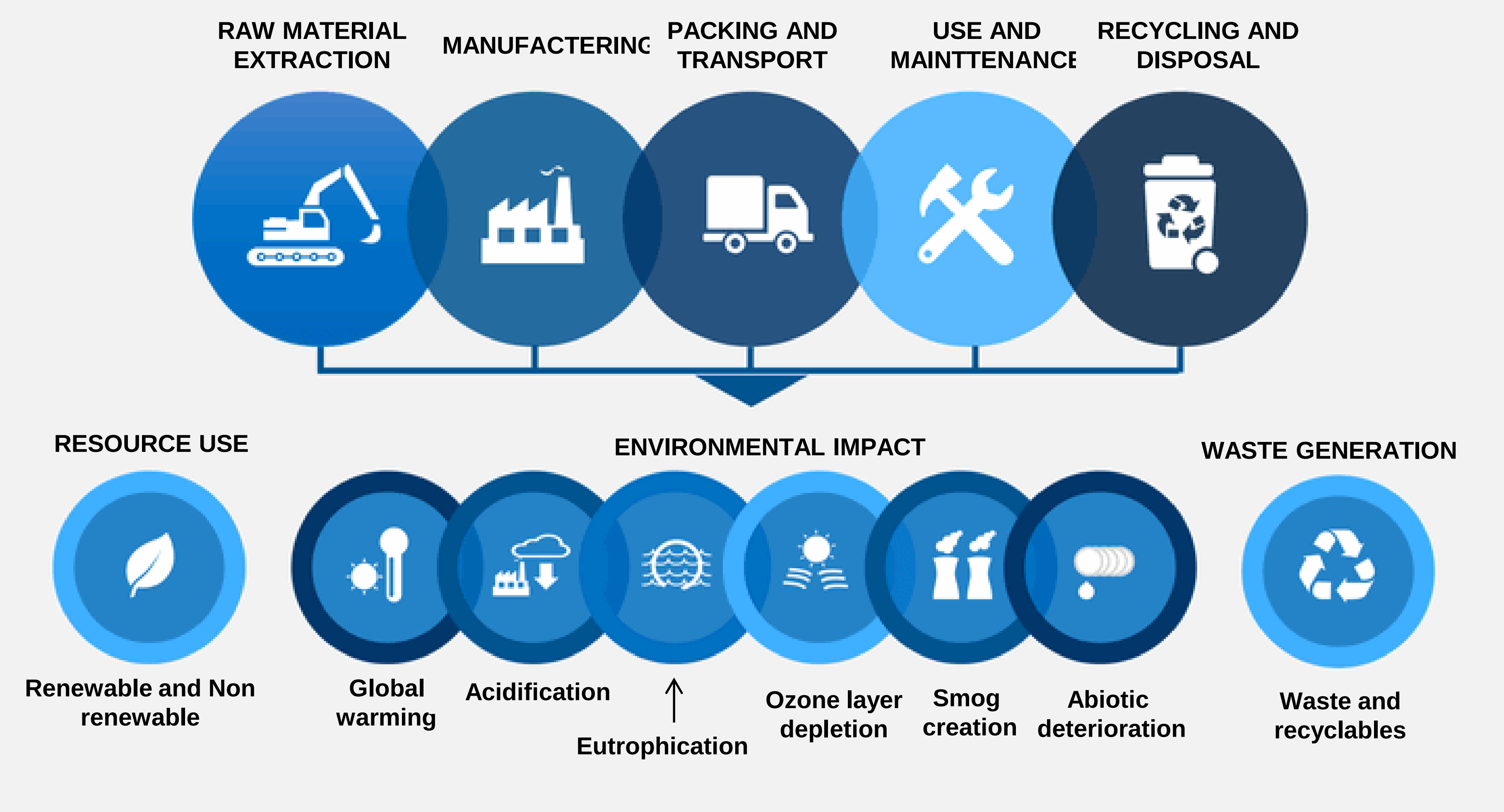
SCIENCE	TECHNOLOGY & MARKETING	MARKETING & FINANCAL	LEGAL	Business Expertise

Business Dynamics.



R	Dev.	Manuf.	M & F
5%	10 -15 %	15 -20 %	60 %

Life Cycle Assessment.



RAW MATERIAL EXTRACTION

MANUFACTERING

PACKING AND TRANSPORT

USE AND MAINTTENANCE

RECYCLING AND DISPOSAL

RESOURCE USE

Renewable and Non renewable

ENVIRONMENTAL IMPACT

Global warming

Acidification

Eutrophication

Ozone layer depletion

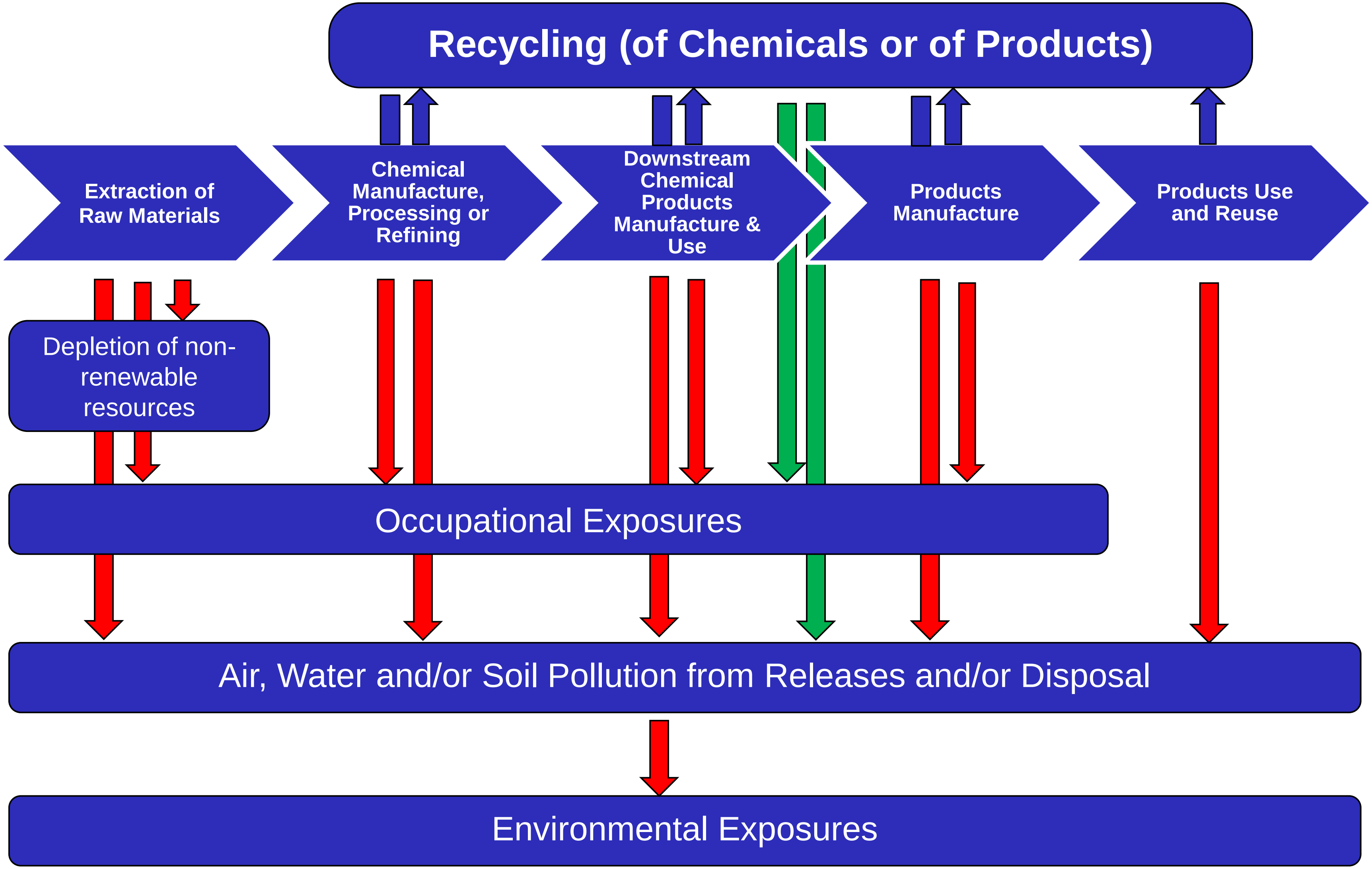
Smog creation

Abiotic deterioration

WASTE GENERATION

Waste and recyclables

Life Cycle of Chemicals.



Recycling (of Chemicals or of Products)

Extraction of Raw Materials

Chemical Manufacture, Processing or Refining

Downstream Chemical Products Manufacture & Use

Products Manufacture

Products Use and Reuse

Depletion of non-renewable resources

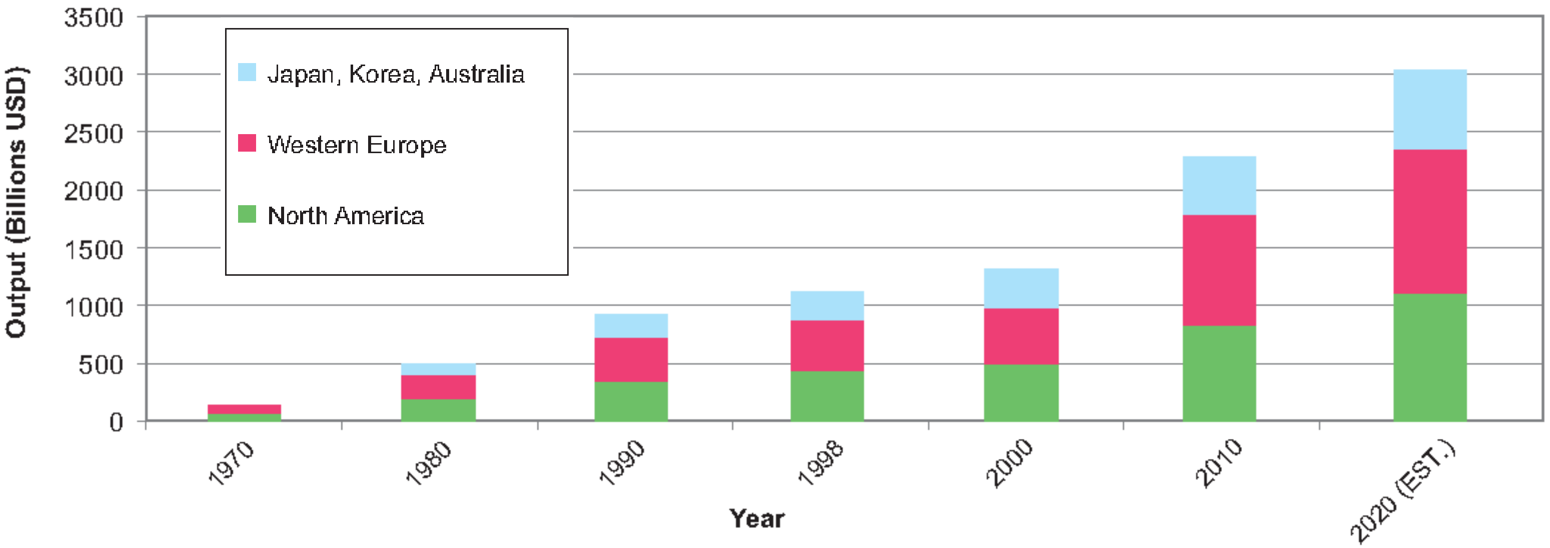
Occupational Exposures

Air, Water and/or Soil Pollution from Releases and/or Disposal

Environmental Exposures

Chemical Industry Output: Developed* and Less Developed** Regions.

*



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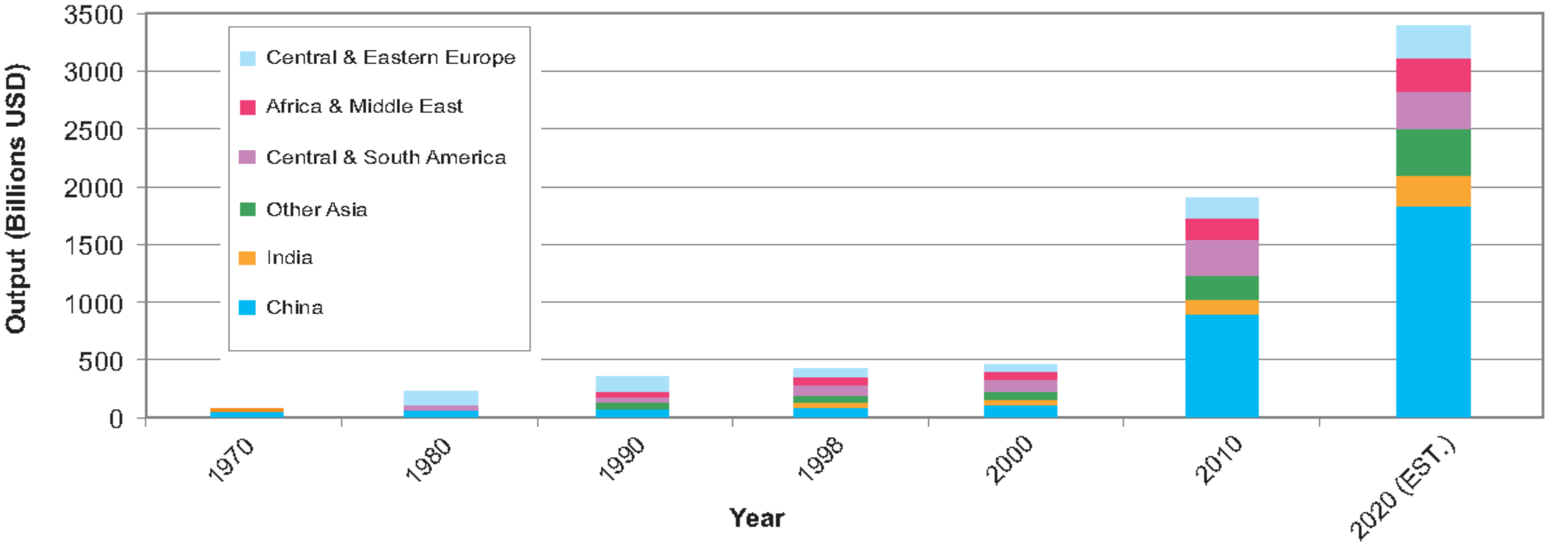

Life-cycle Assessment (LCA)

LCA is defined by "Society of Environmental Toxicology and Chemistry" (SETAC)*

"Life-cycle assessment is an objective process to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and materials used and wastes released to the environment and to evaluate and implement opportunities to effect environmental improvements".

and according to **(International Organisation for Standardization)** ISO 14040 :

LCA is a technique […] compiling an inventory of relevant inputs and outputs of a product system; evaluating the potential environmental impacts associated with those inputs and outputs; and interpreting the results of the inventory and impact phases in relation to the objectives of the study.

*Society of Environmental Toxicology and Chemistry *Guidelines for Life Cycle Assessment 'A Code of Practice'* August 1993

The Starting Years.

- The first studies on life cycle aspects of products and materials come back to 1968-1972, and were focused on themes as energy efficiency, feedstock consumption and waste disposal.
- In 1969 was published, for instance, a study on soft drink containers and, in Europe, was developed an approach to LCA, known as ‘Ecobalance’.
- In 1972, in UK, Boustead calculated the total energy used in the production of some consumer goods and consolidate the methodology to make it applicable to various materials (*Handbook of Industrial Energy Analysis, 1979).*
- Initially, the energy was considered to high priority respect to waste and to by-products. Therefore, no difference was made between development of inventory (resources which end to product) and analysis of associated total impacts. However, after the oil crisis, the energy issue becomes less demanding and, even if attention for LCA was maintained, relevant novelties were lacking.
- Only in the middle of 80 - start 90 years the interest for LCA growth in general form both from industries and design or commercial firms. Numerous studies without common methodology result in contradicting results.

Rapid Grown and Youth.

- "LCA is again a young tool“. Only in 1992 UN established that methodologies of life cycle assessment were between the more promising supports to face a wide spectrum of environmental management tasks.
- The good collection on LCA is the textbook *The LCA Sourcebook* (1993). These studies flowing into a close scientific community in Europe and North America, finally go from laboratory to real world.
- 1993, SETAC *publishes Guidelines for Life-Cycle Assessment: A ‘Code of Practice’* (Consoli et al.)
- Even now competences in LCA are limited at world level, but more developed nations have organized with academics, consultants and societies to address the more complex environmental problems.
- 1997-2000, ISO publishes Standards 14040-43, defining the different LCA stages
- 1998-2001, ISO publishes Standards and Technical Reports 14047-49
- 2000, UNEP and SETAC create the Life Cycle Initiative
- **2006 ISO publishes Standards 14040 & 14044, which update and replace 14040-43.**

Towards Maturity.

- In the present time the methodology is developing and consolidating. The acquired confidence degree suggests a real future both for the realization of inventories and for acquiring a life cycle mentality.
- Some researchers however think that LCA is again far to offer key analyses and solutions open to all. The main difficulties are connected to:
  - complexity of majority of methodologies and processes;
  - High costs and the long temporal scale, despite the progress made;
  - the need to express opinions in the course of the analysis
  - The lack of internationally accepted standard (attempts were the SPOLD LCA and the ISO standard);
  - the persistent invisibility of major work on LCA to community
- The difficulties in parte arise from the accessibility of conclusions also to non experts and in the transparency of related decisions from authority.
- Some simplifications were introduced, in particular a series of software, but the difficulty to acquire affordable initial data remains.

LCA Application.

- LCA approach was developed originally to create support tools to decisions for differentiate products, products systems, or services on environmental basis (The term "product" is used frequently as synonym both of products, product systems, and services).
- During the LCA evolution, several correlated applications emerged; the more relevant are:
    - LCA can be used by: industry and other types of commercial enterprises, governments at all levels, non-governmental organizations such as consumers organizations and environmental groups, and consumers. The motivations for use vary among the user groups.
    - An LCA study may be carried out for operational reasons, as in the assessment of individual products, or for strategic reasons, as in the assessment of different policy scenarios, waste management strategies or design concepts.
    - LCA may be used for internal or external applications and for commercial scope.

LCA: International Organizations.

LCA play an important role in the environmental policy of products. The following international organizations have a relevant role in the development and application of LCA:

- SETAC (Society of Environmental Toxicology and Chemistry), is the international scientific forum of LCA;
- ISO (International Organization of Standardization). ISO has introduced the standard for LCA (series ISO 14040-14044) and has contribute to uniform different schools of this methodology. As a result, the credibility of LCA is strongly increased;
- UNEP (United Nations Environmental Program). The focus of UNEP is the LCA applications. Collaborate with SETAC for the “life cycle initiative”, with the target to promote in industry the “life cycle management”, to find the best methods in the impact assessment and to improve the LCA data quality.
- ELCD 3.2, the European life cycle database, release in 2006, comprises Life Cycle Inventory (LCI) data from front-running EU-level business associations and other sources for key materials, energy carriers, transport, and waste management.

European Reference Life Cycle Database (ELCD)* & International Reference Life Cycle Data System (ILCD)*.

ILCD Handbook provide a guidance on all the steps required to conduct a Life Cycle Assessment (LCA). The ELCD3.2 (European reference Life Cycle Database)** is a database that provide detailed data for LCI analysis.

In the Communication on Integrated Product Policy, the European Commission committed to produce a handbook on best practice in LCA. The Sustainable Consumption and Production Action Plan confirmed that “(…) consistent and reliable data and methods are required to assess the overall environmental performance of products (…)”.

The Handbook’s main goal is to ensure quality and consistency of life cycle data, methods and assessments. It’s main target audience is LCA practitioners, data providers, and reviewers.

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* http://eplca.jrc.ec.europa.eu/uploads/JRC-Reference-Report-ILCD-Handbook-Towards-more-sustainable-production-and-consumption-for-a-resource-efficient-Europe.pdf

** http://eplca.jrc.ec.europa.eu/ELCD3/datasetDownload.xhtml

European Platform for LCA - Support life cycle thinking and assessment in gov. and business.

Integrated Product Policy Communication (IPP)

Sustainable Consumption and Production Action Plan (SCP)

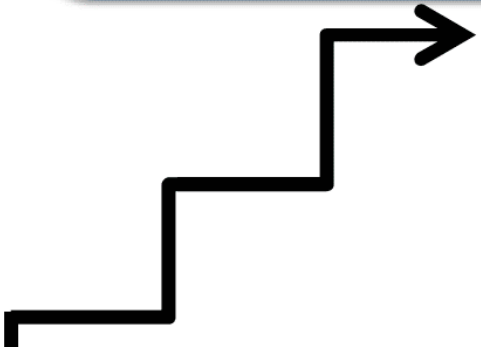
http://eplca.jrc.ec.europa.eu/

European ELCD.

European Reference Life Cycle Database (ELCD)

New version online since mid 2009!

- Reference data for EU
- Promote LCT and LCA
- Step-wise harmonization

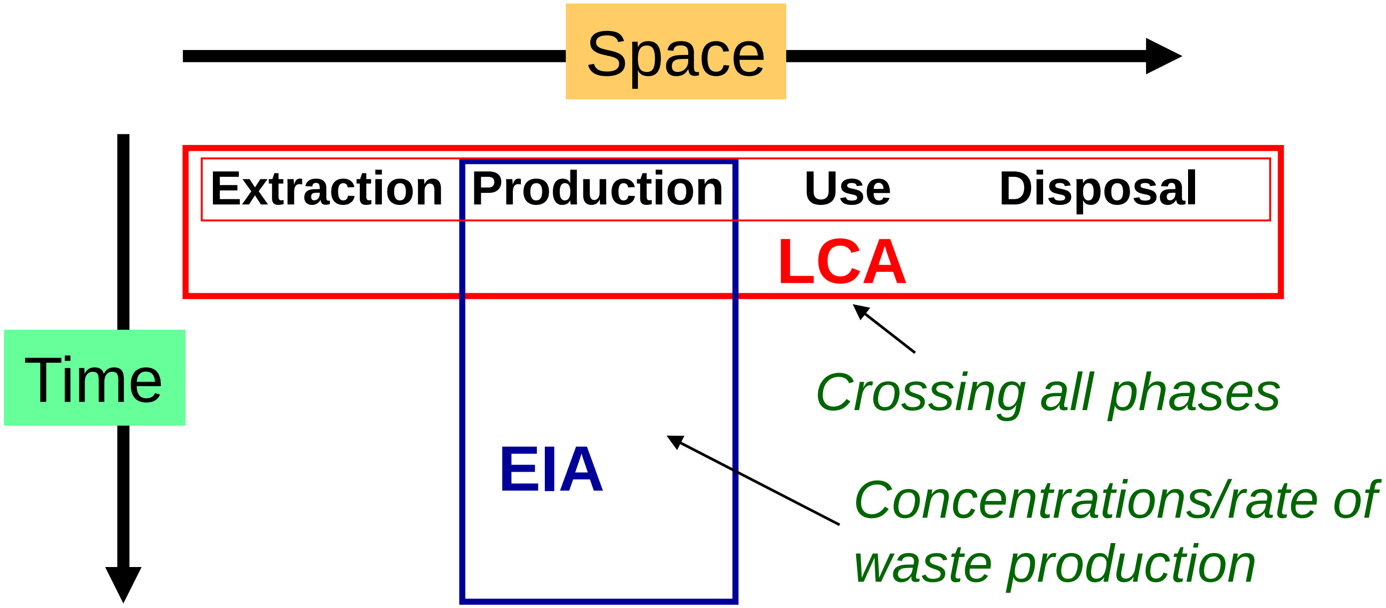


Content	350 data sets , 150 core goods and services, EU market
Scope	Core materials, energy , transport, end-of-life services
Provider	EAA european aluminium association European Copper Institute The Alliance for Beverage Cartons and the Environment FEFCO CEWEP PlasticsEurope Association of Plastics Manufacturers IMA Europe EUROGYPSUM The voice of the European gypsum industry ZINC EUROFER European Confederation of Iron and Steel Industries CEMBUREAU
In preparation	ACEA marcogaz LDA International TBE Tiles and Bricks of Europe Stay with Clay CEI-Bois

LCA Tools

- **EIA** (*environmental impact assessment*) a site-specific tool typically used to evaluate the environmental impact of capital investments/ designed services. (a procedure for encouraging decision-makers to take account of the possible effects of development investments on environmental quality and natural resource productivity and a tool for collecting and assembling the data planners need to make development projects more sustainable and environmentally sound [and ...] is usually applied in support of policies for a more rational and sustainable use of resources in achieving economic development)
- **EA** (*environmental assessment*) a site-specific tool typically used to evaluate an existing service. Include considerations on communications and management of information on environment.
- **RA** (*risk assessment*, seldom included both in EA and EIA) consider the risk shown by a material or service and includes considerations both of potential danger and of occurrence probability.

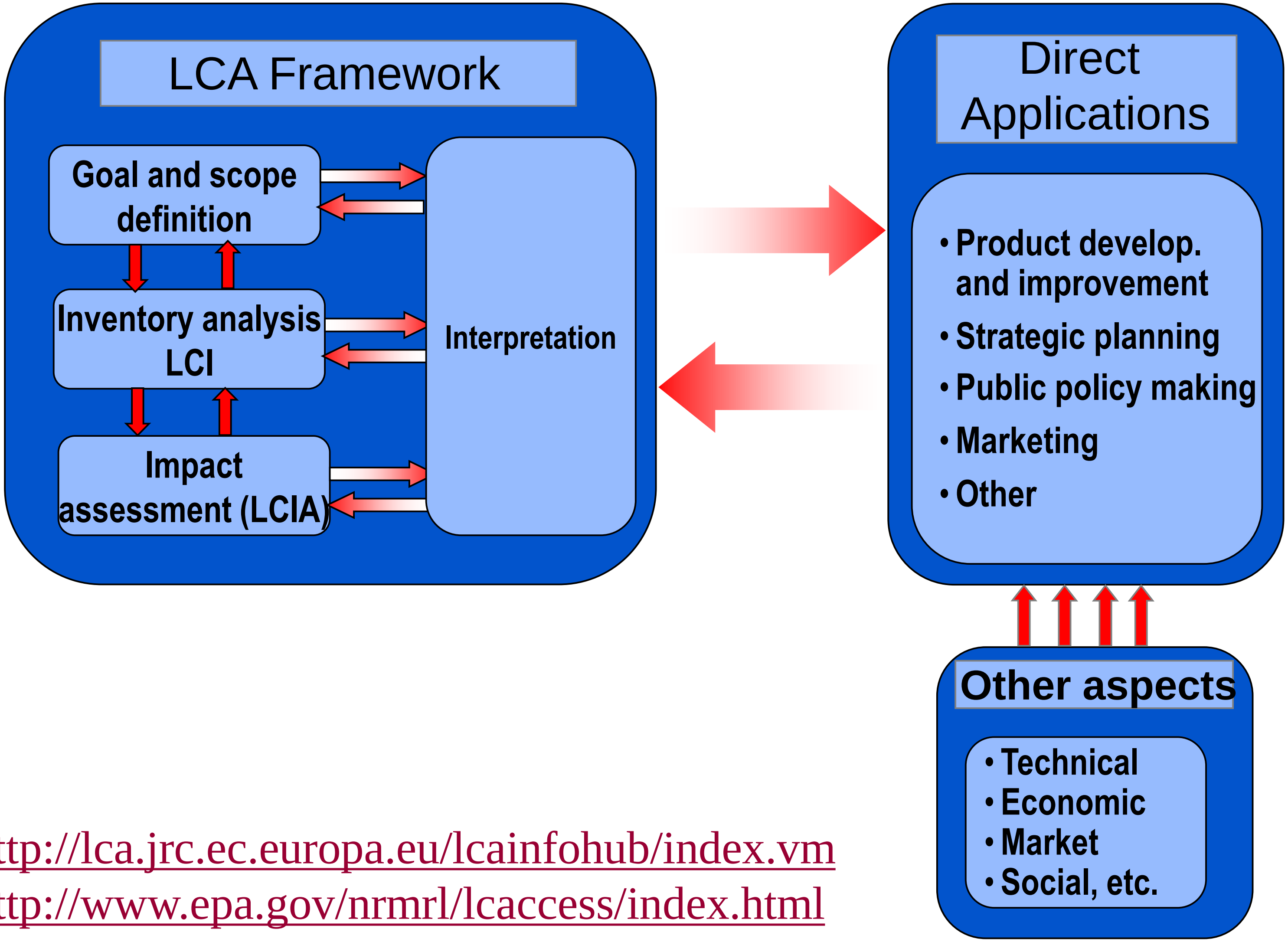
LCA vs. EIA (Environmental Impact Assessment)



A complete Life Cycle Analysis normally refers to a flow of materials and energy involved in a product from cradle to grave: starts from raw materials in their natural state and covers all the processes and operations of product use until its final discharge as waste.

The Eco Profiles are, on the contrary, an analysis from cradle to gate, and are concluded with the realisation of an useful, more or less finished, product.

Life Cycle Assessment: Principles and Framework



http://lca.jrc.ec.europa.eu/lcainfohub/index.vm
http://www.epa.gov/nrmrl/lcaccess/index.html

LCA Steps (ISO 14044)

Generally, a LCA consists of several main activities:

a. Goal definition and Scoping:
  - Define and describe the product, process or activity. The basis and scope of the evaluation are defined.

b. Inventory Analysis (LCI):
  - Create a process tree in which all processes from raw material extraction through wastewater treatment are mapped out and connected and mass and energy balances are closed (all emissions and consumptions are accounted for).

c. Impact Assessment (LCIA):
  - Emissions and consumptions are translated into environmental effects. The environmental effects are grouped and weighted.

d. Interpretation/Improvement Assessment:
  - Evaluate the results of the inventory analysis and impact assessment. Areas for improvement are identified.

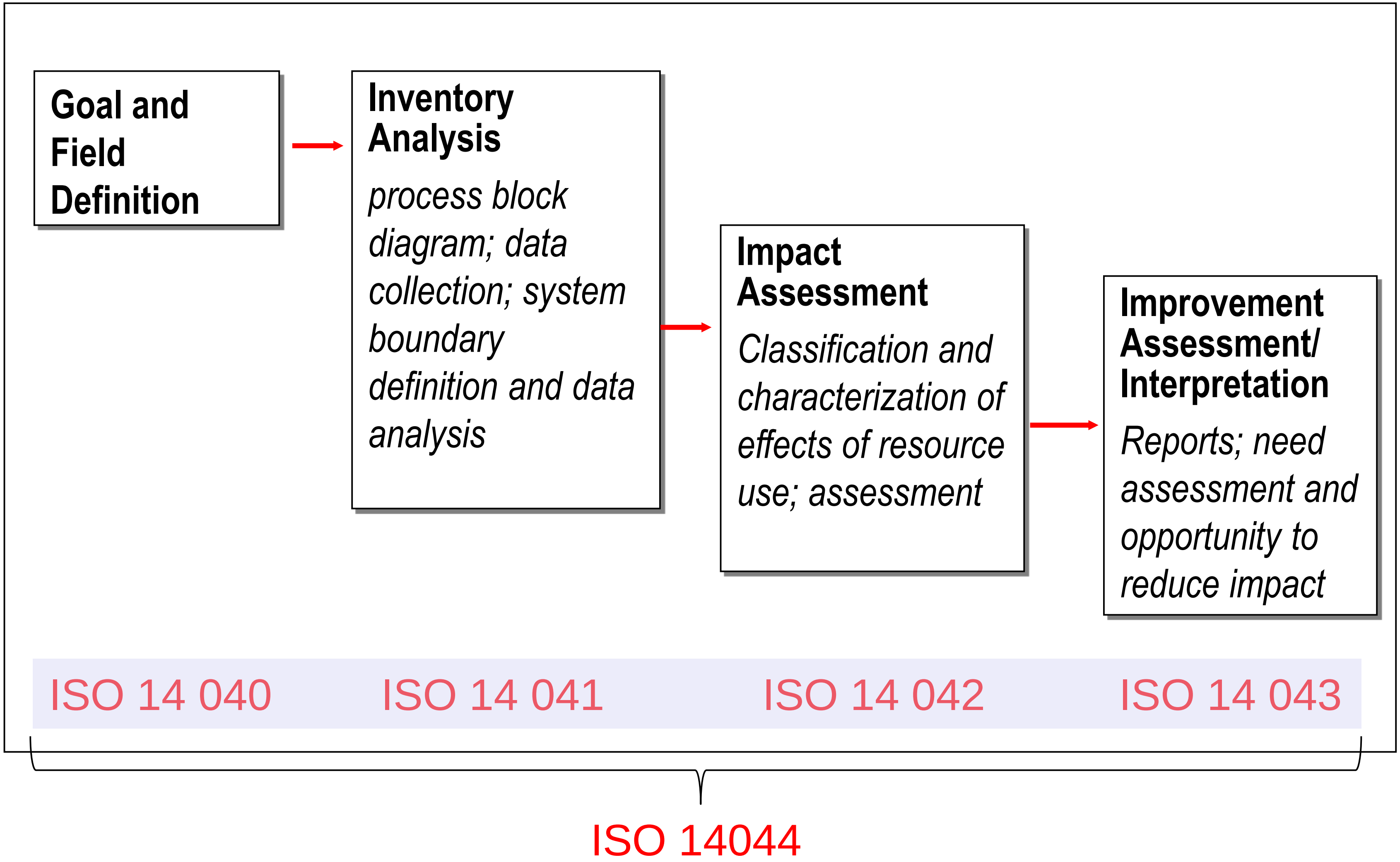
e. reporting and critical review of the LCA,

f. limitations of the LCA,

g. relationship between the LCA phases, and

h. conditions for use of value choices and optional elements.

Life Cycle Assessment and ISO 14 000 Standards



Goal and Field Definition

Inventory Analysis
process block diagram; data collection; system boundary definition and data analysis

Impact Assessment
Classification and characterization of effects of resource use; assessment

Improvement Assessment/ Interpretation
Reports; need assessment and opportunity to reduce impact

ISO 14 040 ISO 14 041 ISO 14 042 ISO 14 043

ISO 14044

Two Different Approaches of LCA

	LCA of products	LCA of processes
Goal	Assessment of environmental impacts through whole life cycle of products/processes fulfilling the function of interest	
Object	Products with specific function	Processes for specific product
Main stream	Production-use-waste disposal	Construction-operation-demolition
Base of assessment	Functional unit : performance characteristic of products Reference flow : quantity of product fulfilling functional unit	Functional unit : quantity of product or treatment object Reference flow : same as functional unit

The LCA Process for Products

Goal → **Scope** → **Inventory** → **Impact assessment**

Goal

- Assess product
- Improve product
- Compare products
- Design new product
- Create product specifications

Scope

- Functional Unit
- Reference product(s)
- Assessment parameters
- Important Processes
- Time Horizon
- Allocation

Inventory

Environmental Exchanges

- Inputs (Energy & Materials)
- Outputs (Air, Water & Waste)
- Work Environment

Impact assessment

Impact Potentials

- Resource Consumption (Energy & Materials)
- Environmental Impacts (Global Warming, Acidification, Ozone, etc.)
- Impact on Work Environment

LCA – Goal Definition

- The goal shall unambiguously state the intended application, the reasons for carrying out the study , criteria to be adopted, and the intended audience.
- Moreover, the system boundary – both temporal and spatial – must be determined.
- The scope should include / consider the following:

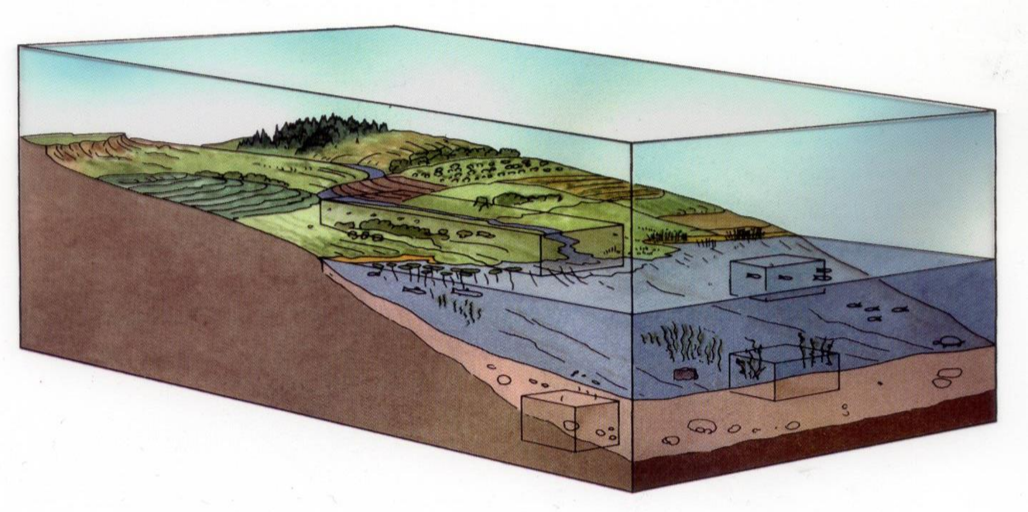
function of the product	**assumptions**
functional unit	limitations
boundaries	type of report format
allocation procedures	the product system
types of impact and methodology of assessment	data requirements

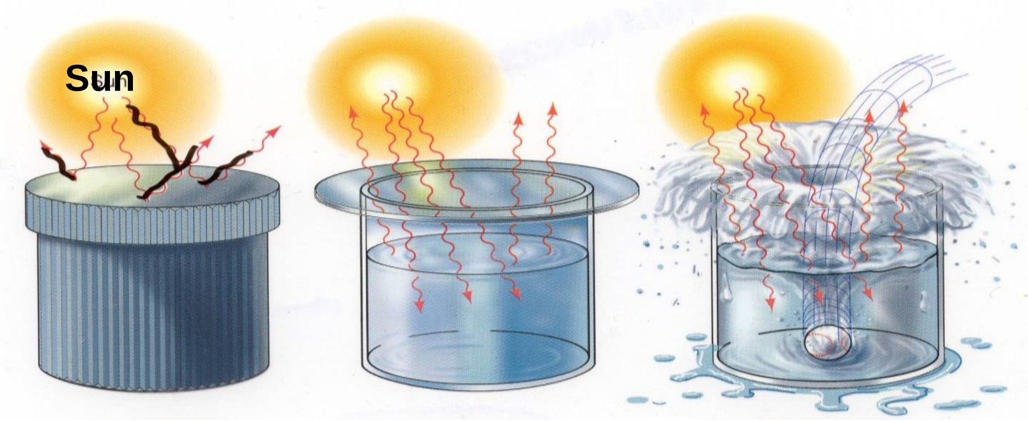
System

- System – *a group of interconnected and interacting objects and phenomena; any portion of universe that can be isolated from remaining universe with the aim to observe changes*
- *Surrounding* – *region outside the system boundary*

    - Classification:
        - Boundary nature
        - Open
        - Closed
        - Isolated

System Classification

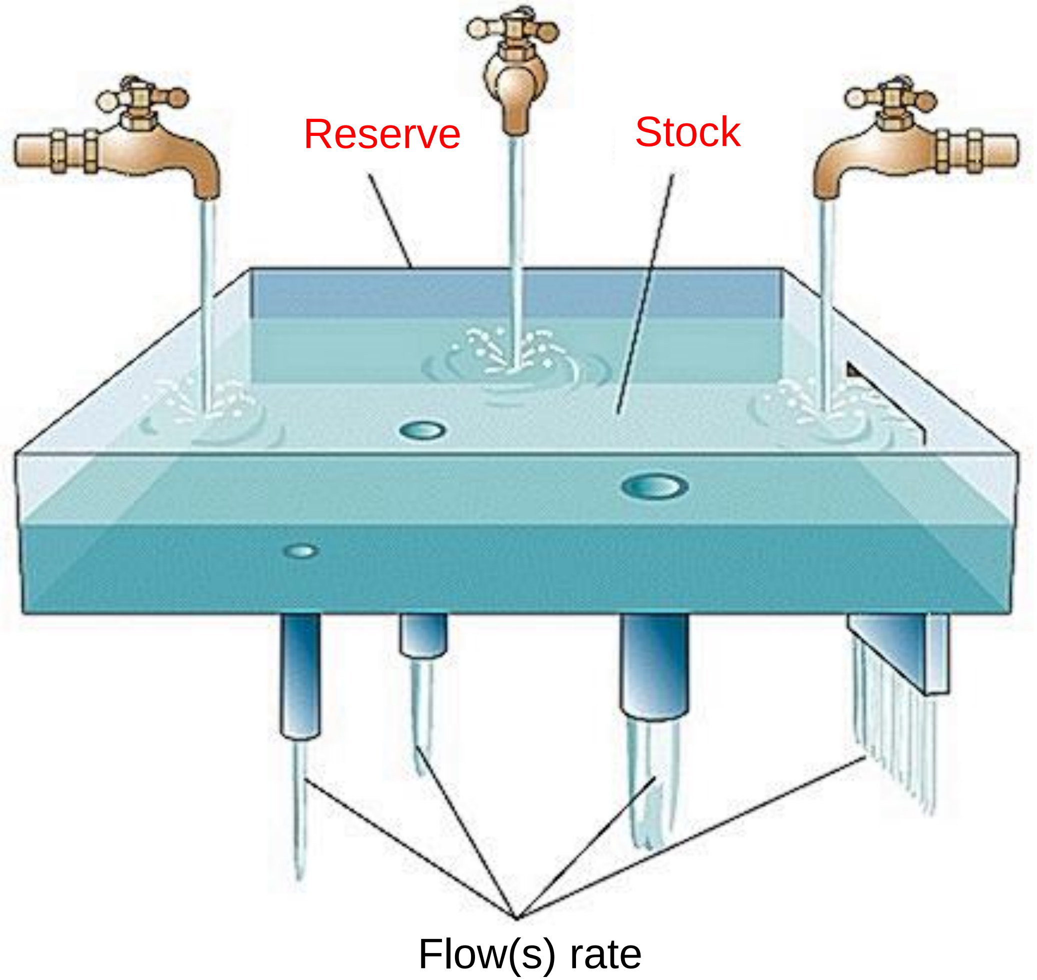




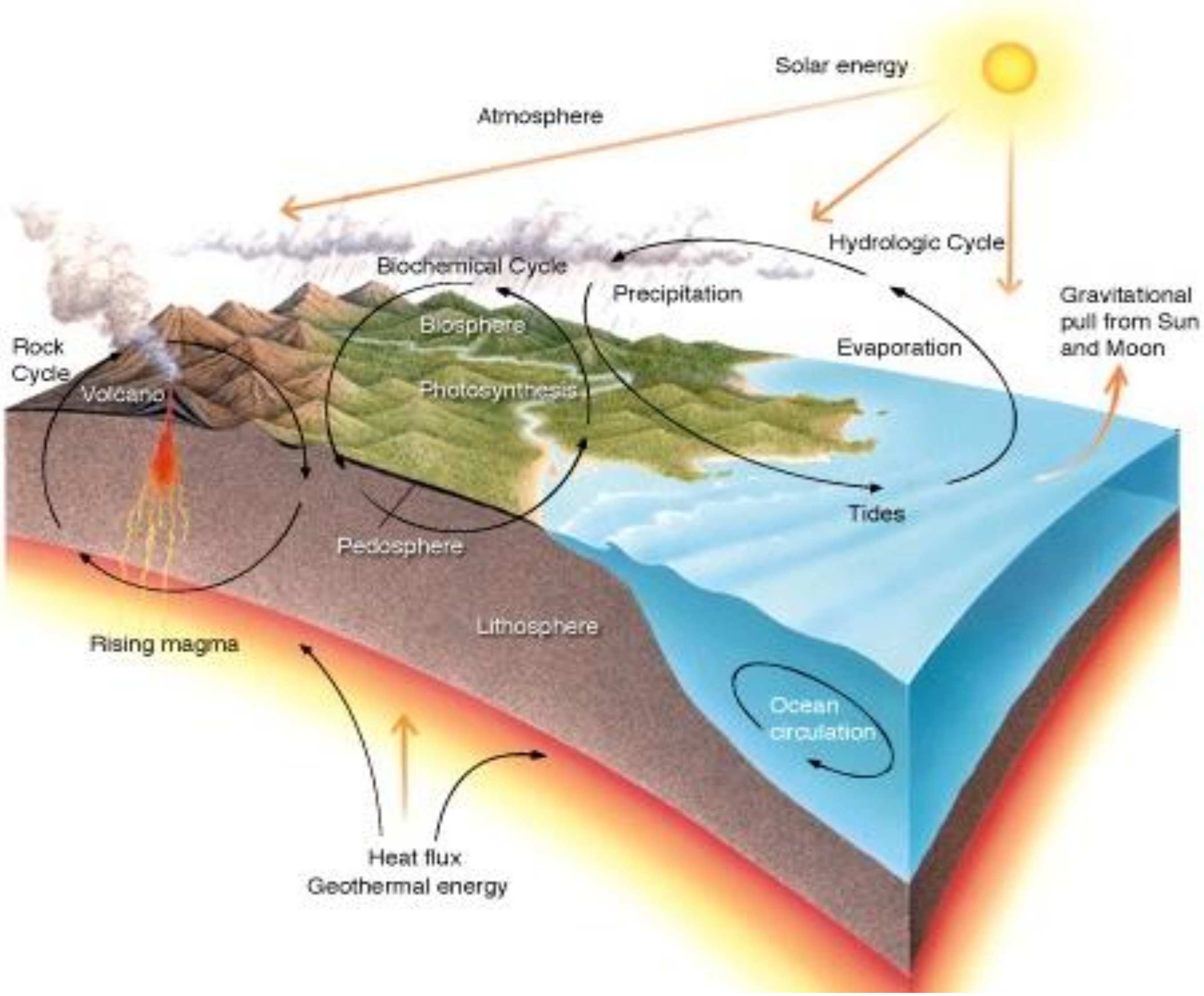
A. Isolated system **B. Closed system** **C. Open system**

The main terrestrial systems are **Dynamic Systems**

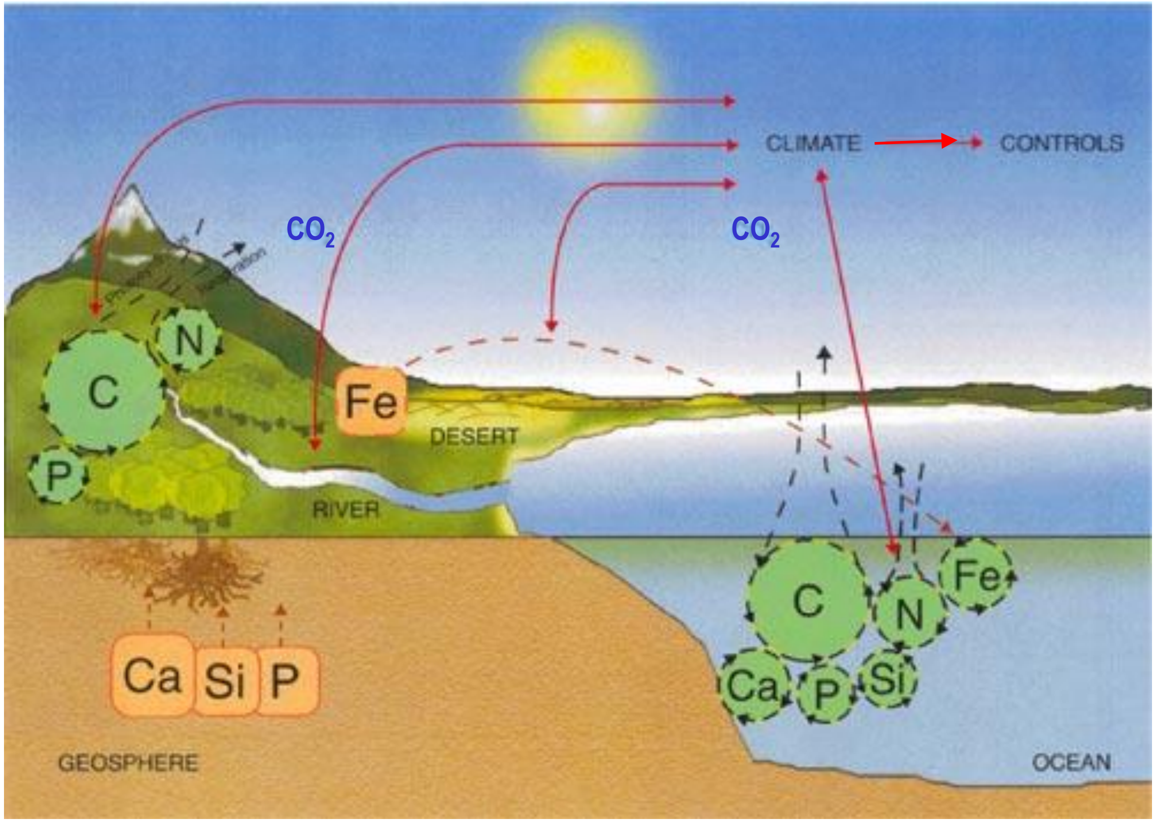
System Components



Earth System



Cycles of carbon, nitrogen, phosphorous and several other biologically essential elements are strictly coupled in terrestrial, fresh water and see waters ecosystems



These three subsystems of the biosphere are linked each other through the changes of the hydrological cycle of the atmosphere. The ocean-atmosphere gas exchange, which is controlled by marine biology at long times, determines the atmospheric concentration of CO_2 and therefore the global climate. Terrestrial plants are sensitive to climate and CO_2 concentration in the atmosphere. The state of the vegetation controls the speed of transfer from land to sea essentials to marine organisms, thus closing the cycle.

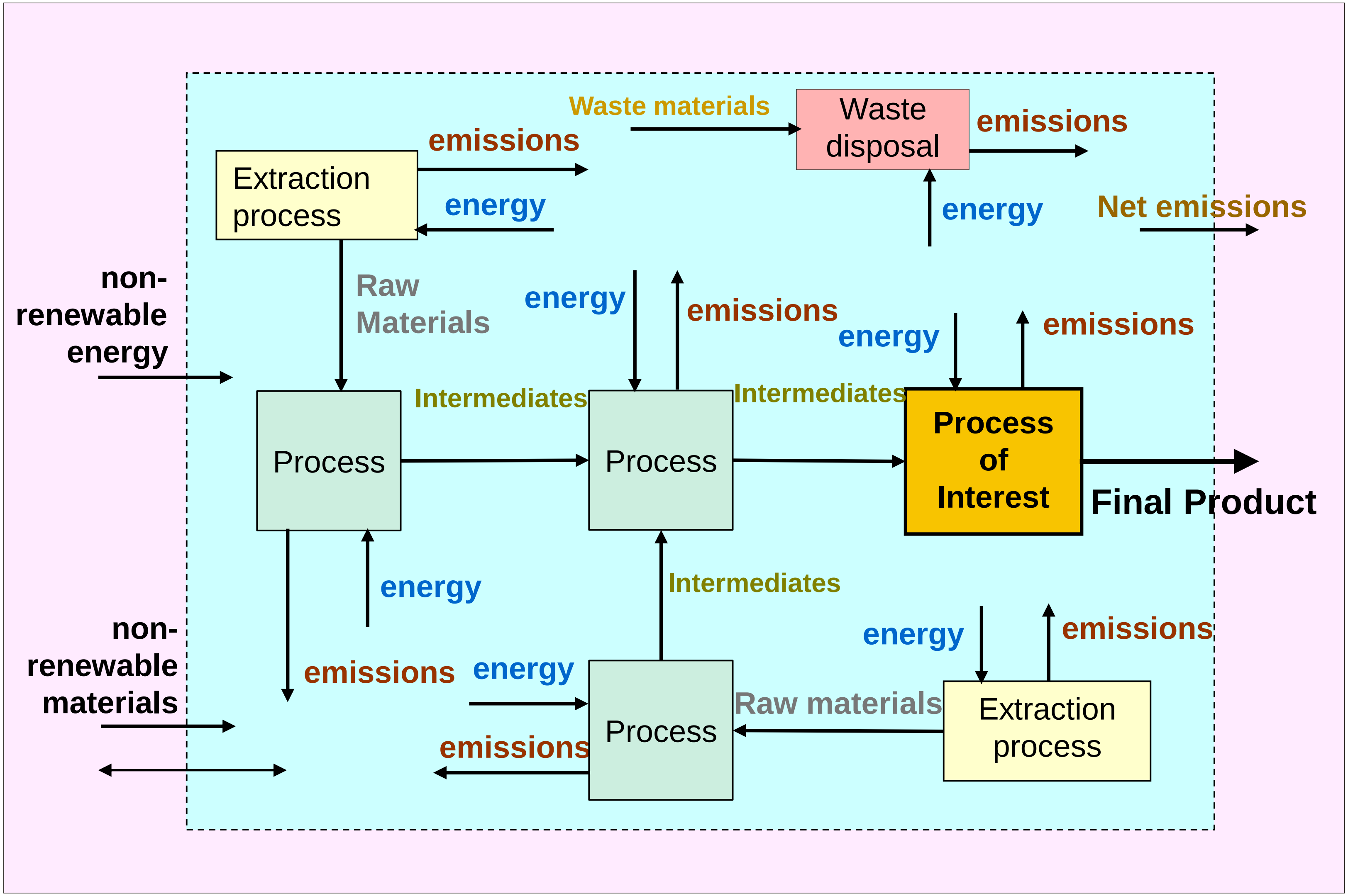
Boundaries

- The choice of processes, products, and activities that are accounted for and those that are not, can have a major impact on life-cycle analysis results…. at times the placement of boundaries can have direct bearing on the overall conclusions.
- It is impossible to clinically isolate a process or product – of course, the question literally is:

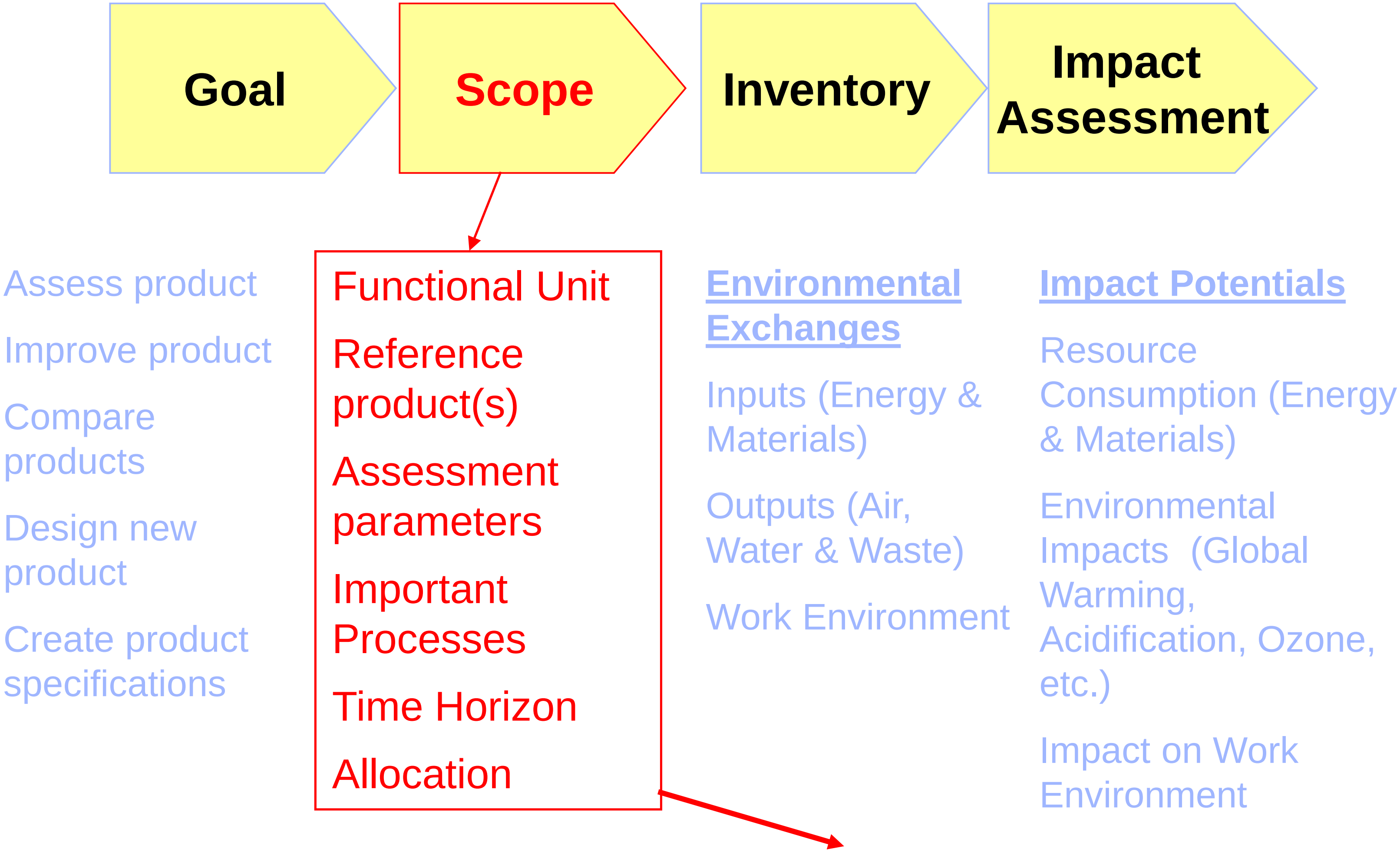
where do we draw the line?

- Determined by several factors:
    - intended application of the study
    - assumptions
    - cut-off criteria
    - data and cost constraints
    - intended audience

System Boundary and Structure



The LCA Process



Goal

Scope

Inventory

Impact Assessment

Assess product

Improve product

Compare products

Design new product

Create product specifications

Functional Unit

Reference product(s)

Assessment parameters

Important Processes

Time Horizon

Allocation

Environmental Exchanges

Inputs (Energy & Materials)

Outputs (Air, Water & Waste)

Work Environment

Impact Potentials

Resource Consumption (Energy & Materials)

Environmental Impacts (Global Warming, Acidification, Ozone, etc.)

Impact on Work Environment

Functional Unit (FU) or Basis

A FU is a measure of the performance of the functional outputs of the product system. In LCA the focal point is not the product, but the service or function provided by the product

- Purpose → provide a reference to which the inputs and outputs are related.
- Necessary → to ensure comparability of LCA results

FU must be defined and measurable.

vs.

~~1 million bottles for distributing water”~~

“Distributing 1 million liters of bottled water”

Scope

Functional Unit

- What provides the service?
  - Egg tray
    - Transports 12 eggs from grocery store to home without breaking…
  - Crane arm
    - Fits on existing base, lifts at least 200 kg…

Reference product(s)

- Existing products that delivery same or almost same service
  - Egg trays already in use
  - Are there existing cranes that deliver ~ same service?

Scope (cont.)

Assessment parameters

- Environmental Impacts
- Resource Consumption
- Work Environment…

Important Processes

Time Horizon

- While product is manufactured?
- While product is in use?
- Long-term environmental effects?
    - Could be hundreds of years or more

Allocation

- It may be difficult to allocate environmental impacts

- May be multiple products from single processes
- Inputs may be byproducts of other processes
- Outputs may become inputs for other processes

The LCA Process

Goal → **Scope** → **Inventory** → **Impact assessment**

Goal
- Assess product
- Improve product
- Compare products
- Design new product
- Create product specifications

Scope
- Functional Unit
- Reference product(s)
- Assessment parameters
- Important Processes
- Time Horizon
- Allocation

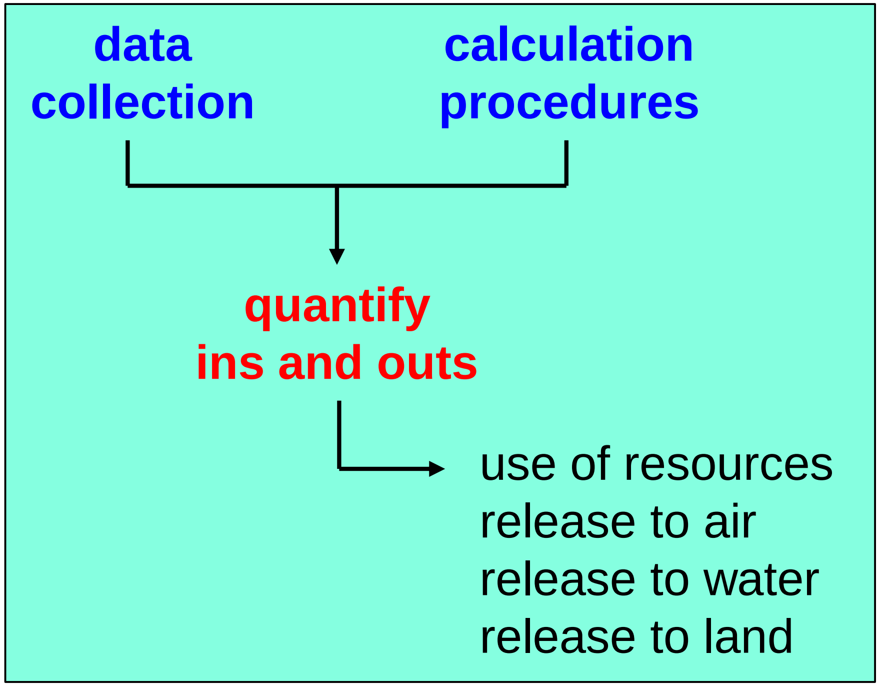
Inventory
- **Environmental Exchanges**
- Inputs (Energy & Materials)
- Outputs (Air, Water & Waste)
- Workplace

Impact assessment
- **Impact Potentials**
- Resource Consumption (Energy & Materials)
- Environmental Impacts (Global Warming, Acidification, Ozone, etc.)
- Impact on Work Environment

What are Inventory Flows?

LCA inventory is an objective, data-based process of quantifying material and energy flows throughout the life cycle of a product, process activity…

- energy and raw material requirements
- air emissions
- waterborne effluents
- solid waste
- etc.



data collection

calculation procedures

quantify ins and outs

use of resources
release to air
release to water
release to land

Inventory Analysis (LCI)

- Assess that the inputs and outputs of all life-cycle processes have to be determined in terms of material and energy (i.e. kg of a product used × kg of CO_2 produced /kg)

- Start with making a process tree or a flow-chart classifying the events in a product's life-cycle which are to be considered in the LCA, plus their interrelations.

- Next, start collecting the relevant data for each event: the emissions from each process and the resources (back to raw materials) used.

- Establish (correct) material and energy balance(s) for each process stage and event.

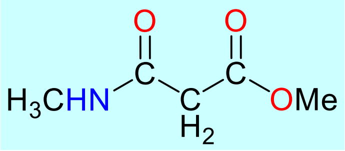
Inventory Examples

- Gas contributing to global worming
- Gas contributing to ozone layer depletion
- Gas favoring the smog formation
- Toxic chemicals
- Energy
- Degradation of land/habitat

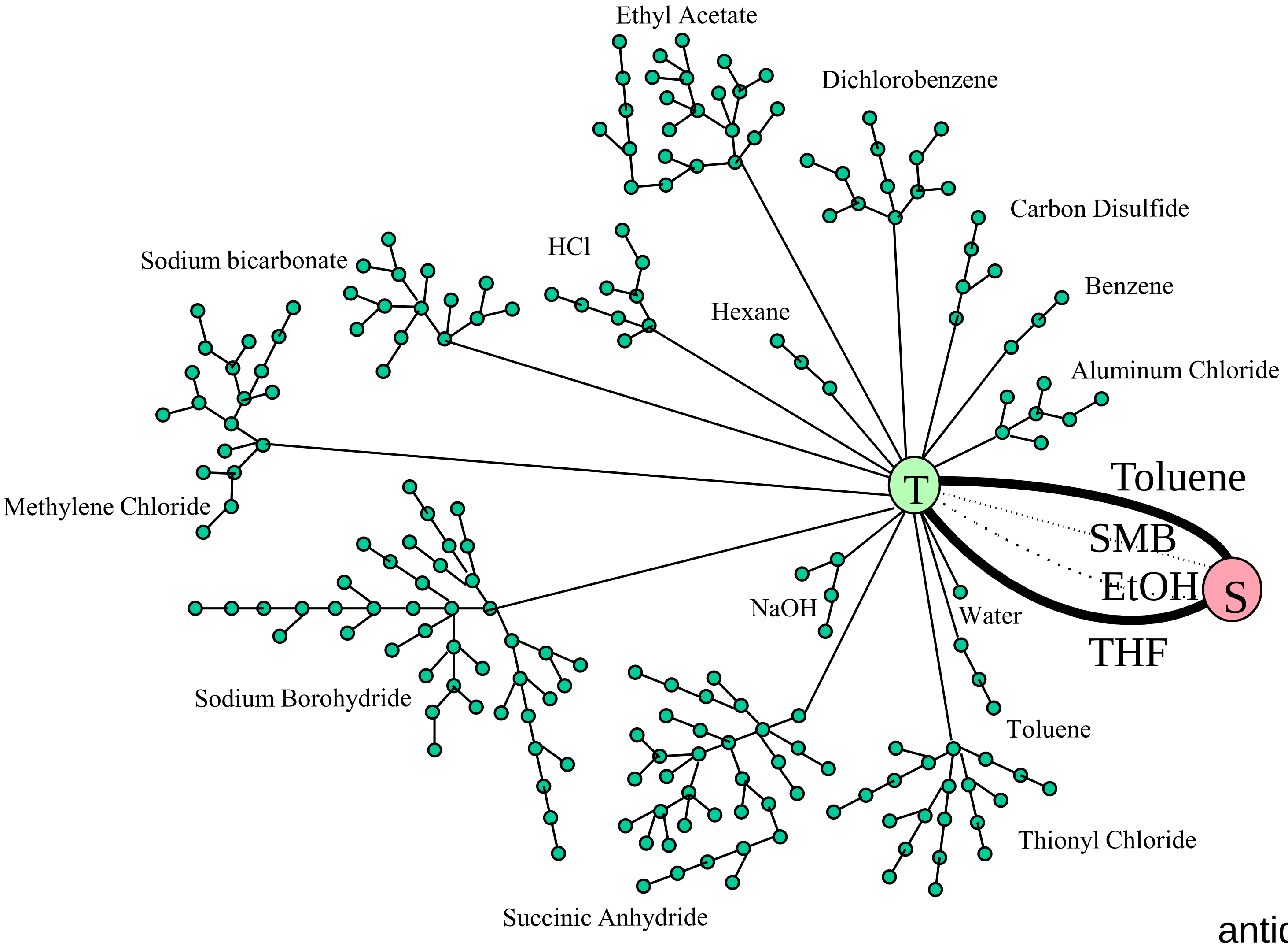
Inventory in the Synthesis of MonoMethylAminoMalonate (MMAM)

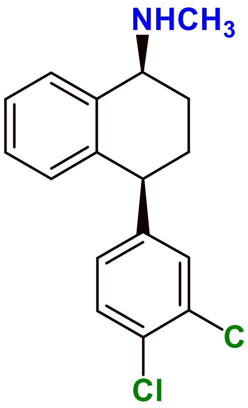
1° | 2° | 3° | 4° | 5° | 6° | 7° | 8° | 9° | 10° | 11° | 12°

- MMAM
  - Dimethyl malonate
    -
      - Acetic acid
        - Methanol
          - Natural gas
          - Hydrogen
            - Natural gas
          - Carbon monoxide
            - Natural gas
        - Carbon monoxide
          - Natural gas
      - Acetic anhydride
        - **Acetic acid**
          - **Methanol**
            - **Natural gas**
            - **Hydrogen**
              - **Natural gas**
            - **Carbon monoxide**
              - **Natural gas**
        - **ketene**
          - **Acetone**
            - **Isopropanol**
              - Propylene
                - **Petroleum extraction/refin.**
                - **Water**
              - Sulfuric acid
                - **Sulfur trioxide**
                  - **Sulfur dioxide**
                    - **Sulfur**
                      - **Petroleum extraction/refinery**
                    - **Oxygen**
                  - **Oxygen**
                - **Water**
              - Water
            - **Oxygen**
      - **Chlorine**
        - **Sodium Chloride**
          - **Salt**
          - **Water**
        - **Water**
    - **Sodium Cyanide**
      - Sodium hydroxide
        - **Sodium Chloride**
          - **Salt**
          - **Water**
        - **Water**
      - **Hydrogen cyanide**
        - **Ammonia**
          - **Air**
          - **Natural gas**
          - **Water**
        - **Natural gas**
        - **Oxygen**
          - **Air**
    - **Methanol**
      - Natural gas
      - Hydrogen
        - **Natural gas**
      - Carbon monoxide
        - **Natural gas**
    - **Sodium hydroxide**
      - **Sodium Chloride**
        - **Salt**
        - **Water**
      - **Water**
    - **Sulfuric acid**
      - **Sulfur trioxide**
        - **Sulfur**
          - **Petroleum extraction/refinery**
        - **Air**
        - **Water**
  - **Methylamine**
    - **Methanol**
      - **Natural gas**
      - **Hydrogen**
        - **Natural gas**
      - Carbon monoxide
        - **Natural gas**
    - **Ammonia**
      - **Air**
      - **Natural gas**
      - **Water**
    - Water
  - **Water**
  - Ethyl acetate
    - **Sulfuric acid**
    - **Acetic acid**
    - **Ethanol**
    - Water



Flow Diagram for the Synthesis of Sertraline



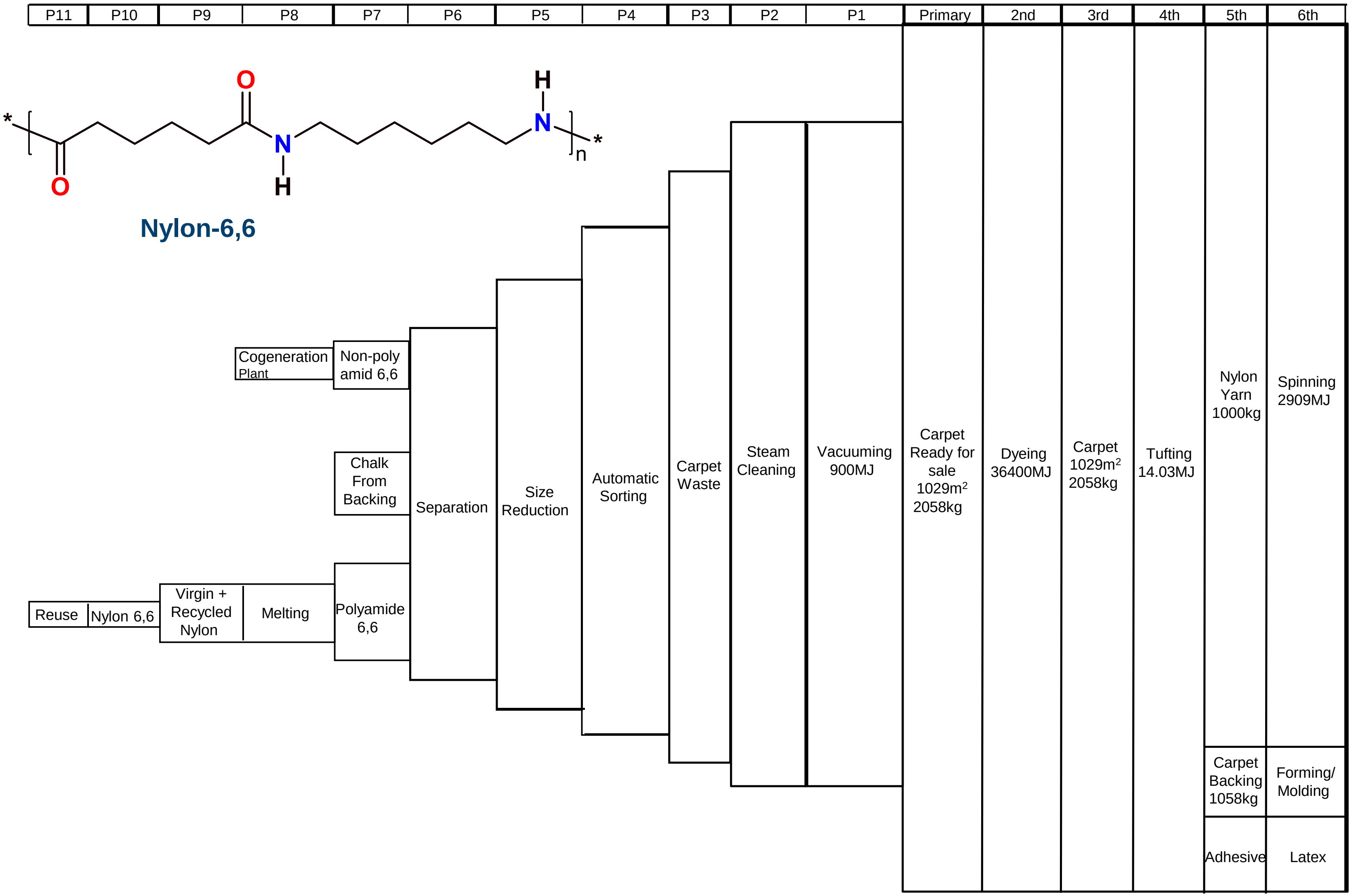


antidepressant drug

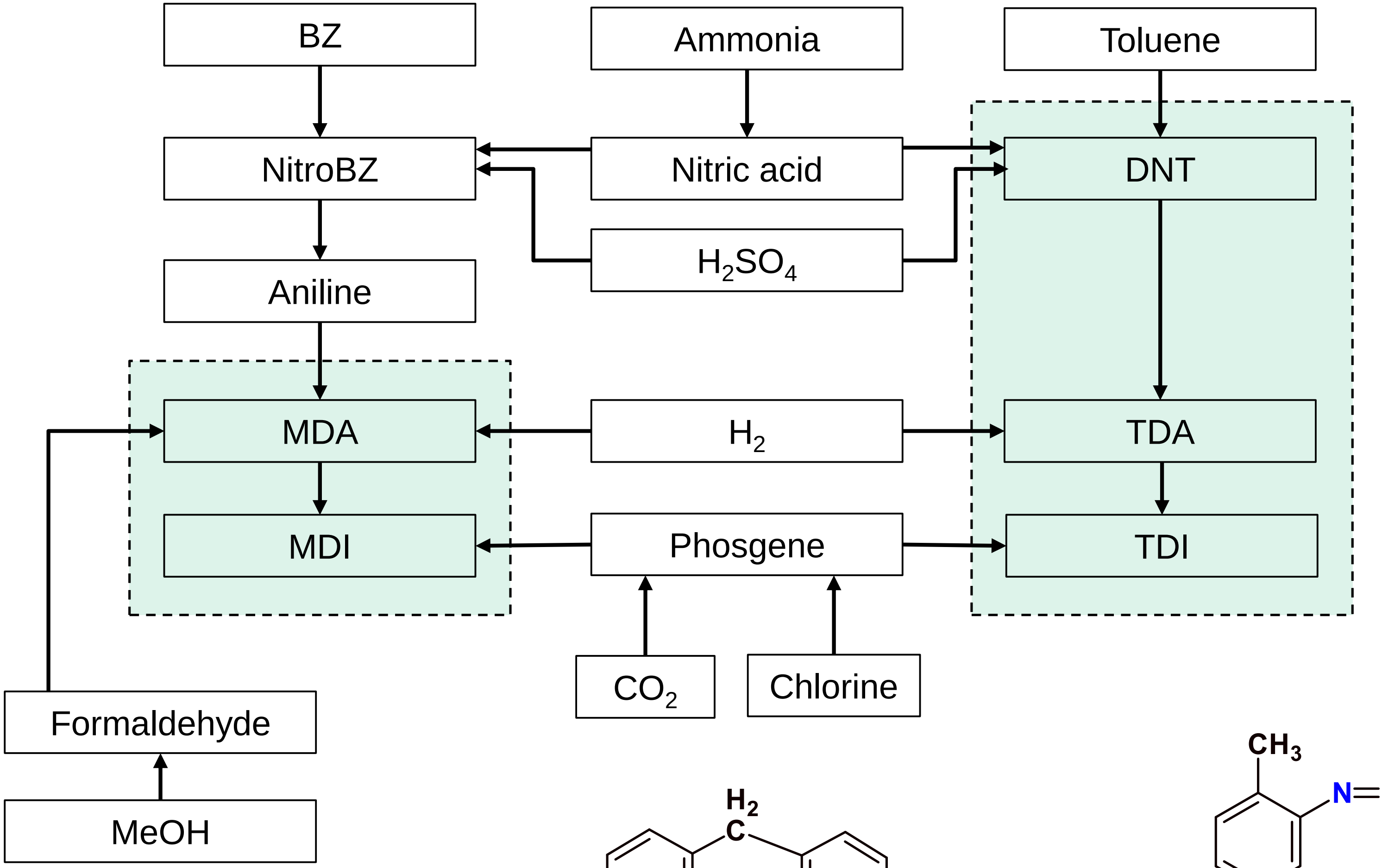
Quantified Inventory in the production of some polymers (Nylon 6,6, Polypropylene, Rubber NR)

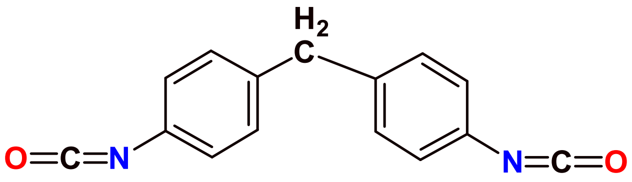
7 th	8 th	9 th	10 th	11 th	12 th	13 th	14 th	15 th
Nylon 6.6 (1000 kg)	Hexamethylene-Diamine (476 kg)	Adiponitrile (443 kg)	Adipic acid (599 kg)	Cyclohexanol (223 kg)	Cyclohexane (196 kg)	Benzene (182 kg)	Nafta (2230 kg)	Oil Refinery
						Hydrogen (14.9 kg)	Natural Gas (209 kg)	
							Water (418 kg)	
							Oxygen (61.1 kg)	Air (364 kg)
					Oxygen (22.5 kg)	Air (134 kg)		
				Cycloexanone (223 kg)	Cyclohexane (265 kg)	Benzene (246 kg)	Nafta (3010 kg)	Oil Refinery
						Hydrogen (20.1 kg)	Natural Gas (72.4 kg)	
							Water (145 kg)	
							Oxygen (82.4 kg)	Air (489 kg)
					Oxygen (72.7 kg)	Air (433 kg)		
				Nitric Acid (6410 kg)	Ammonia (1560 kg)	Air (2800 kg)		
						Natural Gas (697 kg)		
						Water (1870 kg)		
					Water (641 kg)			
					Air (22000 kg)			
			Ammonia (140 kg)	Air (252 kg)				
				Natural Gas (62.5 kg)				
				Water (168 kg)				
		Hydrogen (33.1 kg)	Natural Gas (119 kg)					
			Water (283 kg)					
			Oxygen (136 kg)	Air (811 kg)				
	Adipic acid (645 kg)	Cyclohexanol (241 kg)	Cyclohexane (212 kg)	Benzene (197 kg)				
				Hydrogen (16.1 kg)				
			Oxygen (24.3 kg)	Air (145 kg)				
		Cyclohexanone (241 kg)	Cyclohexane (286 kg)	Benzene (265 kg)				
				Hydrogen (21.7 kg)				
			Oxygen (78.6 kg)	Air (469 kg)				
		Nitric Acid (6902 kg)	Ammonia (1679 kg)	Air (3010 kg)				
				Natural Gas (751 kg)				
				Water (2010 kg)				
			Water (699 kg)					
			Air (23700 kg)					
Polypropylene (1058 kg)	Propylene (1058 kg)	Nafta (6010 kg)	Oil refinery					
		Steam (3005 kg)	Water (3005 kg)					
Hevea Brasiliensis sap	Hevea Brasiliensis tree							

Life Cycle Diagram of Nylon-6,6 Carpet

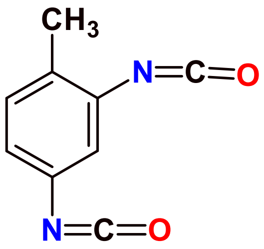


MDI and TDI routes with respect to other Large Volume chemical processes


BZ
Ammonia
Toluene
NitroBZ
Nitric acid
DNT
H_2SO_4
Aniline
MDA
H_2
TDA
MDI
Phosgene
TDI
CO_2
Chlorine
Formaldehyde
MeOH



MDI
methylenediphenyl diisocyanate



TDI
Toluene diisocyanate

Eco-Effectiveness and Design

Get Free of Known Culprits

- Avoid chemicals that are known problems
  - E.g., cadmium, lead, mercury

Follow Informed Personal Preferences

- When dealing with gray areas, data uncertainty…

Create Lists

- X list (known culprits): avoid
- Grey list: problematic, but may be the best, or only, available
- Positive list: preferred

Reinvent

Good
Better
Optimum
↓

Cradle to Cradle, by
McDonough & Braungart, 2002

Five Main Criteria to Assess Dangerous Chemicals

(1) **Quantity**. The amount of chemical to apply, as well as the method.

(2) **Persistence**. Is provided in terms of half life or residence time.

(3) **Toxicity** - LC_{50} and LD_{50}

(4) **Bioaccumulation and bioamplification**. The risk is that bioaccumulation may cause toxicity. The majority of pesticides are hydrophobic, ”soluble in water," and lipophilic. Moreover, they can have more than one functional group which influence the properties of solubility.

(5) **Other negative effects** , i.e. unusual chemical properties as chelating ability which alter the availability of other chemicals in the environment, generating other problematic substances.

REACH – white book EU

Green Purchasing

The basic three principles of Green Purchasing

- ➢ Taking into account the product cycle
- ➢ Politics and practices of Green Purchasing management
- ➢ Availability of eco-correlated information to assess product manufacturers and sellers

Green Purchasing work at 2 levels

- → Purchase more safe, eco-compatible materials, technology, etc. by manufacturers
- → End users demand of of Eco-compatible products

The LCA Process

Goal → **Scope** → **Inventory** → **Impact assessment**

Assess product

Improve product

Compare products

Design new product

Create product specifications

Functional Unit

Reference product(s)

Assessment parameters

Important Processes

Time Horizon

Allocation

Environmental Exchanges

Inputs (Energy & Materials)

Outputs (Air, Water & Waste)

Work Environment

Impact Potentials

Resource Consumption (Energy & Materials)

Environmental Impacts (Global Warming, Ozone, Acidification, etc.)

Impact on Work Environment

Impacts Assessment

Impacts identification → impacts evaluation

Methods of assessment :

1) Models
   - Based on a mathematical relationship between the cause and effect
   - Can be: Physical, Chemical, Biological
2) Experiments
   - Field
   - Laboratory
3) Physical representation (pictures, photographs, films, 3D models)
4) Assessment
   - Used to calculate the cost or benefit of an environmental aspect as a result of an activity

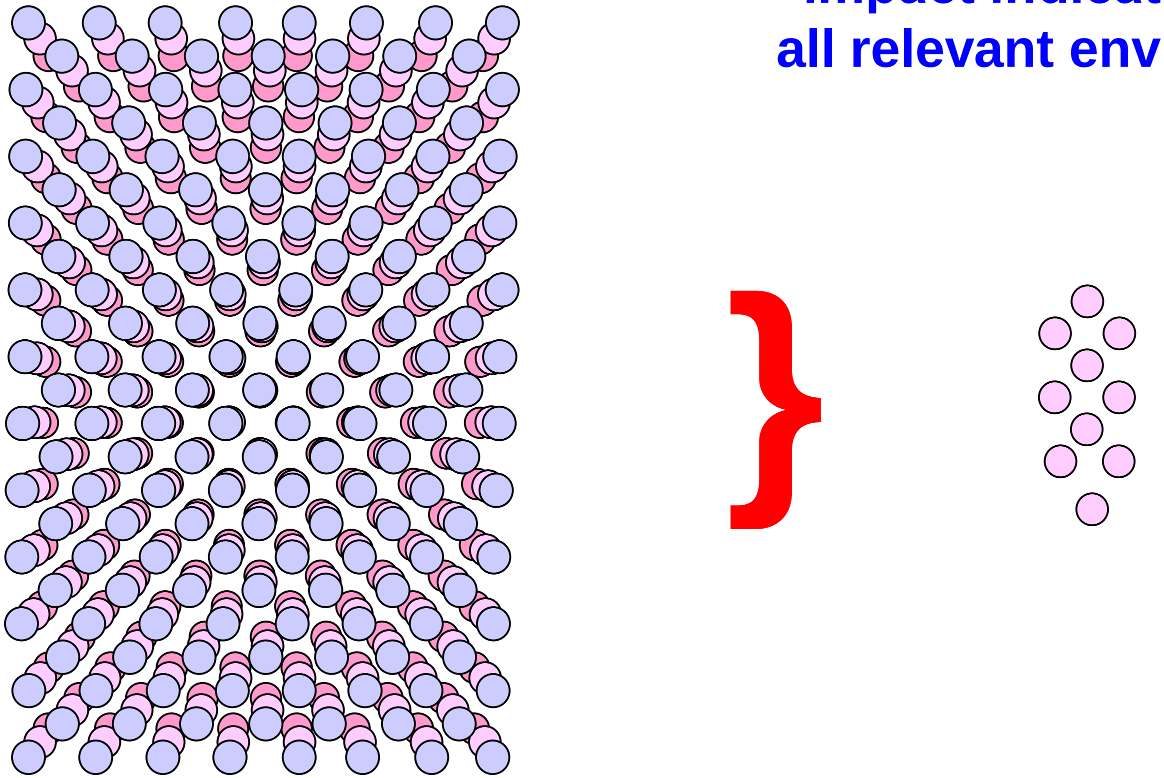
LCI to LCA – Making the Data Useful

Life-Cycle Inventory

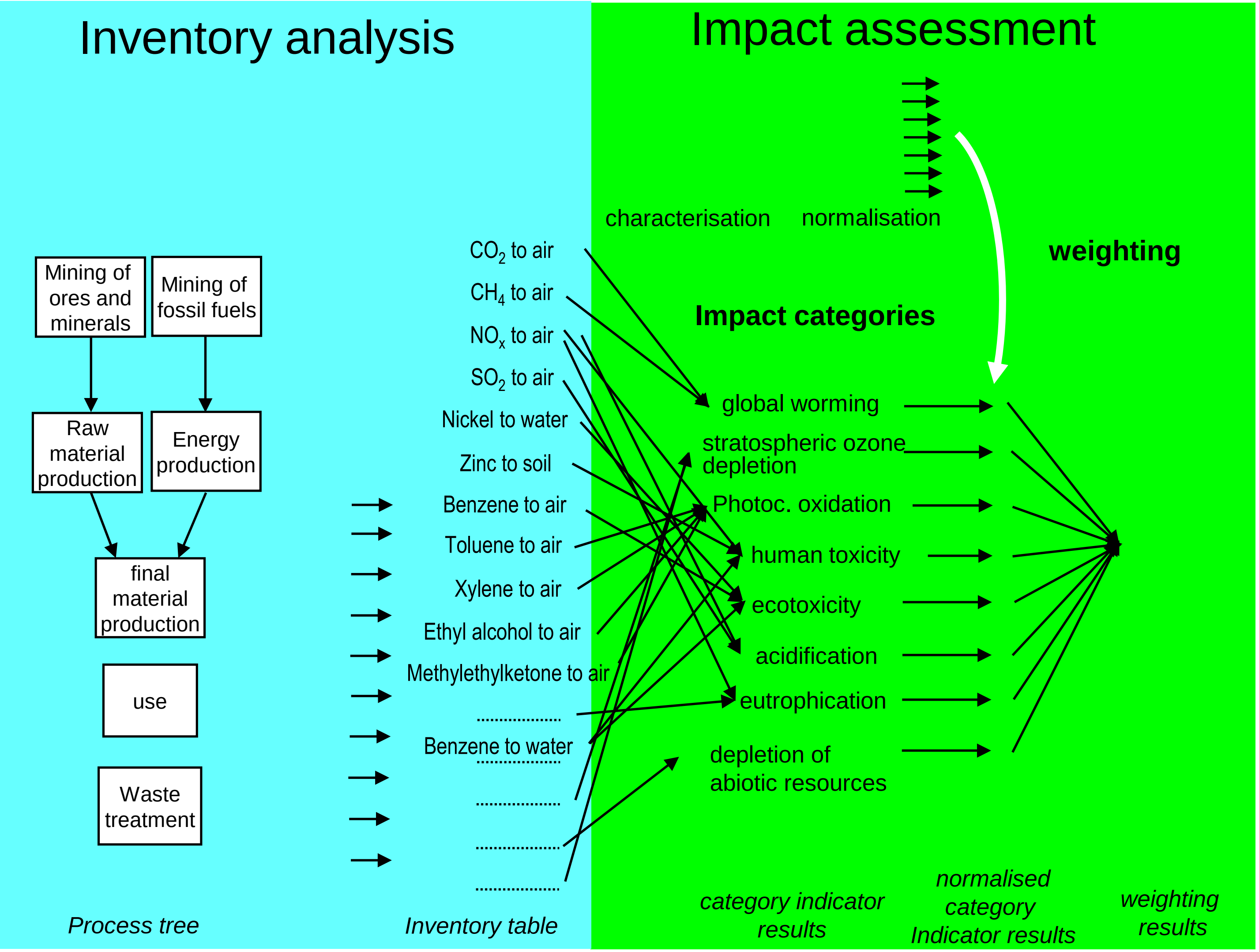
> 5000 data points

Life-Cycle Impact Assessment

converts LCI data into 12-20 "impact indicators" that address all relevant environmental issues



LCI to LCA



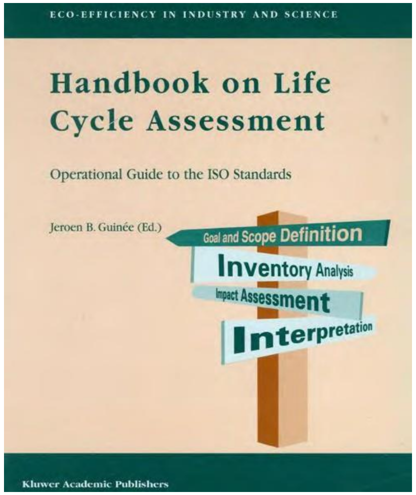
Source (modified): Study "Policy Review on Decoupling" (CML and partners) for EC, DG Env

Selection of Impact Category

Commonly the following impact categories are taken into consideration:

- Abiotic resources
- Biotic resources
- Land use
- Global warming
- Acidification

- Ecotoxicological impact
- Toxicological human impact
- Oxidant formation from light
- Stratospheric ozone depletion
- Eutrophication
- Work environment



ECO-EFFICIENCY IN INDUSTRY AND SCIENCE

Handbook on Life Cycle Assessment

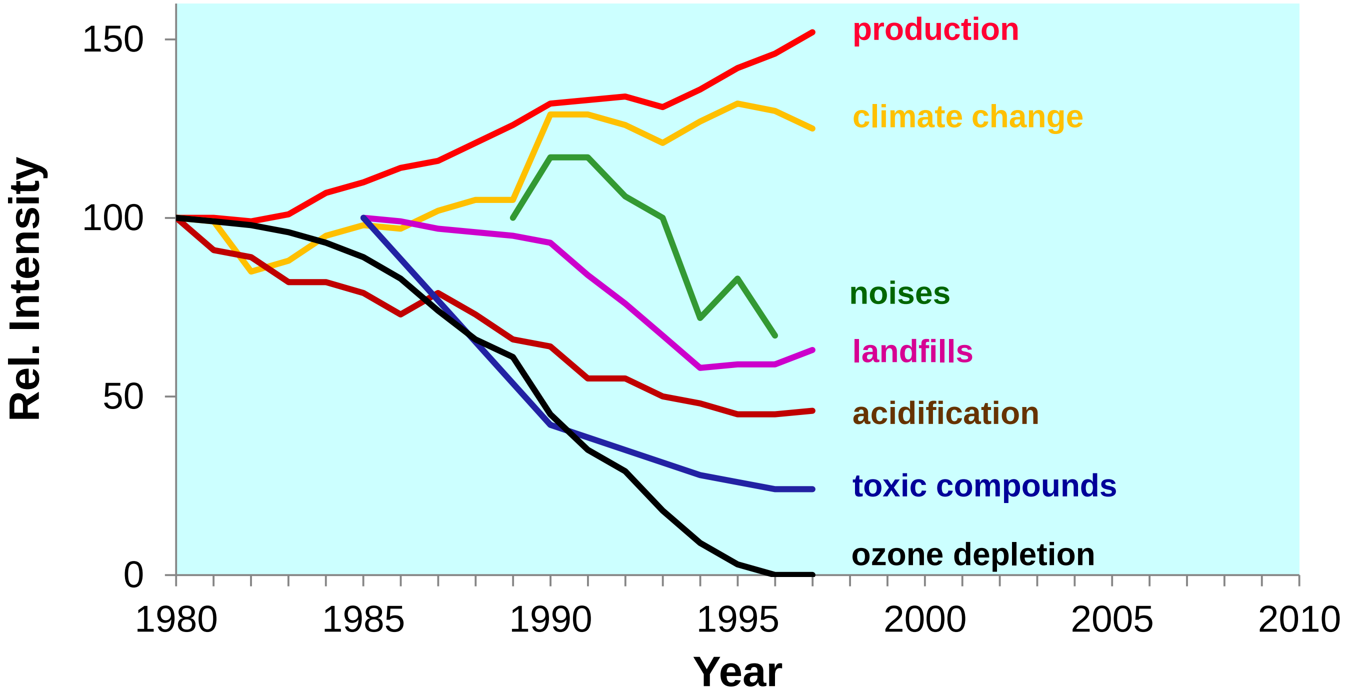
Operational Guide to the ISO Standards

Jeroen B. Guinée (Ed.)

Kluwer Academic Publishers

Environmental Indicators (EPI)

“An indicator is a parameter (or value derived from parameters) which provide information on a phenomenon. The indicator include a meaning which overcomes the properties directly associates to the value of the parameter”



Indicator Themes -
The Three Bottom Lines

Physical/chemical/ biological

- Volatility
- GWP
- Primary Energy
- Aquatic Ecotoxicity
- Atom Efficiency

Financial

- Turnover
- Net earnings
- “Added Value”
- Cash flow
- etc..

Social

- Adult literacy rate
- Access to drinking water
- Household income
- etc.

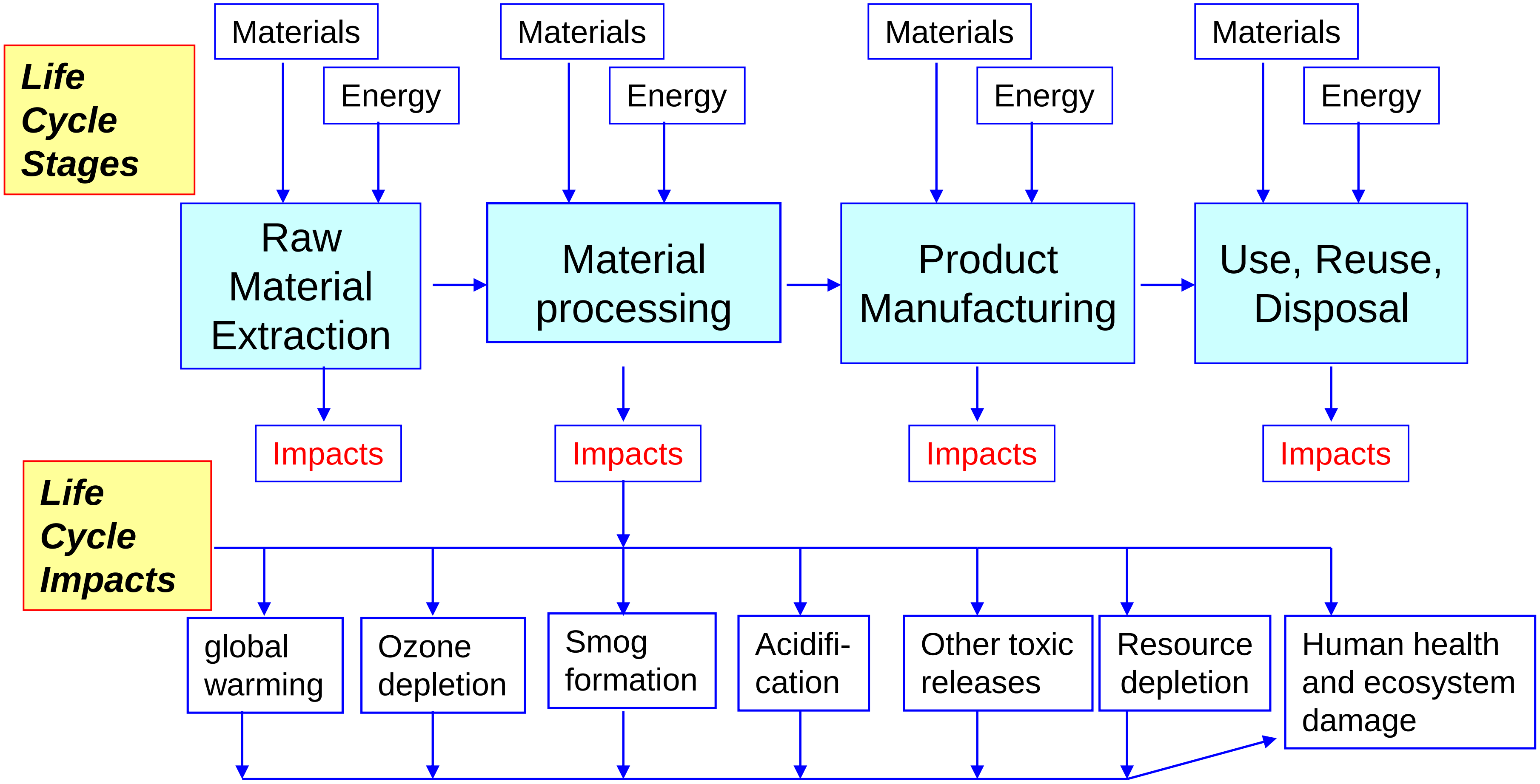
Commonly Used LCIA Impact Categories

Impact Category	Scale	Relevant LCI Data (i. e., classification)	Common Characterization Factor	Description of Characterization Factor
Global Warmin (GWP)	Global	Carbon Dioxide (CO_2) Nitrogen Dioxide (NO_2) Methane (CH_4) Chlorofluorocarbons (CFC) Hydrochlorofluorocarbons (HCFC) Methyl Bromide (CH_3Br)	Global Warming Potential	Converts LCI data to carbon dioxide (CO_2) equivalents Note: global warming potentials can be 50, 100, or 500 year potentials.
Stratospheric Ozone Depletion - increased UV	Global	Chlorofluorocarbons (CFC) Hydrochlorofluorocarbons (HCFC) Halon Methyl Bromide (CH_3Br)	Ozone Depleting Potential	Converts LCI data to trichlorofluoromethane (CFC-11) equivalents.
Acidification **(AC)**	Regional Local	Sulfur Oxides (SO_x) Nitrogen Oxides (NO_x) Hydrochloric Acid (HCl) Hydroflouric Acid (HF) Ammonia (NH_4)	Acidification Potential	Converts LCI data to hydrogen (H^+) ion equivalents.
Eutrofiz-zazione **(EP)**	Local	Phosphate (PO_4) Nitrogen Oxide (NO) Nitrogen Dioxide (NO_2) Nitrates Ammonia (NH_4)	Eutrophication Potential	Converts LCI data to phosphate (PO_4) equivalents.

Commonly Used LCIA Impact Categories

Impact Category	Scale	Relevant LCI Data (i. e., classification)	Common Characterization Factor	Description of Characterization Factor
Photochemical Smog (POCP) -	Local	Non-methane hydrocarbon (NMHC)	Photochemical Oxidant Creation Potential	Converts LCI data to ethane (C_2H_6) equivalents.
Terrestrial Toxicity (TETP)	Local	Toxic chemical compounds with a known lethal concentration on rats	LC_{50}	Converts the data LCI into equivalents.
Aquatic Toxicity (AETP)	Local	Toxic chemical compounds with a known lethal concentration on fish	LC_{50}	Converts the data LCI into equivalents.
Uman Health (HTP)	Global Local Regional	Total release in air, in water, and in soil.	LC_{50}	Converts the data LCI into equivalents.
Resources Depletion	Global Local Regional	Amount of used minerals Amount of used fossil fuels	Resource Depletion Potential	Converts the data LCI in a ratio between the amount of used re source and the amount of leaved resource
Land Use **(LU)**	Global Local Regional		Solid wastes	Converts the mass of solid waste in volume using density values

Complexity of Impact Assessment Related to Life Cycle



Life Cycle Stages

Materials

Energy

Raw Material Extraction

Material processing

Product Manufacturing

Use, Reuse, Disposal

Impacts

Life Cycle Impacts

global warming

Ozone depletion

Smog formation

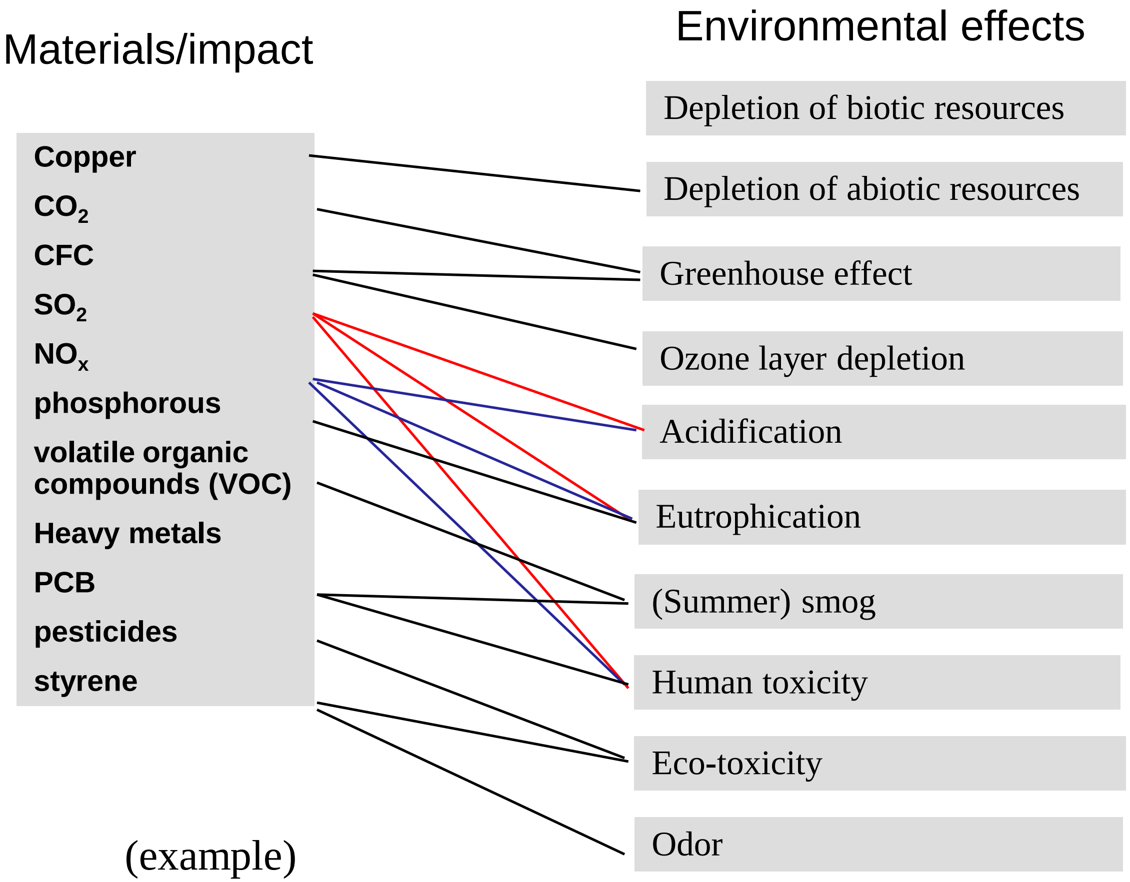
Acidifi-cation

Other toxic releases

Resource depletion

Human health and ecosystem damage

Impact Assessment Focuses more Specifically on Evaluation of Type and Severity of Environmental Impact



Materials/impact

Environmental effects

- Copper
- CO_2
- CFC
- SO_2
- NO_x
- phosphorous
- volatile organic compounds (VOC)
- Heavy metals
- PCB
- pesticides
- styrene

- Depletion of biotic resources
- Depletion of abiotic resources
- Greenhouse effect
- Ozone layer depletion
- Acidification
- Eutrophication
- (Summer) smog
- Human toxicity
- Eco-toxicity
- Odor

(example)

Weighting of effect?

There are different ways to assess and weight the environmental effects.

Eco Indicators - Methodology

- All environmental impacts converted to Eco-indicator points using weighting method
- Point calculated for:
  - Material Production (per kg)
  - Production Processes (per unit appropriate to process)
  - Transportation ($m^3 \cdot km^{-1}$)
  - Energy Generation (electricity and heat)
  - Disposal (per kg)
    - Negative Eco-points for recycling and reuse

- Inventory emissions, resource extractions, land uses related to life cycle of product
- Calculate damage to human health, ecosystem quality, and resources
- Weight three damage categories to come up with one number

Impact Assessment: Classification and characterization – Acidification Potential

Impact category	**Acidification**
LCI results	Emissions of acidifying substances to the air (in kg)
Characterization model	model describing the fate and deposition of acidifying substances, adapted to LCA
Category indicator	Deposition/acidification critical load
Characterization factor	Acidification potential (AP) for each acidifying emission to the air (in kg SO_2 equivalents/kg emission)
Unit of indicator result	kg SO_2 eq.

Compound	**MW**	**Resulting Acid**	**α**	**AP_i**
SO_2	64.1	H_2SO_4	2	1.00
NO	30.0	HNO_3	1	1.07
NH_3	17.0	HNO_3	1	1.88
NO_2	46.1	HNO_3	1	0.70
HCl	36.5	-	1	0.88
HF	20.0	-	1	1.60
H_2S	34.8	H_2SO_4	2	1.88
HNO_3	63.1	-	1	0.51
H_2SO_4	98.2	-	3	0.65

← (in kg SO_2 equivalents/ kg emission)

$$AP_i = \frac{\alpha_i / MW_i}{\alpha_{SO_2} / MW_{SO_2}}$$

$$I_A = \sum_i AP_i \cdot m_i$$

Impact Assessment: Classification and characterization – Ozone Depletion Potential

Impact category	**Stratospheric ozone depletion**
LCI results	Emissions of ozone-depleting gases to the air (in kg)
Characterization model	The model developed by WMO, defining the ozone depletion potential of different gases
Category indicator	Stratospheric ozone breakdown
Characterization factor	Ozone depletion potential in the steady state (ODP_∞) for each emission (in kg CFC-11 equivalents/kg emission)
Unit of indicator result	kg CFC-11 eq.

Formula	Name	Lifetime, y	ODP
CH_3Br	methyl bromide		0.37
CH_2Cl_2	methylene chloride	0.47	<0.001
$CHCl_3$	chloroform	0.17	<0.001
$CHClF_2$	HCFC-22	15	0.055
$CHBrF_2$	Halon 1201	60	1.4
CCl_4	carbon tetrachloride	47	1.1
CCl_3F	CFC-11	60	1.0
CCl_2F_2	CFC-12	120	0.82
$C_2HCl_2F_3$	CHFC-123	1.4	0.012
$CBrF_3$	Halon 1301		16.0
CBr_2ClF_2	Halon 1211	13	4.00

$$ODP_i = \frac{\delta[\mathrm{O}_3]_i}{\delta[\mathrm{O}_3]_{CCl_3F}}$$

$$I_{OD} = \sum_i ODP_i \cdot m_i$$

Impact Assessment: Classification and characterization – SMOG

$$SFP_i = \frac{MIR_i}{MIR_{ROG}}$$

$$I_{SF} = \sum_i SFP_i \cdot m_i$$

- Allen and Shonnard, Green Engineering, Prentice-Hall, 2002
- Extensive list in Guinée, Handbook on Life Cycle Assessment, Kluwer 2002, pg 335 (but divided by 3.1)

Alkanes

Chemical	MIR
Methane	0.015
Ethane	0.25
Propane	0.48
Butane	1.02
Pentane	1.04
Hexane	0.98
Octane	0.60
Decane	0.46
Methylpentanes	1.5
Cyclopentane	2.40
Cyclohexane	1.28

Alkenes/Alkynes

Chemical	MIR
Ethene	7.40
Propene	9.40
1-Butene	8.90
1-Hexene	4.40
1-Octene	2.70
2-Butenes	10.0
2-Pentenes	8.80
2-Hexenes	6.70
1,3-Butadiene	10.9
Ethyne	0.50
Propyne	4.10

Aromatics

Chemical	MIR
Benzene	0.42
Toluene	2.7
o-Xylene	6.5
m-Xylene	9.0
p-Xylene	6.6
1,3,5-Trimethylbenzene	10.1
Naphthalene	1.17
Tetralin	0.94
Methylnaphthalenes	3.3
Styrene	2.2

SMOG

Alcohols & ethers

Chemical	MIR
Methanol	0.56
Ethanol	1.34
Propanol	2.08
2-Propanol	0.56
1-Butanol	2.70
t-Butyl alcohol	0.42
Ethylene glycol	1.74
Phenol	1.12
Alkyl phenols	2.30
Diethyl ether	2.82
Methyl t-butyl ether	0.62
Ethylene oxide	0.03
Propylene oxide	0.31
Furan	16.9

Carbonyl-containing

Chemical	MIR
Carbon monoxide	0.05
Methyl acetate	0.09
Ethyl acetate	0.53
Vinyl acetate	5.27
Methyl acrylate	5.27
Ethyl acrylate	4.53
Formaldehyde	7.20
Acetaldehyde	5.50
C3 aldehydes	6.50
Benzaldehyde	-0.57
Acetone	0.56
2-Butanone	1.09
2-Pentanone	2.54[e]
2-Heptanone	2.33[e]
Propylene carbonate	0.33

Halide-containing

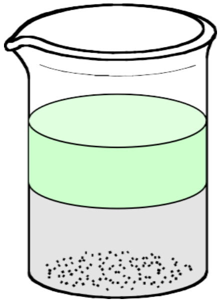
Chemical	MIR
Trifluoromethylbenzene	0.28
Chlorobenzene	0.25
2-Chlorotoluene	2.86[c]
1-Chlorobutane	0.74
1,4-dichlorobenzene	0.09
1,2-dichlorobenzene	0.17[c]
Dichloromethane	0.03
Trichloromethane	0.03
Vinyl chloride	1.93
Chlorine	18.3[d]
1,2-Dichloroethane	0.2[a]
1,2-Dibromoethane	0.1[a]
Methyl iodide	-0.54[b]

Others

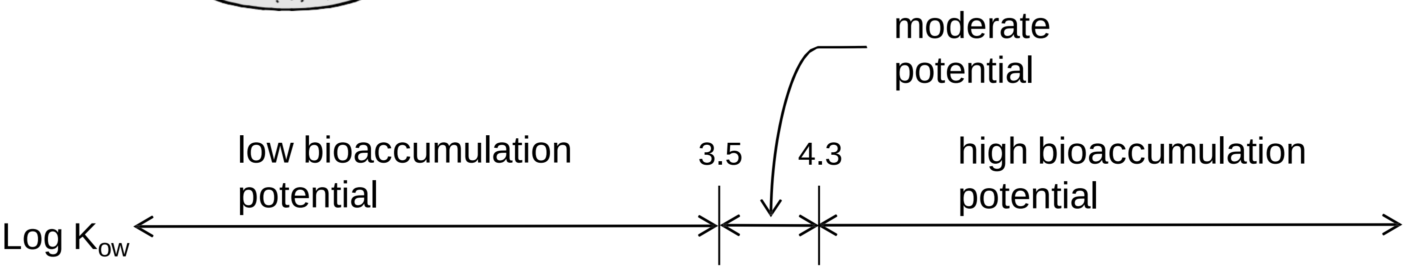
Chemical	MIR
DMSO	5.86[b]
ROG	3.10

[c] Carter, Report to the California Air Resources Board, Contract 06-408, February 2008.

K_{ow} and Bioaccumulation



$$K_{ow} = \frac{[\text{solute}]_{\text{octanol}}}{[\text{solute}]_{\text{water}}}$$



methanol -0.7
1-butanol 0.8
1-hexanol 2.0
1-decanol 4.6
C_6Cl_6 5.5
$(C_6Cl_5)_2O$ 8.3

HCO_2H -0.5
THF 0.5
NEt_3 1.5
toluene 2.7
hexane 4.0
octane 5.2
decane 6.3
stearic acid 8.2

-1 0 1 2 3 4 5 6 7 8 9 logK_{ow}

hydrophilic
lipophobic

hydrophobic
lipophilic

Abiotic Depletion Potential

$$ADP_i = \frac{(\text{depletion rate})_i \,/\, (\text{reserve})_i}{(\text{depletion rate})_{ref} \,/\, (\text{reserve})_{ref}}$$

$$I_{AD} = \sum_i ADP_i \cdot M_i$$

M_i is mass used, not mass emitted.

Not all elements are of concern.

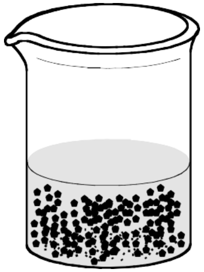
Res.	ADP
Sb	1
Bi	0.0731
B	0.00467
Br	0.00667
Cd	0.33
Cr	0.00086
Co	2.6×10^{-5}
Cu	0.00194
F	3.0×10^{-6}
Ge	1.5×10^{-6}

Res.	ADP
Au	89.5
He	148
In	0.0090
I	0.0427
Ir	32.3
Kr	20.9
Pb	0.0135
Li	9.2×10^{-6}
Mn	1.4×10^{-5}
Hg	0.495

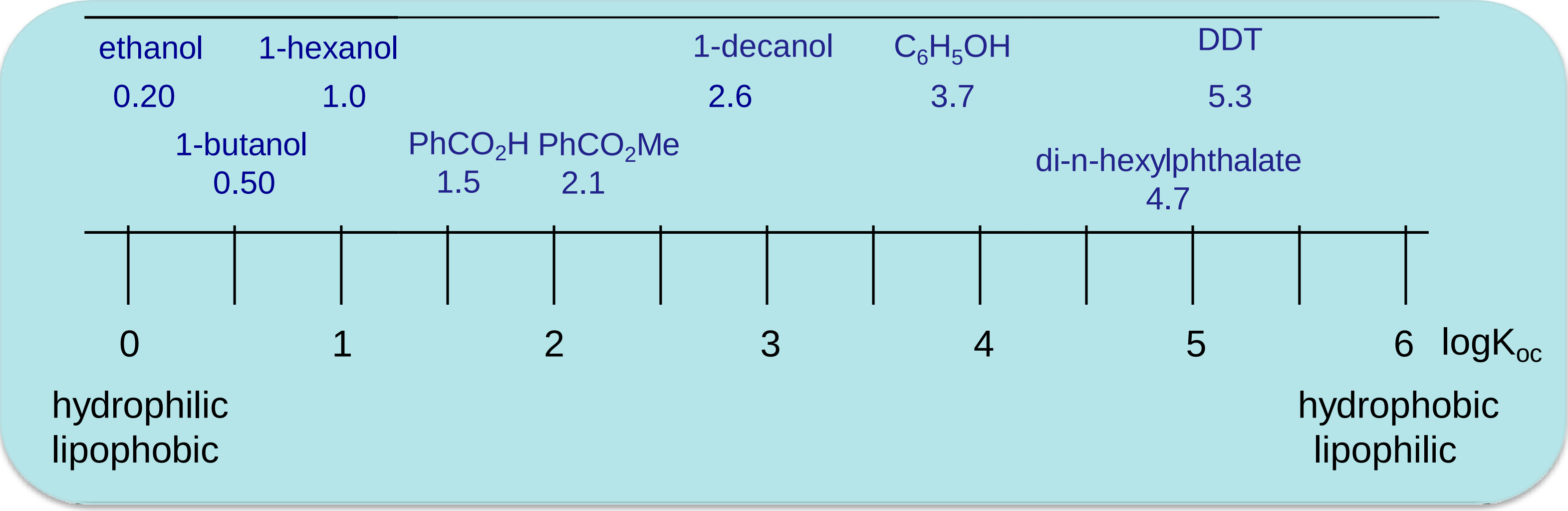
Res.	ADP
Mo	0.032
Ne	0.325
Ni	1.1×10^{-4}
Os	14.4
Pd	0.323
P	8.4×10^{-5}
Pt	1.29
Re	0.77
Rh	32
Ru	32

Res.	ADP
Se	0.48
Ag	1.8
S	3.6×10^{-4}
Sn	0.33
W	0.012
U	0.0029
V	1.2×10^{-6}
Xe	17,500
Zn	9.9×10^{-4}
Zr	1.9×10^{-5}

Soil Sorption Coefficient (K_{oc})



$$K_{oc} = \frac{\text{Concentration in organic carbon of soil (in µg per g of organic C)}}{\text{Concentration in the water (in µg per ml)}}$$



ethanol 0.20

1-butanol 0.50

1-hexanol 1.0

$PhCO_2H$ 1.5

$PhCO_2Me$ 2.1

1-decanol 2.6

C_6H_5OH 3.7

di-n-hexylphthalate 4.7

DDT 5.3

hydrophilic
lipophobic

hydrophobic
lipophilic

Data available from: Huuskonen, *J. Chem. Information & Computer Sci.* (2003), 43(5), 1457 (available online, choose the supporting information PDF file)

hint: $K_{oc} \approx 0.41\ K_{ow}$

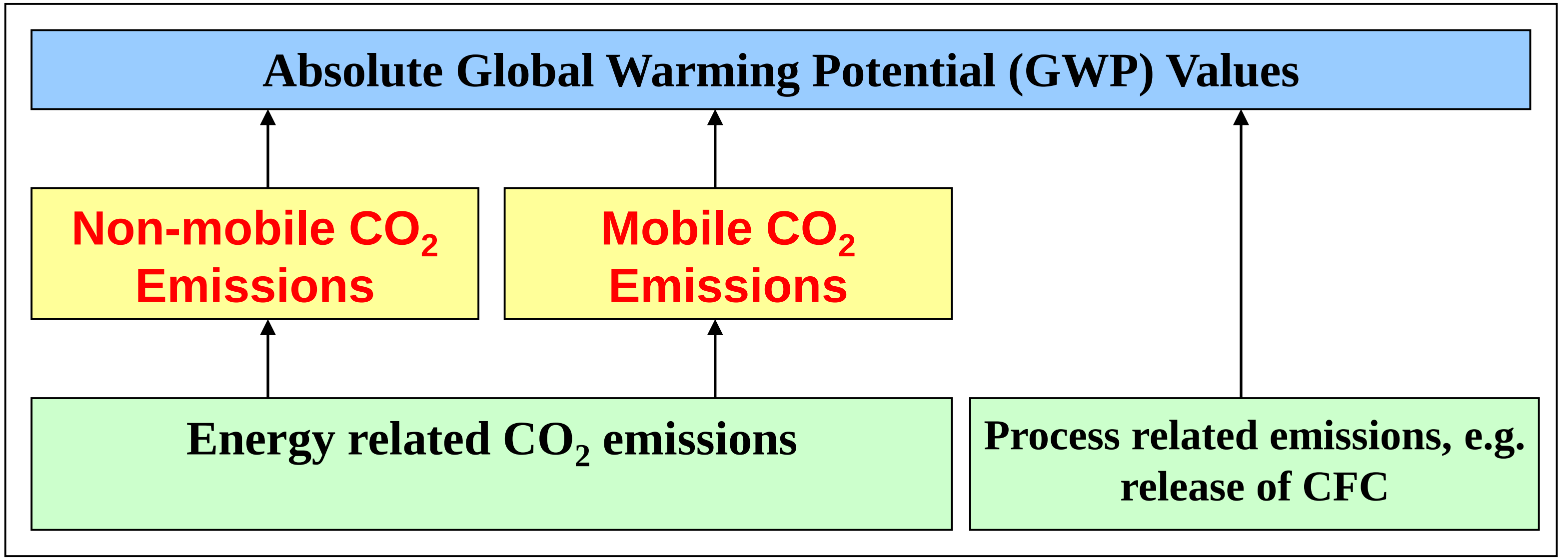
Impact Assessment: Classification and Characterization – GWP

Impact category	**Climate change**
LCI results	Emissions of greenhouse gases to the air (in kg)
Characterization model	the model developed by the IPCC defining the global warming potential of different gases
Category indicator	Infrared radiative forcing ($W \cdot m^{-2}$)
Characterization factor	Global warming potential for a 100-year time horizon (GWP_{100}) for each GHG emission to the air
Unit of indicator result	in kg CO_2 equivalents/kg emission

$$I_{GW} = \Sigma\, GWP_i \bullet m_i$$

	Abundance 1998, ppt	Trend, ppt/yr	Annual emissions	Lifetime, y	GWP
CO_2	367,000	2,000	6.4 PgC	-	1
CH_4	1,745	7.0	600 Tg	8	23
N_2O	314	0.8	16 TgN	120	296
CF_4	80	1.0	15 Gg	>50,000	6,500
C_2F_6	3	0.08	2 Gg	10,000	11,900
SF_6	4.2	0.24	6 Gg	3,200	23,900
CHF_3	14	0.55	7 Gg	260	12,000
CF_3CH_2F	7.5	2.0	25 Gg	14	1,300
CH_3CHF_2	0.5	0.1	4 Gg	1	120
$CHCl_3$					4

Indicator Methodology:
Global Warming (GWP-indirect)



Absolute Global Warming Potential (GWP) Values

Non-mobile CO_2 Emissions

Mobile CO_2 Emissions

Energy related CO_2 emissions

Process related emissions, e.g. release of CFC

Indicator expression :

“Absolute global warming potential (MT CO_2)”

GWP for short-lifetime chemicals

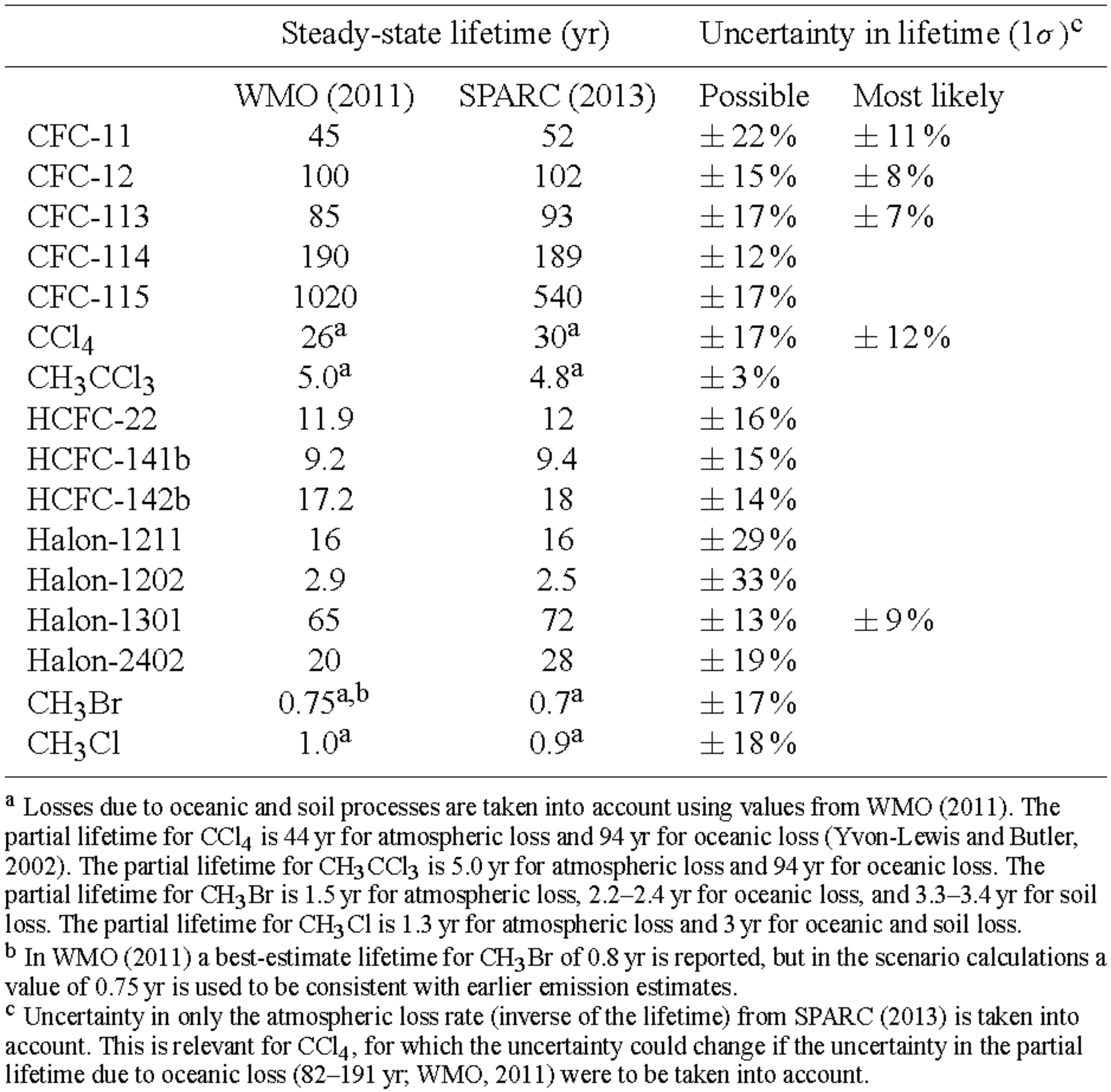
$$GWP_i(\text{indirect}) = \frac{NC_i / MW_i}{NC_{CO_2} / MW_{CO_2}}$$

Importance of Substances for GWP (IPCC 1996)

	Time span considered	
	20 years	100 years
CO_2	1	1
CH_4	62	23
NO_2	290	320
O_3		2000
H1201 Halon*	6200	5600
R134aFCKW**	3300	1300
R22FCKW***	4300	1700

*CHF_2Br
**CH_2FCF_3
***CHF_2Cl

Lifetimes and uncertainties of ODSs from WMO and SPARC - 2013



	Steady-state lifetime (yr)		Uncertainty in lifetime (1σ)[c]	
	WMO (2011)	SPARC (2013)	Possible	Most likely
CFC-11	45	52	±22%	±11%
CFC-12	100	102	±15%	±8%
CFC-113	85	93	±17%	±7%
CFC-114	190	189	±12%	
CFC-115	1020	540	±17%	
CCl_4	26[a]	30[a]	±17%	±12%
CH_3CCl_3	5.0[a]	4.8[a]	±3%	
HCFC-22	11.9	12	±16%	
HCFC-141b	9.2	9.4	±15%	
HCFC-142b	17.2	18	±14%	
Halon-1211	16	16	±29%	
Halon-1202	2.9	2.5	±33%	
Halon-1301	65	72	±13%	±9%
Halon-2402	20	28	±19%	
CH_3Br	0.75[a,b]	0.7[a]	±17%	
CH_3Cl	1.0[a]	0.9[a]	±18%	

[a] Losses due to oceanic and soil processes are taken into account using values from WMO (2011). The partial lifetime for CCl_4 is 44 yr for atmospheric loss and 94 yr for oceanic loss (Yvon-Lewis and Butler, 2002). The partial lifetime for CH_3CCl_3 is 5.0 yr for atmospheric loss and 94 yr for oceanic loss. The partial lifetime for CH_3Br is 1.5 yr for atmospheric loss, 2.2–2.4 yr for oceanic loss, and 3.3–3.4 yr for soil loss. The partial lifetime for CH_3Cl is 1.3 yr for atmospheric loss and 3 yr for oceanic and soil loss.

[b] In WMO (2011) a best-estimate lifetime for CH_3Br of 0.8 yr is reported, but in the scenario calculations a value of 0.75 yr is used to be consistent with earlier emission estimates.

[c] Uncertainty in only the atmospheric loss rate (inverse of the lifetime) from SPARC (2013) is taken into account. This is relevant for CCl_4, for which the uncertainty could change if the uncertainty in the partial lifetime due to oceanic loss (82–191 yr; WMO, 2011) were to be taken into account.

ODS = ozone-depleting substances

G. J. M. Velders and J. S. Daniel
Atmos. Chem. Phys., 14, 2757–2776, 2014

Calculate Indicator Results

Indicator Value = ∑ (Inventory Result × Characterization Factor)

Example – Global Warming Potential:

Inventory – 1000 kg CO_2 emissions and 100 kg CH_4 emissions per 0.454 kg of product

GPW = (1000 kg CO_2 × 1 eq/kg CO_2) + (100 kg CH_4 × 23 eq/kg CO_2)

GPW = 1000 kg CO_2 eq + $\underline{2300}$ kg CO_2 eq

GPW = 3300 kg CO_2 eq per 0.454 kg of product

Note: Inventory data alone will tell you to focus on CO_2 emissions. Impact assessment informs you that methane emissions (CH_4) have a bigger impact on global warming.

Global Warming due to Energy Requirements

To heat a liquid = q = m C_P (T_f-20˚C)

To distill a liquid = q = m C_P (T_b-20 ˚C) + m ΔH_{vap} To

reflux a liquid = q = m C_P (T_b-20 ˚C) + n m ΔH_{vap}

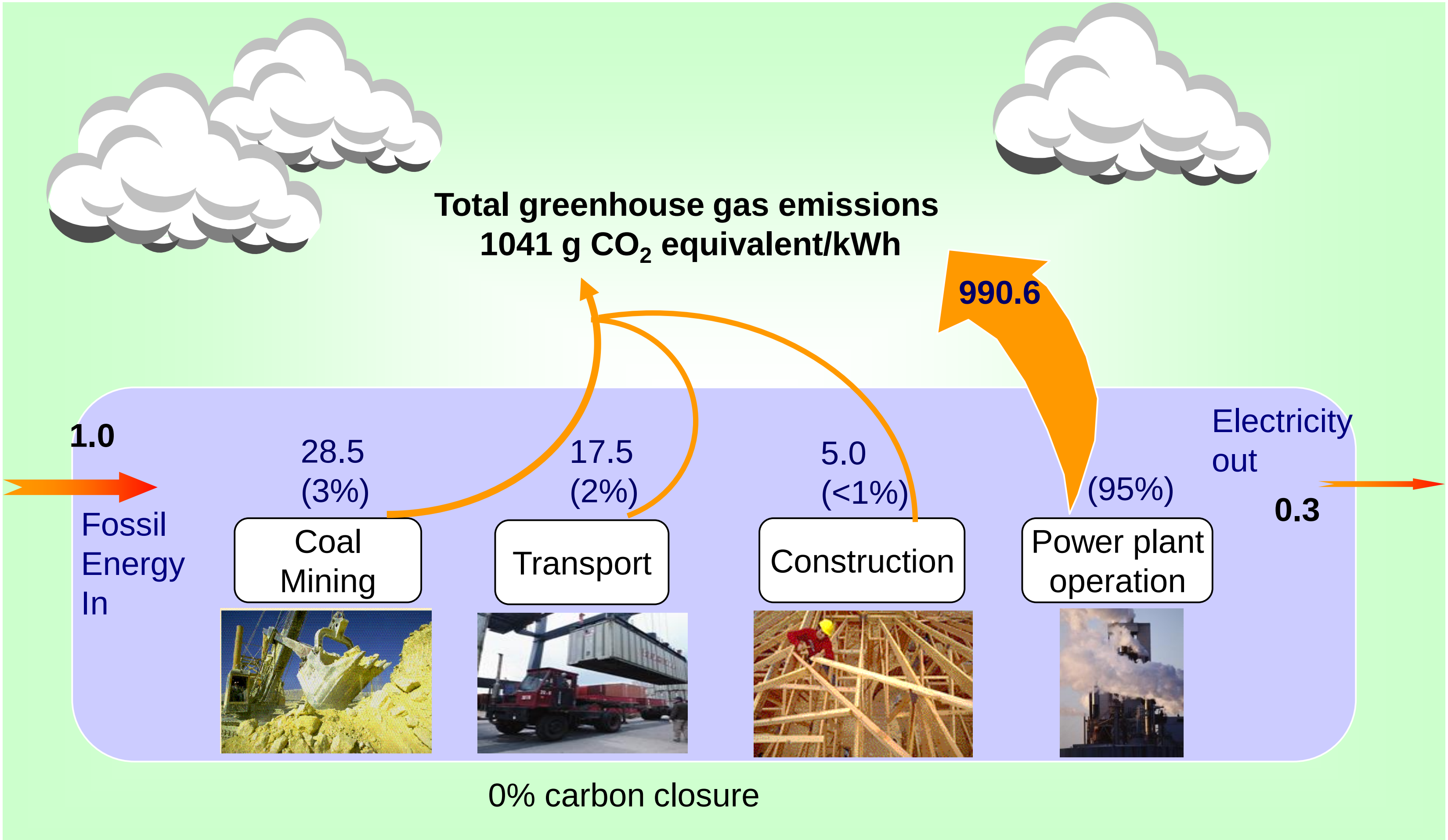
×

150 g CO_2 per kWh
or 0.042 g CO_2 per kJ

Solvent	**T_b, ˚C**	**C_p, J g^{-1} K^{-1}**	**ΔH_{vap} J g^{-1}**	**Heat to distill, J/g**
Acetone	56	2.18	501	580
Acetonitrile	82	2.23	725	863
Benzene	80	1.74	393	498
Chloroform	61	0.96	245	284
Dichloro-methane	40	1.19	330	354
Ether	34	2.33	358	390
DMF	153	2.06	578	852
DMSO	189	1.96	552	883

Solvent	**T_b, ˚C**	**C_p, J g^{-1} K^{-1}**	**ΔH_{vap} J g^{-1}**	**Heat to distill, J/g**
Ethyl acetate	77	1.94	363	473
Ethanol	78	2.44	837	979
Hexane	69	2.27	335	446
Methanol	65	2.53	1099	1213
Nitromethane	101	1.75	557	699
Tetrahydrofuran	65	1.72	413	491
Toluene	111	1.70	360	515
Water	100	4.18	2259	2593

Life Cycle GWP and Energy Balance for a Coal-Fired Power System



Total greenhouse gas emissions
1041 g CO_2 equivalent/kWh

990.6

1.0

Fossil Energy In

28.5
(3%)

Coal Mining

17.5
(2%)

Transport

5.0
(<1%)

Construction

(95%)

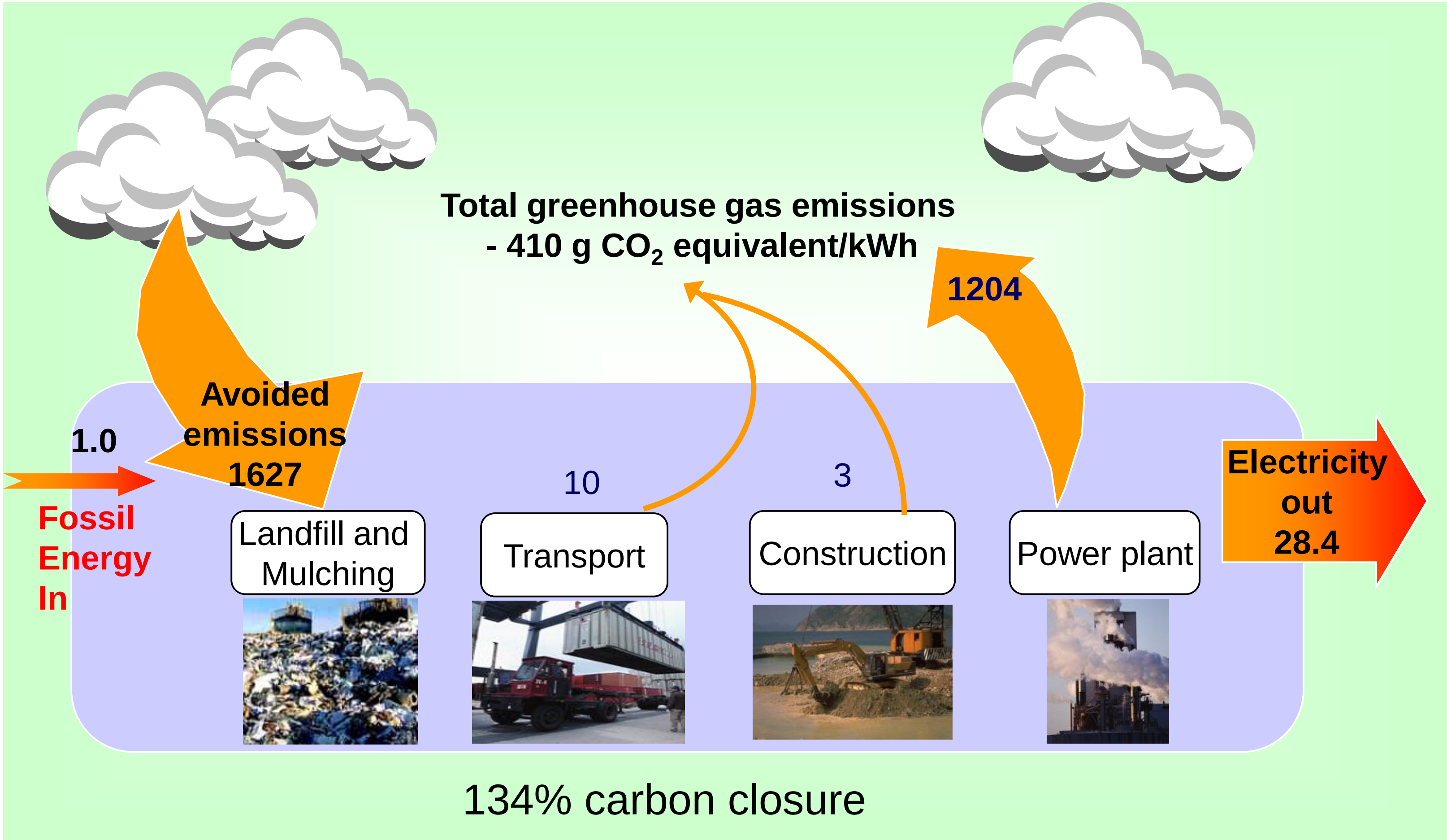
Power plant operation

Electricity out

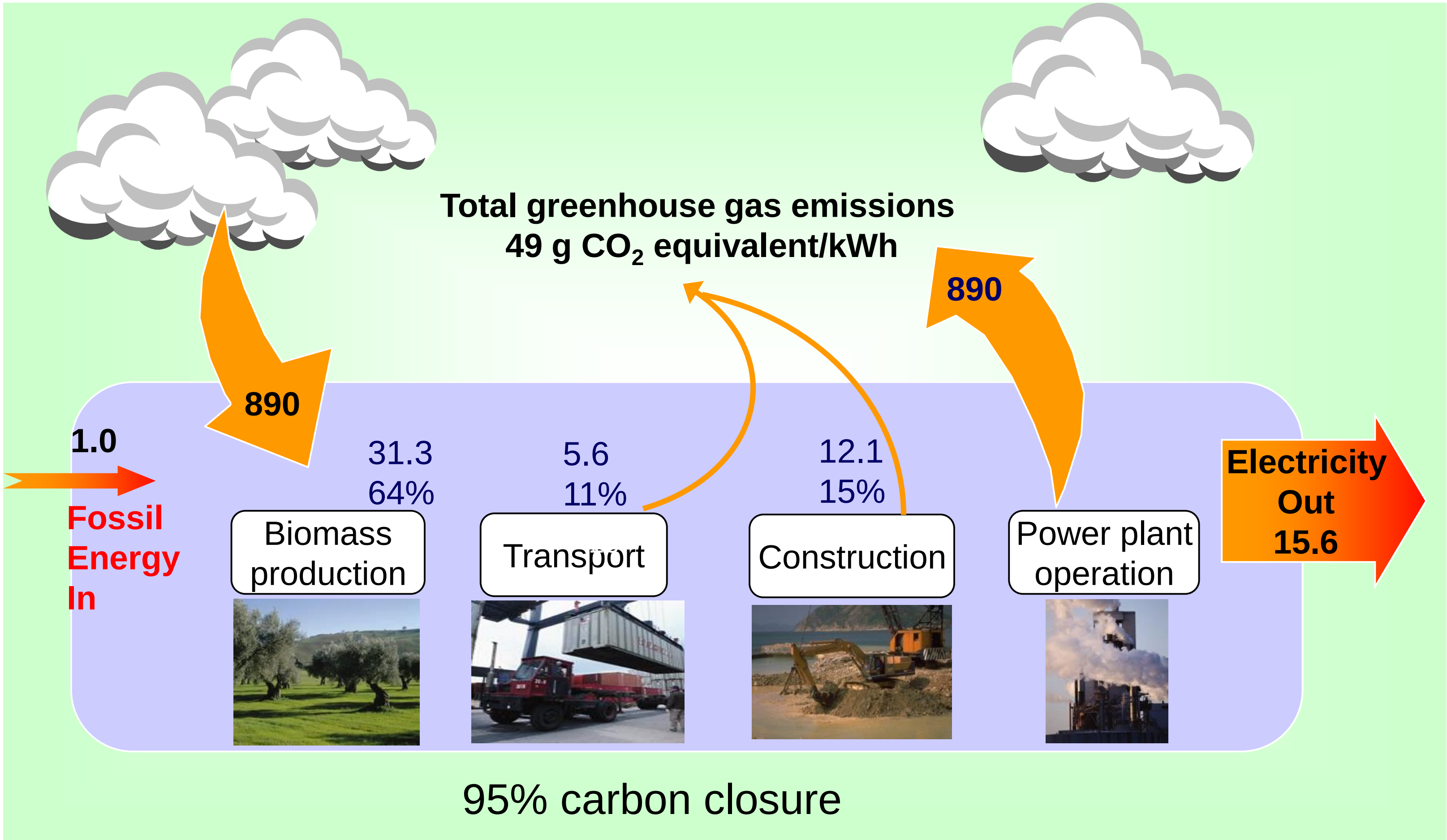
0.3

0% carbon closure

Life Cycle GWP and Energy Balance for a Direct-Fired Residue-Biomass Power System



Life Cycle GWP and Energy Balance for Advanced IGCC Technology using Energy Crop Biomass

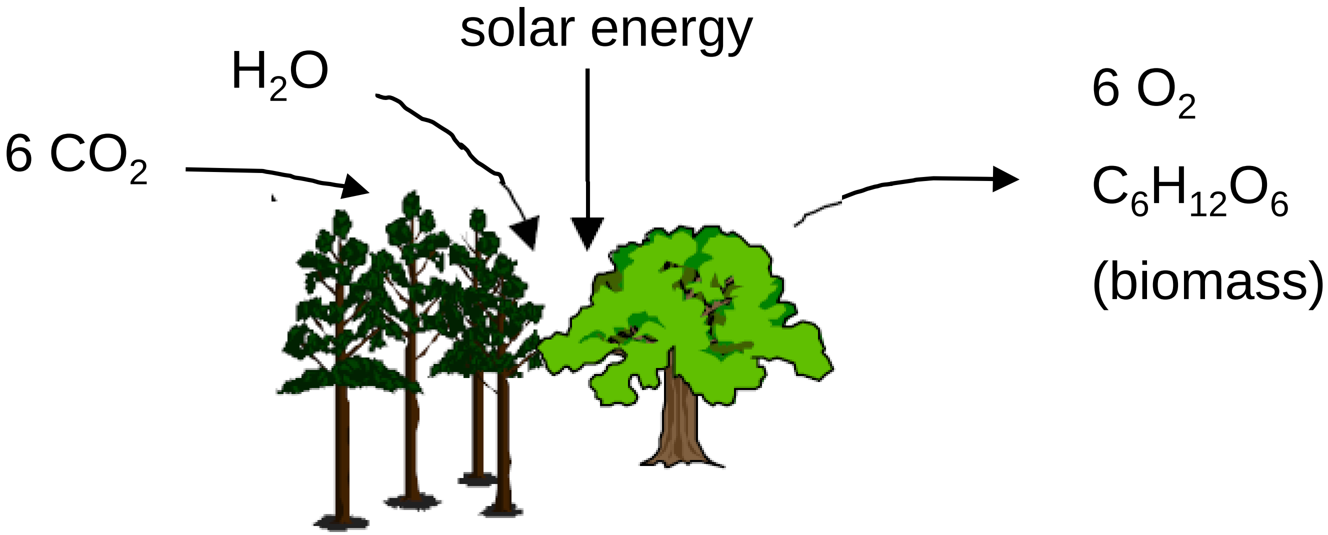


Total greenhouse gas emissions
49 g CO_2 equivalent/kWh

95% carbon closure

Remember!!!

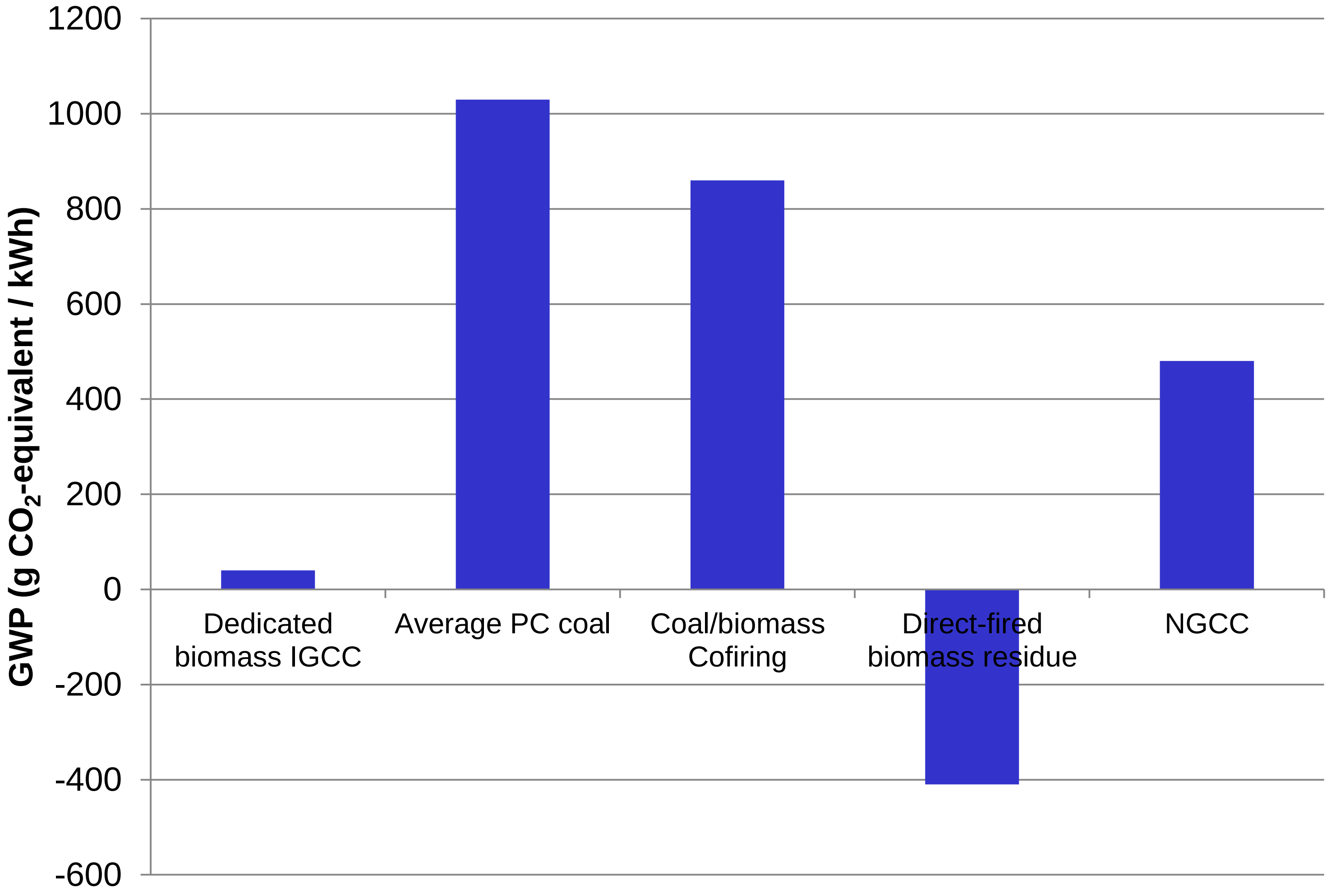
Photosynthesis



Balance for 1 kg wood

Input	Output
1.44 kg CO_2	1 kg biomass
0.56 kg H_2O	1 kg O_2
18.5 MJ solar energy	18.5 MJ thermal use

Life Cycle Greenhouse Gas Emissions



SUMMARY OF THE POTENTIALS

1.	Acidification	$AP_i = \frac{\alpha_i / MW_i}{\alpha_{SO_2} / MW_{SO_2}}$	$I_A = \sum_i AP_i \cdot m_i$
2.	Ozone depletion	$ODP_i = \frac{\delta[\mathrm{O}_3]_i}{\delta[\mathrm{O}_3]_{CCl_3F}}$	$I_{OD} = \sum_i ODP_i \cdot m_i$
3.	Smog formation	$SFP_i = \frac{MIR_i}{MIR_{ROG}}$	$I_{SF} = \sum_i SFP_i \cdot m_i$
4.	Global warming	GWP_i	$I_{SF} = SFP_i \cdot m_i$
5.	Human toxicity by inhalation	$INHTP_i = \frac{C_{i,a} / RfC_i}{C_{tol,a} / RfC_{tol}}$	$I_{INH} = INHTP_i \cdot m_i$
6.	Human toxicity by ingestion	$INGTP_i = \frac{C_{i,w} / RfD_i}{C_{tol,w} / RfD_{tol}}$	$I_{ING} = INGTP_i \cdot m_i$
7.	Persistence	Boethling index	
8.	Bioaccumulation	$\log K_{ow}$	
9.	Abiotic resource depletion	ADP_i	$I_{AD} = ADP_i \cdot M_i$

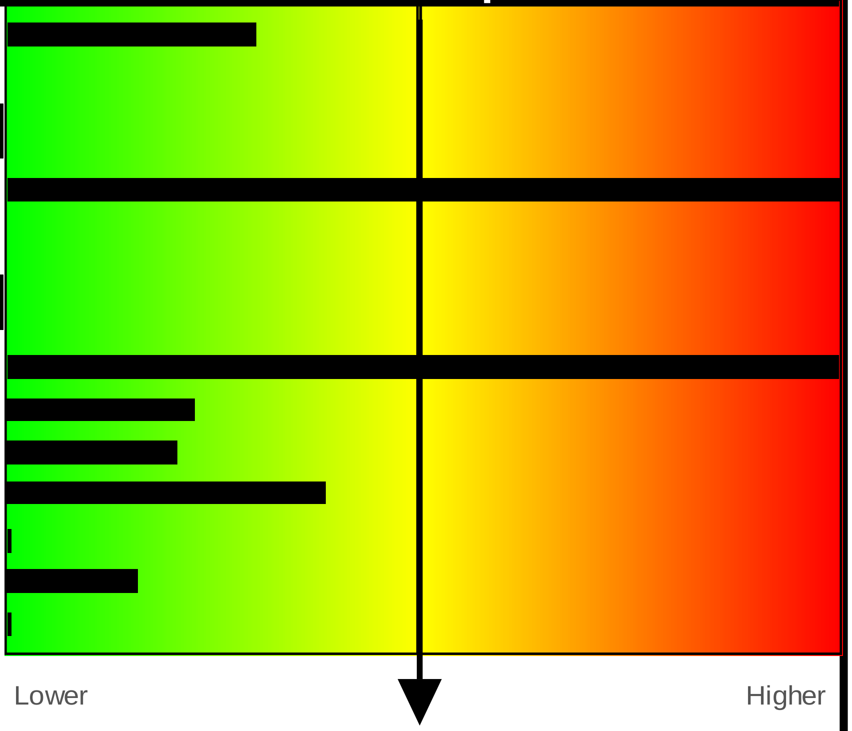
where m = mass of the compound emitted
M = mass of the element consumed

Coal Power Plant
Environmental Impact Profile

(1500 MW Capacity; 2,296 GWH Annual Production)

Sustainability of Energy Resources	Amt.*
Net Depletion - energy resources (equiv. tons of oil)	51,800
Ecosystem Disruption	
Terrestrial and Aquatic Habitats (equiv. acres)	4,600
Key Species (% increased mortality)	NA
Emission Loadings and Wastes	
Greenhouse Gases (equiv. tons CO_2)	1,545,000
Acidifying Chemicals (equiv. tons SO_2)	300
Ground Level Ozone (equiv. tons O_3)	180
Particulates (equiv. tons PM-10)	310
Stratospheric Ozone Depletion (equiv. tons CFC-113)	--
Hazardous Air Pollutants (equiv. tons Hg)	0.008
Haz./Radioactive Waste (tons IBHP U ore equiv.)	--

Scale of Impacts



equiv. = equivalent
-- is used to denote negligible results

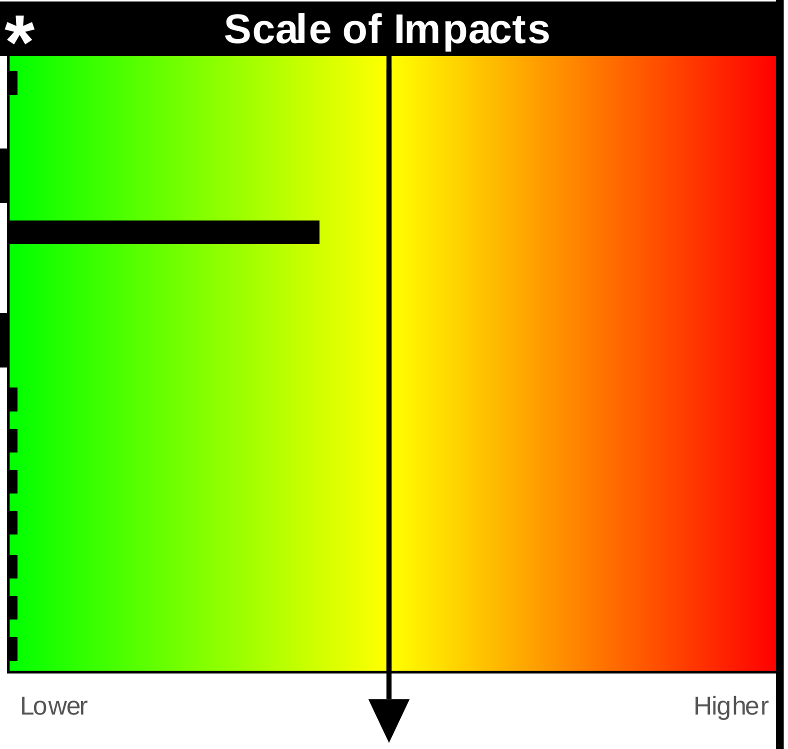
* Per 1,000 GWh

PJM Average Impacts (1998)

Hydropower Plant Environmental Impact Profile

(512 MW Capacity, 1714 GWH Annual Production)

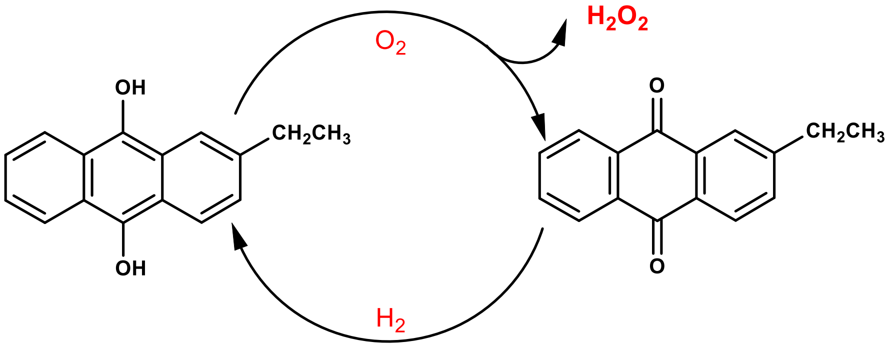
Sustainability of Energy Resources	Amt. *
Net Depletion - energy resources (equiv. tons of oil)	209
Ecosystem Disruption	
Terrestrial and Aquatic Habitats (equiv. acres)	1610
American Shad (% increased mortality)	< 50%
Emission Loadings and Wastes	
Greenhouse Gases (equiv. tons CO$_2$)	1,022
Acidifying Chemicals (equiv. tons SO$_2$)	0.2
Ground Level Ozone (equiv. tons O$_3$)	--
Particulates (equiv. tons PM-10)	--
Stratospheric Ozone Depletion (equiv. tons CFC-113)	--
Hazardous Air Pollutants (equiv. tons Hg)	--
Haz./Radioactive Waste (tons IBHP U ore equiv.)	--

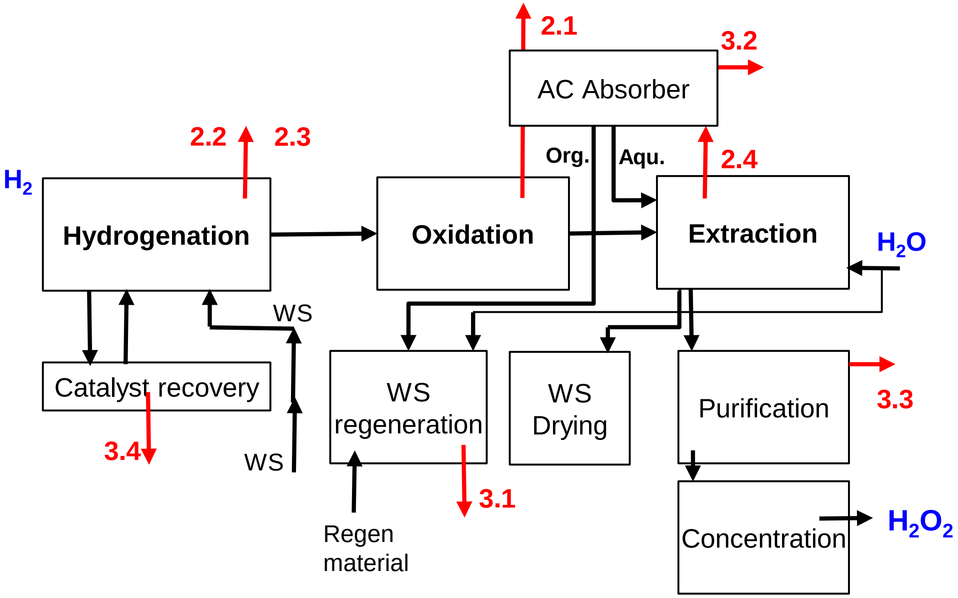


equiv. = equivalent
-- is used to denote negligible results

* Per 1,000 GWh

VOC Emission in the Production of Hydrogen Peroxide



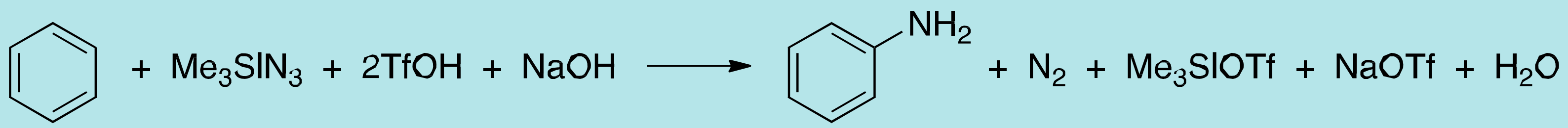


Pollutant	EPD [(1)] (g/kg)	Ecoprofile[(2)] (mg/kg)
CO_2	523000	39000
NO_X	760	210
SO_2	360	400
Dust	170	120
HC	300	150
Aromatic HC		150
CO	130	37
CH_4	410	
Hydrogen		340

(1) AkzoNobel's certified environmental declaration: Overall LCA emission

(2) Cefic Ecoprofile data sheet: Manufacturing process emissions

Synthesis of Benzene to Aniline



Benzene (75 mL, 0.842 mol) and triflic acid (20 mL, 0.22 mol) are warmed to 55 °C. Trimethylsilyl azide (0.037 mol, 4.4 g) in 20 mL benzene (0.224 mol) is added. The mixture is stirred for 50 min until no more N_2 is given off. The mixture is then cooled to room temperature and poured over ice. The organics are extracted with three washings of dichloromethane. The aqueous layer is basified to pH ~13 and any additional product is extracted with three washings of dichloromethane. The organic fractions are combined and dried with $MgSO_4$. The solvent is evaporated off to give aniline in 95% yield and 100% selectivity.

(modified from Olah and Ernst, *JOC* (1989) *54*, 1203)

Table 1. Masses (to make 1 kg)

Compound	**Role**	**Mass used (or made) /kg**	**Mass emitted / kg**
Benzene	Reagent	20	2.0×10^{-2}
Me_3SiN_3	Reagent	1.3	1.3×10^{-3}
Triflic Acid	Reagent	9.8	9.8×10^{-3}
Me_3SiOTf	Byproduct	(2.4)	2.4×10^{-3}
NaOTf	Byproduct	(9.3)	9.3
CH_2Cl_2	Solvent	236	0.24
NaOH	Reagent	2.3	0.12[a]
$MgSO_4$	Drying agent	8.9	8.9
CO_2	Energy by-product	(1.8)	1.8

Assumption about Amounts Used

if the literature method doesn't tell you enough information:

- Refluxing: n = 1 for every half hour
- The standard drying agent is Na2SO4. Assume 10 g per 100 mL of wet solvent.
- The standard column packing for flash chromatography is silica gel. The standard amount of silica gel is 100 g per g of sample. Standard volume of eluting solvent is 1 L per g of sample.
- If you're extracting a product from a solution of volume V, use three batches of extracting solvent each having the same volume. Total volume of extracting solvent is 3V. Same thing for washing a solution,

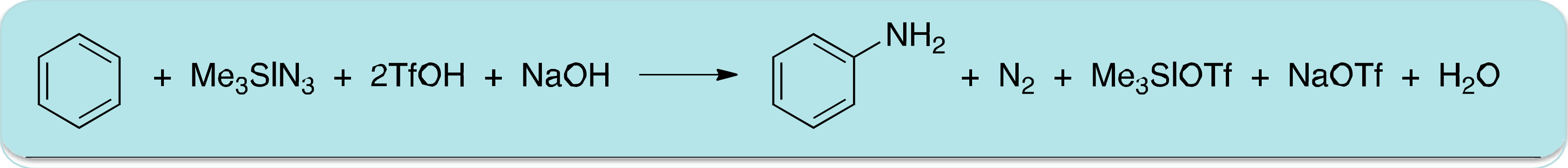
Concentrated solutions:

- Concentrated brine (NaCl) contains 359 g per L of solution
- Concentrated NH_4Cl contains 371 g per L of solution.
- Commercial concentrated NH_4OH is 28 wt% NH4OH.
- Concentrated HCl (12 M) is 37 wt% HCl of 440 g HCl per L of solution.
- Glacial acetic acid (17 M) is 100 wt% acetic acid
- Concentrated sulfuric acid (18 M) is 96% H_2SO_4.
- Concentrated phosphoric acid (15 M) is 85 wt% H_3PO_4.

Assumption about Emissions

- Water, N_2, O_2, H_2 and product are omitted from the calculation.
- 0.1% escape to the environment of all materials consumed in the reaction.
- Non-gaseous organic materials, including solvents, by-products, intermediates and starting materials are incinerated. Assume 0.1 % of the used or generated amount escapes to the environment.
- For reactant gases, gaseous intermediates, inorganic reagents/reactants, and inorganic intermediates, assume 100 % of the remaining material (after the reaction) escapes to the environment.
- 100 % of the used or generated amount escapes to the environment for all other materials, including inorganic by-products, aqueous wastes, drying agents, by-product gases, catalysts, and column packing agents.

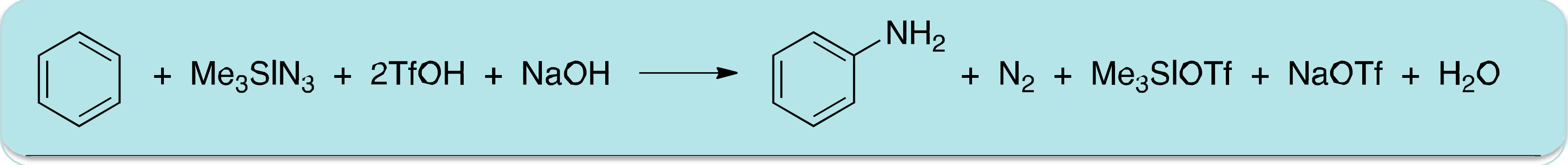
Synthesis of Benzene to Aniline



Potentials

Compound	AP	ODP	SFP	GWP	INHTP	INGTP	PER	ACCU logK$_{ow}$	ADP
Benzene	0	0	0.14	3.4	12	1.0	months	0.6	0
Me_3SiN_3	0	0	0	0	?	?	months	2.3	0
Triflic Acid	0	?	?	0	0	$4.7x10^{-2}$	weeks	-0.5	F: $3.0x10^{-6}$ S: $3.6x10^{-4}$
Me_3SiOTf	0	0	0	0	?	?	months	0.6	n/a
NaOTf	0	0	0	0	0	?	-	n/a	n/a
CH_2Cl_2	0	0.4	$3.0x10^{-2}$	0.5	$5.0x10^{-2}$	160	weeks	1.3	0
NaOH	0	0	0	0	0	?	-	n/a	0
$MgSO_4$	0	0	0	0	0	?	-	n/a	S: $3.6x10^{-4}$
CO_2	0	0	0	1	0	0	-	n/a	0

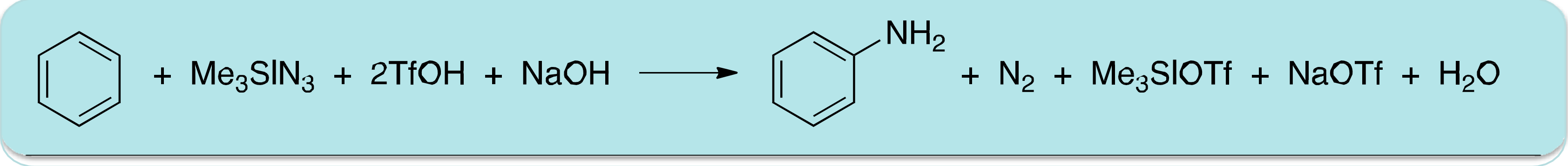
Synthesis of Benzene to Aniline



Indexes

Cmpd.	I_{AP}	I_{OD}	I_{SF}	I_{GW}	I_{INHT}	I_{INGT}	**PER $t_{1/2}$, h**	**ACCU $\log K_{ow}$**	I_{AD}
Benzene	0	0	2.8	66	240	19	months	2.1	0
Me_3SiN_3	0	0	0	0	0	?	months	2.3	0
Triflic Acid	0	0	0	0	0	0.5	weeks	-0.5	F: 0.011 S: 0.754
Me_3SiOTf	0	0	0	0	0	?	months	0.6	-
NaOTf	0	0	0	0	0	?	n/a	n/a	-
CH_2Cl_2	0	94	7.2	123	12	38,081	weeks	1.3	0
NaOH	0	0	0	0	0	?	n/a	n/a	0
$MgSO_4$	0	0	0	0	0	?	n/a	n/a	0.94
CO_2	0	0	0	1829	0	0	n/a	n/a	0
TOTAL	0	94	10	2018	252	38,100	months	2.3	1.7

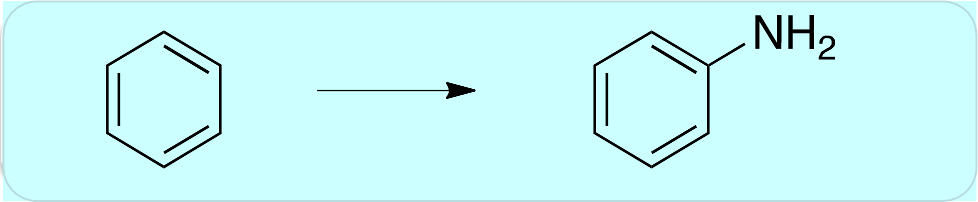
Synthesis of Benzene to Aniline



Indexes

Cmpd	I_{AP}	I_{OD}	I_{SF}	I_{GW}	I_{INHT}	I_{INGT}	PER $t_{1/2}$, h	ACCU $\log K_{ow}$	I_{AD}
Benzene	0	0	2.8	66	240	19	months	2.1	0
Me_3SiN_3	0	0	0	0	0	?	months	2.3	0
Triflic Acid	0	0	0	0	0	0.5	weeks	-0.5	F: 0.011 S: 0.754
Me_3SiOTf	0	0	0	0	0	?	months	0.6	-
NaOTf	0	0	0	0	0	?	n/a	n/a	-
CH_2Cl_2	0	94	7.2	123	12	38,081	weeks	1.3	0
NaOH	0	0	0	0	0	?	n/a	n/a	0
$MgSO_4$	0	0	0	0	0	?	n/a	n/a	0.94
CO_2	0	0	0	1829	0	0	n/a	n/a	0
TOTAL	0	94	10	2018	252	38,100	months	2.3	1.7

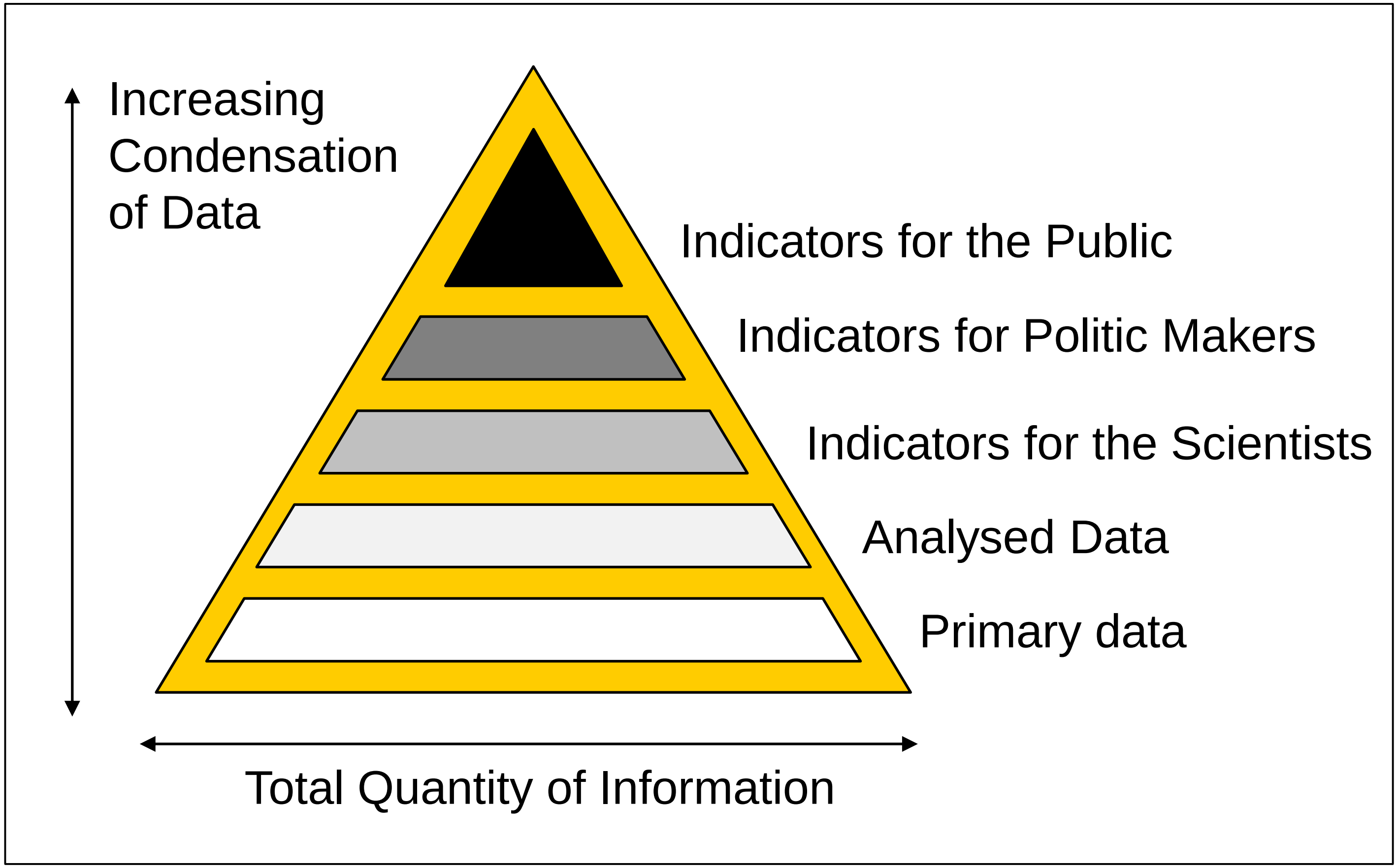
Comparing Syntheses



Comparison of Routes (all in grams)

Process	I_{AP}	I_{OD}	I_{SF}	I_{GW}	I_{INHT}	I_{INGT}	**PER** $t_{1/2}$, **h**	**ACCU** $\log K_{ow}$	I_{AD}
#1	0	90	10	2,000	300	40,000	months	2.3	2
#2	1	0	200	5,000	20	40,000	months	0.6	0.2
#3	600	0	0.2	100	4,000	100,000	months	1.9	0.1
#4	3,000	0	5	1,000	600,000	300,000	months	1.9	1000

Indicator Hierarchy



SOURCE: World Resources Institute, 1995, 'Environmental Indicators'

Indicator Issues

- Aggregation
    - i.e. operation, product, division, structures
    - Biological Diversity?
    - Learning Rate?
    - Community investments?
- Normalization and Measurement
    - “efficiency”, i.e. energy for unit
    - which type (physico-chemical, financial, social)
- Report
- Users
- Standardization and Comparison

Risk Assessment: ECO-it Approach

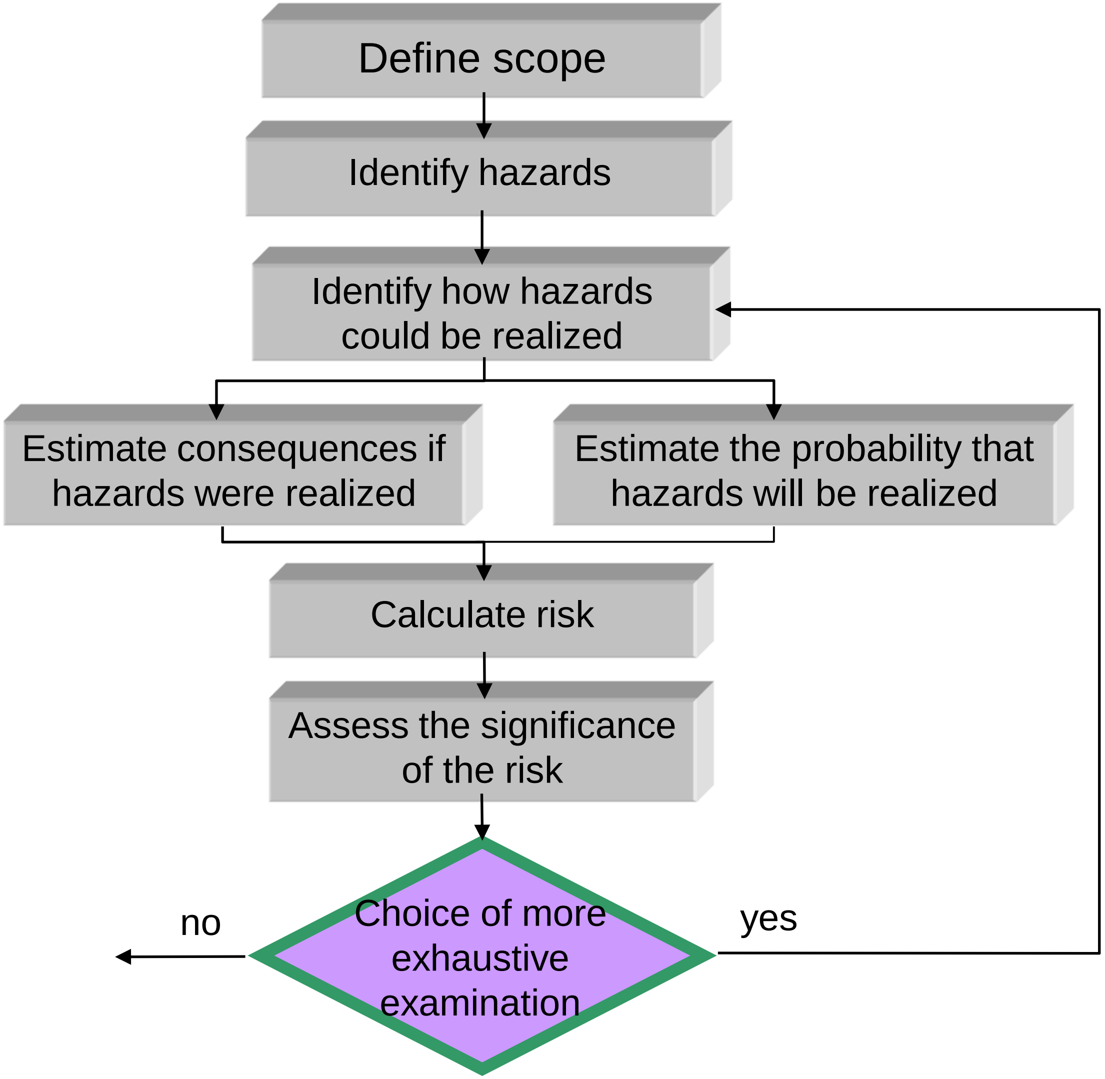
Developed in Netherlands

- Based on European needs and data

Three “Eco”s

- Human Health
  - Number/duration of disease, life-years lost
  - Causes: Climate change, ozone layer depletion, carcinogenic effects, respiratory effects, ionizing radiation
- Ecosystem Quality
  - Species diversity
  - Causes: ecotoxicity, acidification, eutrophication, land-use
- Resources
  - Surplus energy needed in future to extract lower quality mineral / fossil resources
  - Depletion of agricultural / bulk resources considered under land-use

Steps in a Risk Assessment


Define scope

Identify hazards

Identify how hazards could be realized

Estimate consequences if hazards were realized

Estimate the probability that hazards will be realized

Calculate risk

Assess the significance of the risk

Choice of more exhaustive examination

no

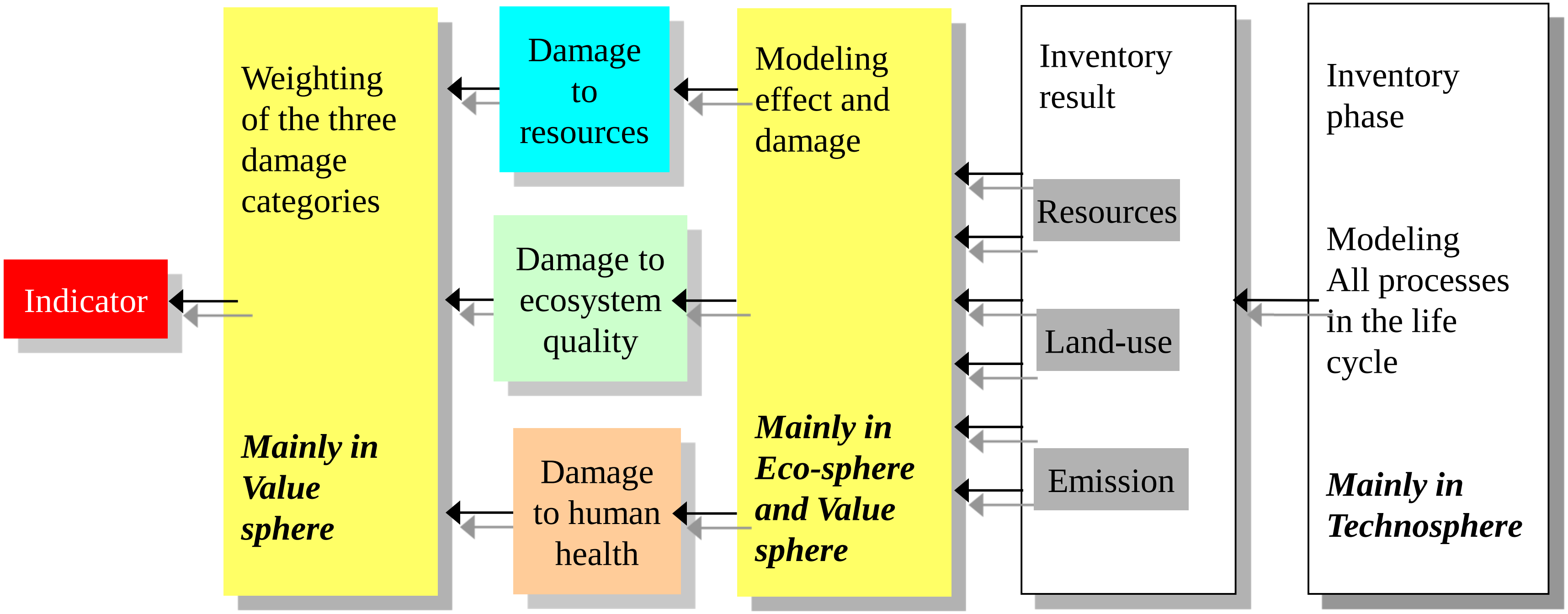
yes

The Core Concept of the Eco-indicator 99 Methodology.

Three spheres are considered:

- Techno-sphere
- Eco-sphere
- Value-sphere

see: http://www.pre.nl/eco-indicator99/



Indicator

Weighting of the three damage categories

Mainly in Value sphere

Damage to resources

Damage to ecosystem quality

Damage to human health

Modeling effect and damage

Mainly in Eco-sphere and Value sphere

Inventory result

Resources

Land-use

Emission

Inventory phase

Modeling All processes in the life cycle

Mainly in Technosphere

Example: Arsenic (As) Levels in Water

Considerations on human health

Unacceptable risks on health

200

Tolerable Concentration, low Risk of skin cancer in Individual very sensitive long term

10

Wanted quality Interval

Level

μg/m^3

Considerations on ecosystem

Acute Effects

Acute effects measurable in 5% of species of aquatic community

130

Chronic Effects

Chronic effects measurable in 5% of species of aquatic community

20

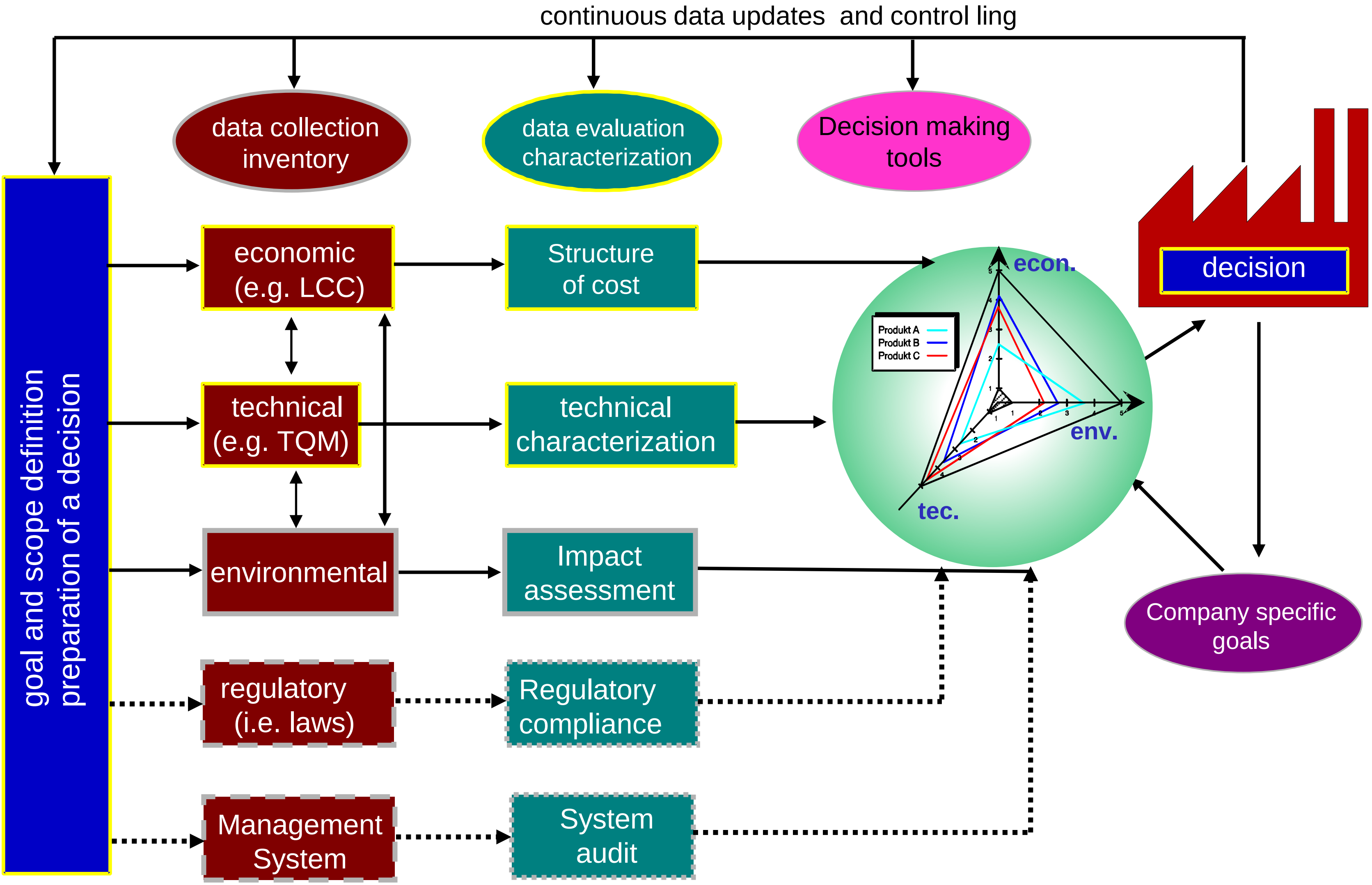
10

Wanted quality Interval

Risk Levels for Arsenic in Water

Weighting	Value	Around Quality
High	5	200 μg/m^3: unacceptable risks to human health and ecosystem in a region for high arsenic concentrations
	4	130 – 200 μg/m^3: high risks to human health and measurable acute effects on aquatic ecosystem
Medium	3	20 – 130 μg/m^3: growing risk to human health and measurable chronic effects on aquatic ecosystem
Low	2	10 – 20 μg/m^3: Low risk to human health and no measurable effect on aquatic ecosystem
	1	0 – 10 μg/m^3: No effect to human health and on ecosystem In a region of arsenic concentration

Life Cycle Engineering



continuous data updates and control ling

goal and scope definition
preparation of a decision

data collection inventory

data evaluation characterization

Decision making tools

economic (e.g. LCC)

Structure of cost

technical (e.g. TQM)

technical characterization

environmental

Impact assessment

regulatory (i.e. laws)

Regulatory compliance

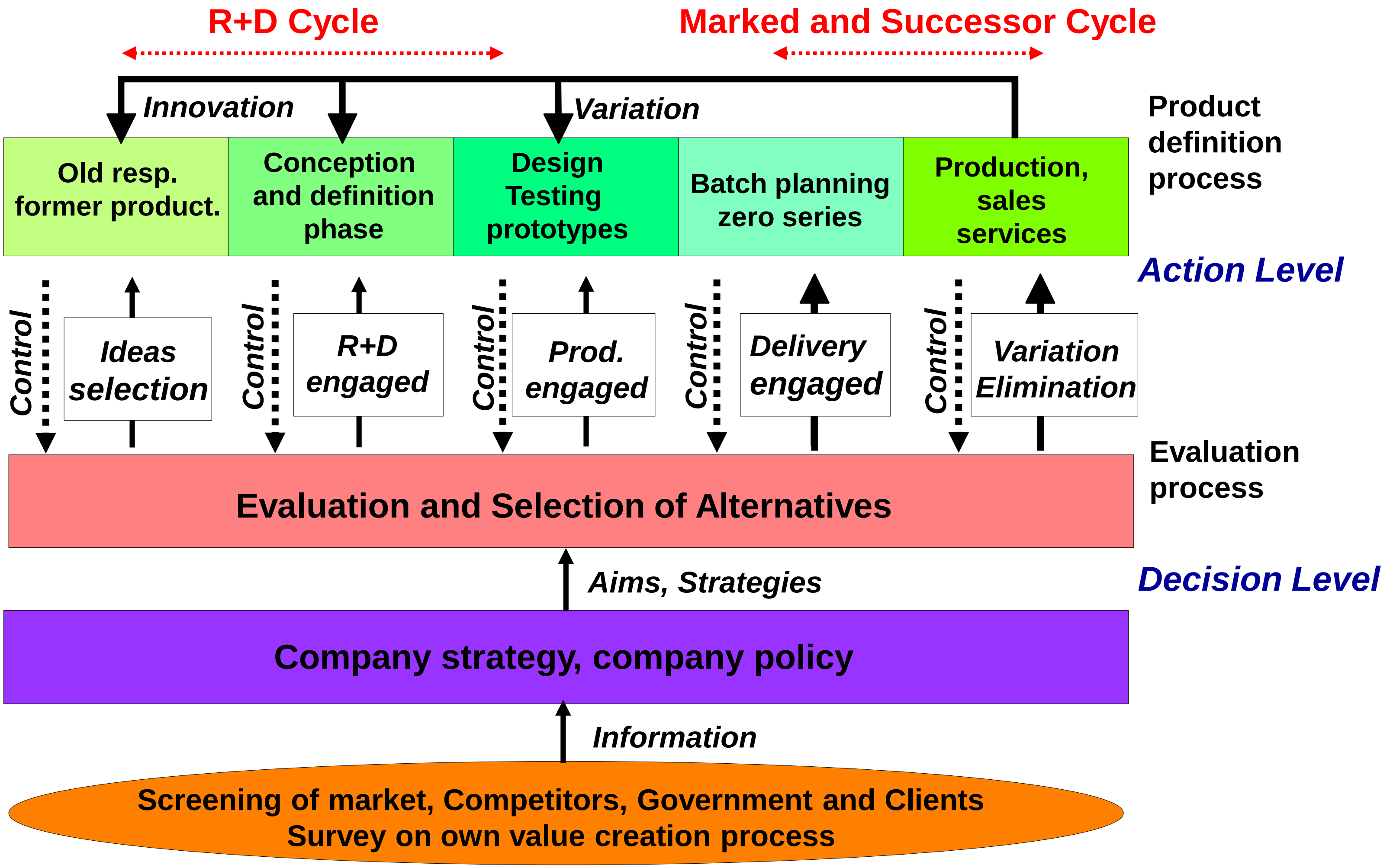
Management System

System audit

decision

Company specific goals

Decision Making Gates



R+D Cycle

Marked and Successor Cycle

Innovation

Variation

Product definition process

Old resp. former product.

Conception and definition phase

Design Testing prototypes

Batch planning zero series

Production, sales services

Action Level

Control

Ideas selection

Control

R+D engaged

Control

Prod. engaged

Control

Delivery engaged

Control

Variation Elimination

Evaluation process

Evaluation and Selection of Alternatives

Aims, Strategies

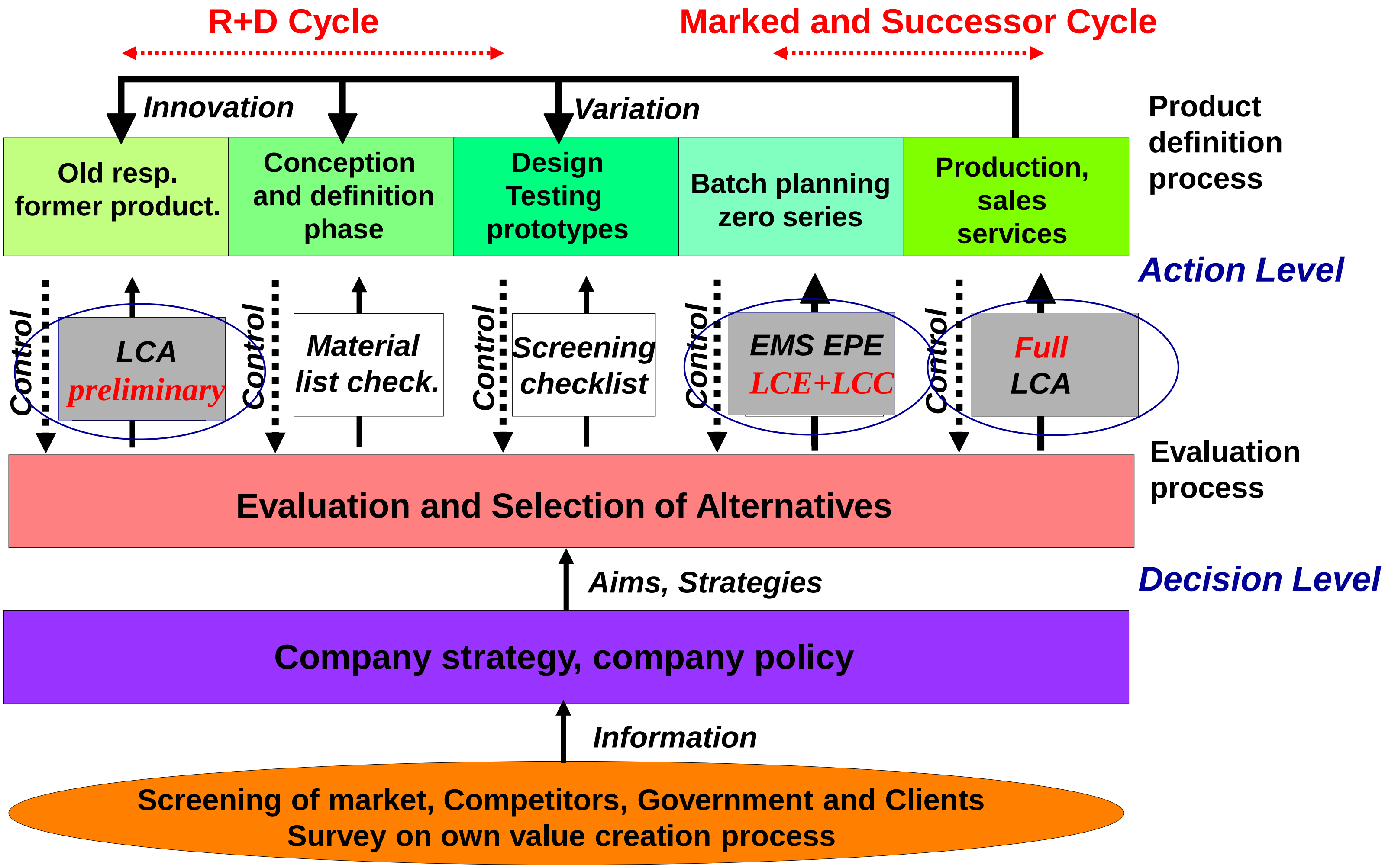
Decision Level

Company strategy, company policy

Information

Screening of market, Competitors, Government and Clients
Survey on own value creation process

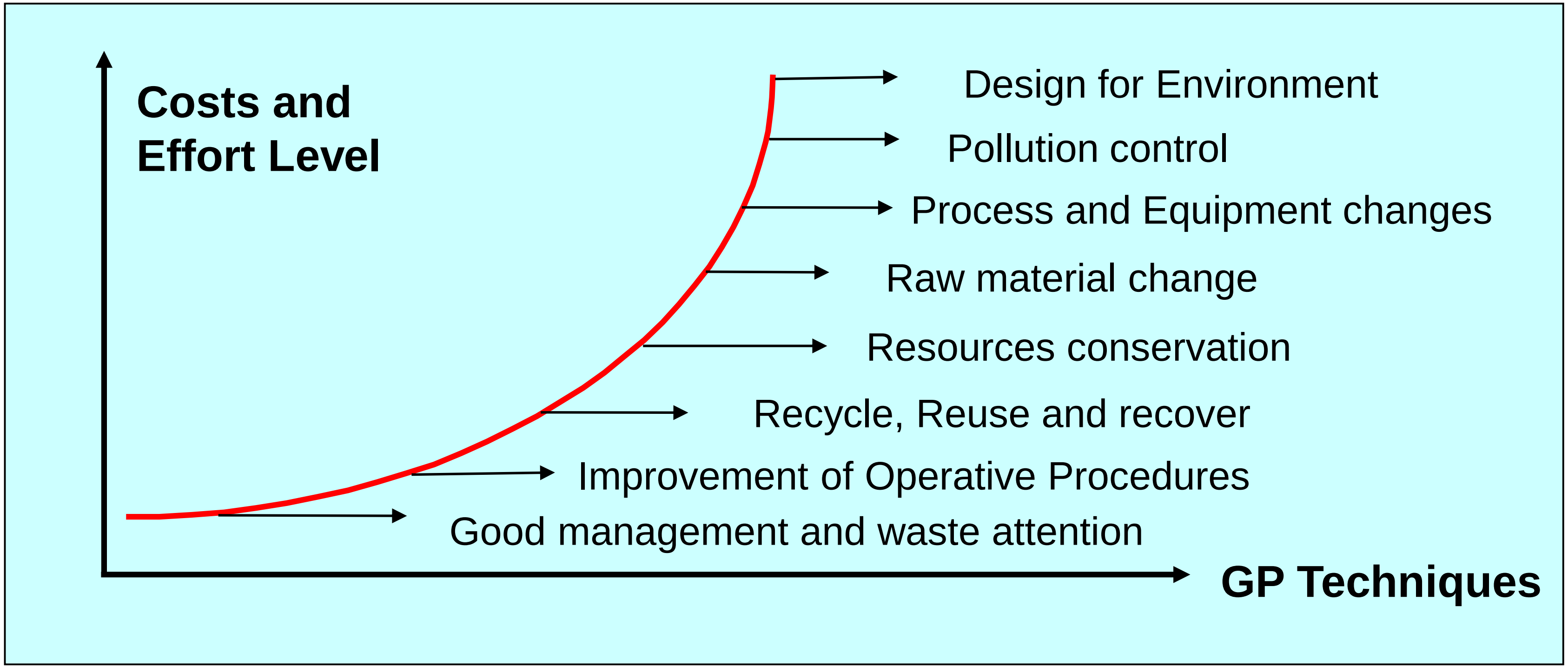
Environmental Information Tools



Target / Effort

- LCA Conceptual –Life cycle Thinking
    - This is the first and more simple level of LCA, used to carry out evaluations based on limited inventory of qualitative type.
- LCA Simplified - investigation
    - The aim of this approach is the same as in detailed LCA but here simplification are provided to significantly reduce the time need to complete the study.
- LCA detailed
    - Is a more specialist and scientific approach.

GP Techniques, Costs and Effort Level



LCA Detail Levels

Detail level in some LCA applications; "x" in bold indicates the more used level.

	LCA detail level.			
Applications	**Conceptual**	**Simplified**	**Detailed**	**Comments**
Design for Environment	**x**	x	-	No LCA formal link
Product Development	x	**x**	x	Strong change in sophistication
Environmental Chain (ISO type II)	**x**			Seldom based on LCA
Environmental labels (ISO type I)		x		Inventory and/or impact evaluation
Environmental accounting (ISO type III)			x	Inventory and/or impact evaluation
Sales organization		**x**	x	Inclusion of LCA in the environmental report
Strategic design	**x**	**x**		development of LCA knowledge
Green procurements	x	**x**		LCA not detailed as in definition of environmental labels
warehouse/delivery scheme		x		LCA with reduced number of parameters
Environmental "green" taxes		x		"

Life Cycle Management (LCM)

- LCM is the application of life cycle thinking to modern business practice with the aim to manage the total life cycle of an organization’s products and services towards more sustainable consumption and production
- LCM is systematic integration of sustainability, e.g. in company strategy and planning, product design and development, purchasing decisions and communication programs
- LCM is not a single tool or methodology but a flexible integrated management framework of concepts, techniques and procedures incorporating environmental, economic, and social aspects of products, processes and organizations
- LCM is voluntary and can be gradually adapted to the specific needs and characteristics of individual organizations

LCM Drivers and Benefits

Corporate strategy

- Expansion of product stewardship programmes
- Competitive advantage: being at the forefront of development
- Reduce costs: Increased operational and resource efficiency
- Improve public reputation, image and general relations to stakeholders
- Enhance product innovation: development and design of new products
- Increased brand value (‘sustainable’ products)

Market requirements

- Increased market share: advantages to ‘first movers’ on sustainability issues
- Ability to focus on sustainability and go beyond the production fence; e.g.
    - Supply chain management (supplier evaluation)
    - Communication in the value chain
    - Environmental product declarations

Financial sector requirements

- Increase shareholder value, to get a ‘Dow Jones Sustainability Index’
- Less risky business with decreased liabilities resulting in lower insurance rates and reduced fines

New regulations or legislative demands

- Anticipate future legislative demands, e.g. ‘Take back legislation’
- Joining eco-labelling schemes and green public procurement programmes
- Joining corporate social responsibility programmes

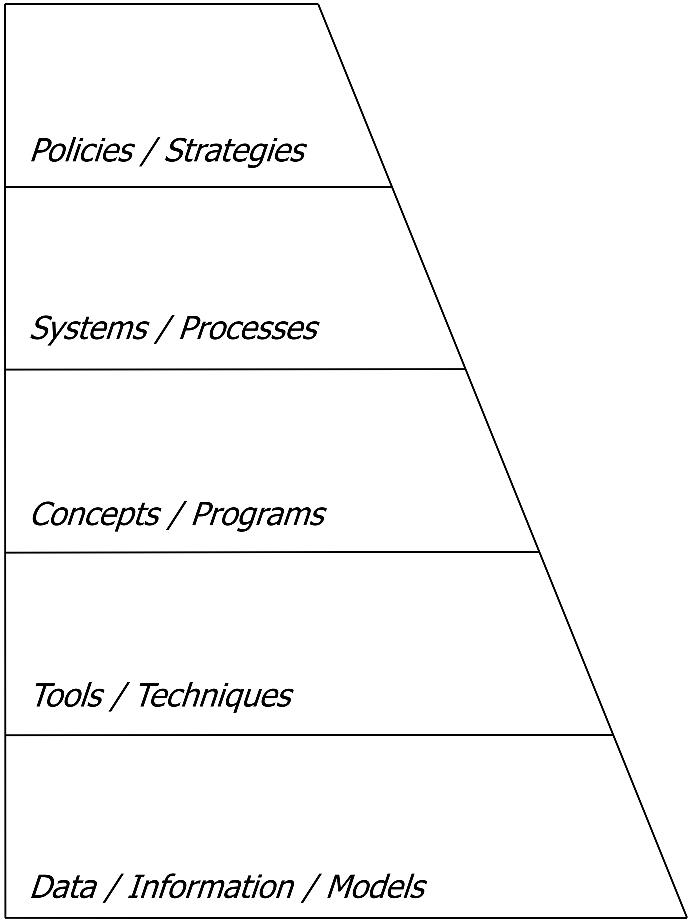
LCM Objectives, Strategies, Systems, Tools

management Level

	Social dimension	Environmental dimension	Economic dimension
Objective	**SUSTAINABILITY**		
Concept	**LIFE CYCLE THINKING**		
Strategies	**LIFE CYCLE MANAGEMENT**		
	Corporate social responsibility	Pollution prevention	Product- and supply chain management
Systems	OHSAS 18001	ISO 14001 & POEMS	ISO 9001, TQM, EFQM
Tools	Work place evaluation	Cleaner production LCA, Eco-design	EMA & LCC

Explanations: OHSAS = Occupational Health And Safety, POEMS = Product Oriented Environmental, Management System, TQM = Total Quality Management, EFQM = European Foundation for Quality Management, LCA = Life Cycle Assessment, EMA = Environmental Management Accounting, LCC = Life Cycle Cost Analysis.

Overview of LCM issues

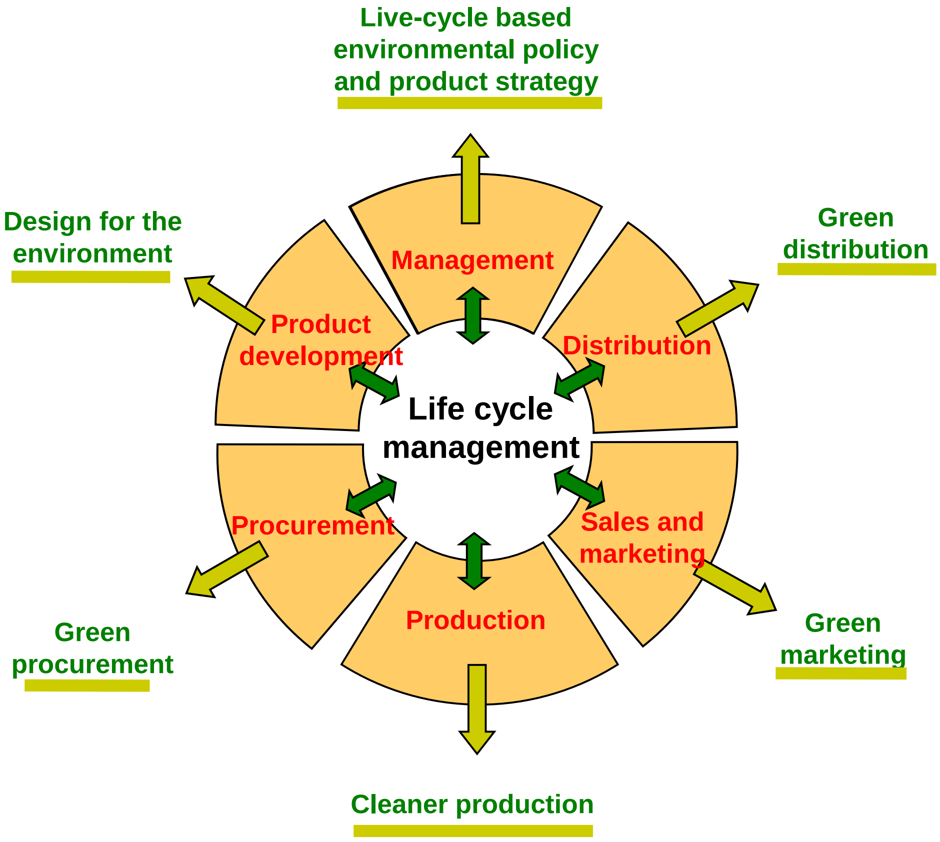


Policies / Strategies	Sustainable Development, Triple Bottom line, Integrated Product Policy (IPP), Dematerialization (Factor 410), Cleaner Production, Industrial Ecology, Eco-efficiency, Sustainable Asset Management, etc.
Systems / Processes	Integrated and Environmental Management Systems (i.e.. ISO 9000/14000, EMAS, EFQM), Extended Producer Responsibility (EPR), Product Development Process (PDP), Certification, Environmental Communication, Value Chain Management, etc.
Concepts / Programs	Product stewardship, Design for Environment, Supply Chain Management, Public Green Procurement, Stakeholder Engagement, Corporate Social Responsibility, Green Accounting, Supplier Evaluation, etc.
Tools / Techniques	Analytical: LCA, MFA, SFA, I/O, ERA, CBA, LCC, TCO, etc. Procedural: Audits, Checklists, Labeling, EIA, etc. Supportive: Weighting, Uncertainty, Sensitivity/Dominance, Scenarios, Back casting, Standards, Voluntary Agreements, etc.
Data / Information / Models	Data Databases, Data Warehousing, Controlling. Information: Best Practice Benchmarks, References, etc. Models: Indicators, Fate, Dose-response, Monte Carlo etc.

LCM must Involve Many Levels of the Organization

- LCM must be a high priority for all parts of management, and all relevant departments / functions must participate

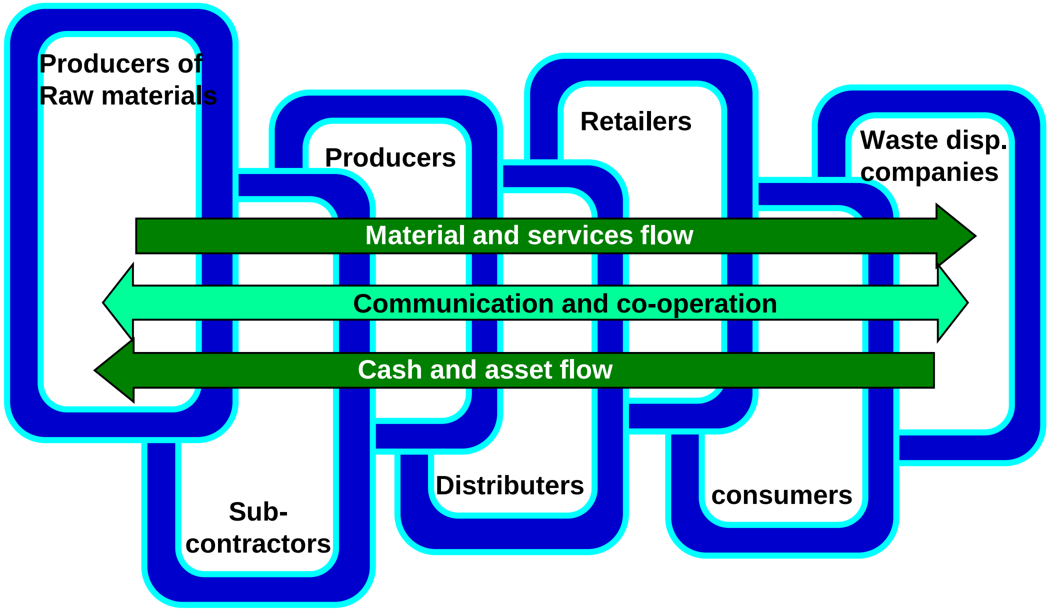
- Participation of employees ensures that LCM initiatives will be deeply rooted in the organization and that the focus will be on concrete improvements to a product's environmental profile, rather than mere talk and data collection.



The Organization must 'go beyond its Facility Boundaries'

Shifting the focus from within the organization's fence to the entire product chain includes:

- The *product* life cycle: flow of materials from acquisition of raw materials to production, transport, use and disposal.
- The *marke*t: a value and currency flow from the consumer to the producer.
- *Communication and cooperation* in form of exchange of knowledge and experience.



Collaboration in the Product Chain

Integrated Management System and Tools: Examples

ISO 9001:2000

- *quality*

ISO 14001:2004

- *environment*

ISO 18001:2004

- *occupational health and safety*

SA 8000:1999

- *social accountability*

AA 1000:1999

- *accountability*

AFNOR FD X 50-189:2003 *Management systems – Guidelines for their integration*

AFNOR AC X 50-200:2003 *Integrated management systems – Good practices and experience feedback*

DS 8001 *Guidance for integrated management systems*

Product Design Based on LCA and Product Development

- **Design** determines:
  - 70~80% of the total project life cycle costs
  - most of the total life cycle environmental impacts

- **Early assessment of the cradle- to- grave environmental aspects** of the product system can lead to effective integration of environmental considerations into the design process

> "Long-term prosperity depends not on the efficiency of a fundamentally destructive system, but on the effectiveness of processes and products designed to be healthy and renewable in the first place"
>
> William McDonough

Design For Environment (DFE)

Examining a product’s entire projected lifecycle and identifying measures that can be taken to minimise the environmental impact of the product at its design stage

DFE strategies considers design measures to reduce the environmental impact in each stage of its life cycle

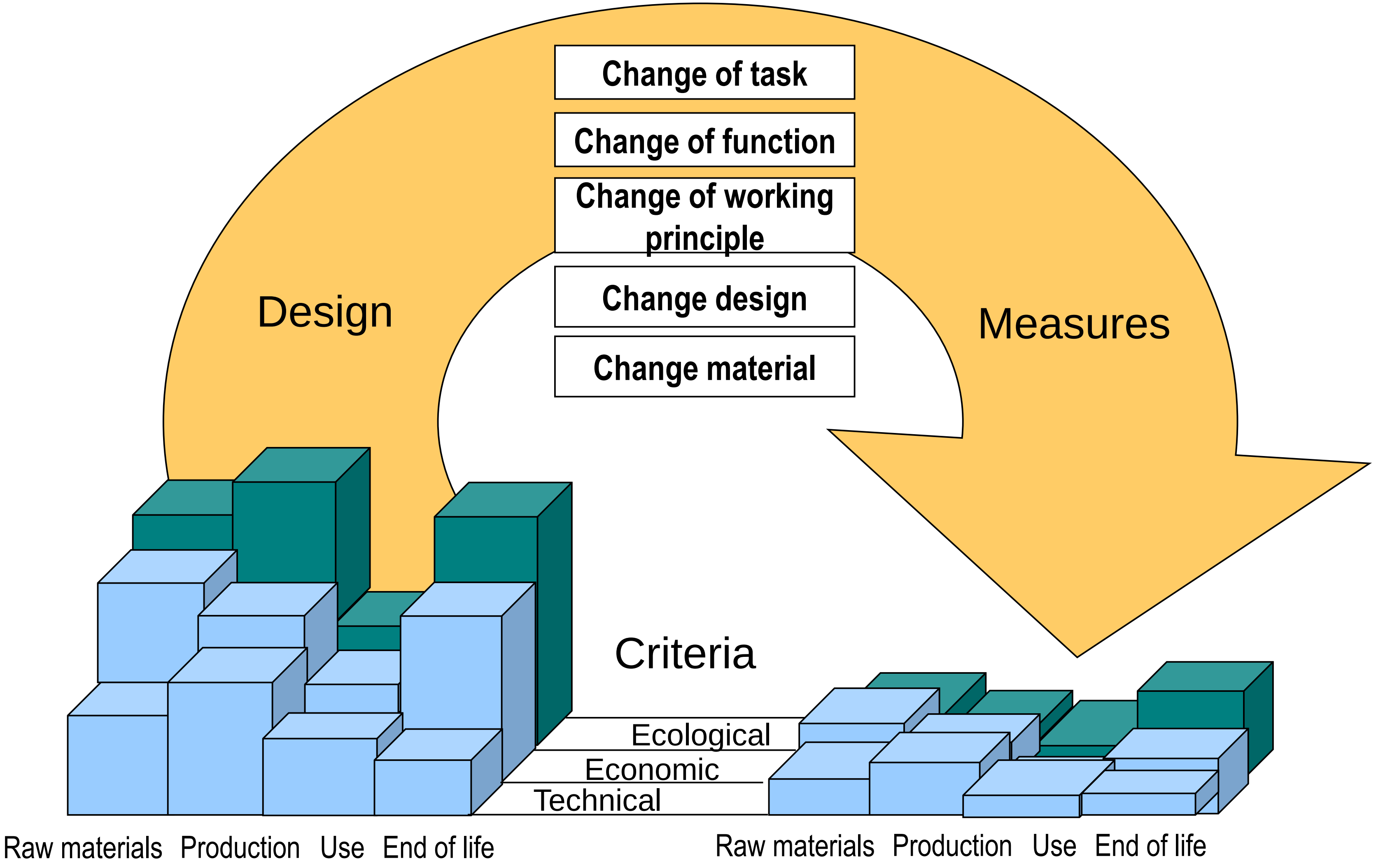
- ***Raw materials:*** **design measures relating e.g. to resource conservation**
- ***Manufacturing*****: providing for eco-efficiency in the production phase**
- ***Product use*****: making provision in product-use phase e.g. for energy and water efficiency, reduced material use, and increased durability**
- ***End-of-life*****: key design considerations include design for disassembly, design for durability, product re-use, and design for recycling**

Design for The Environment (DfE) Evaluation

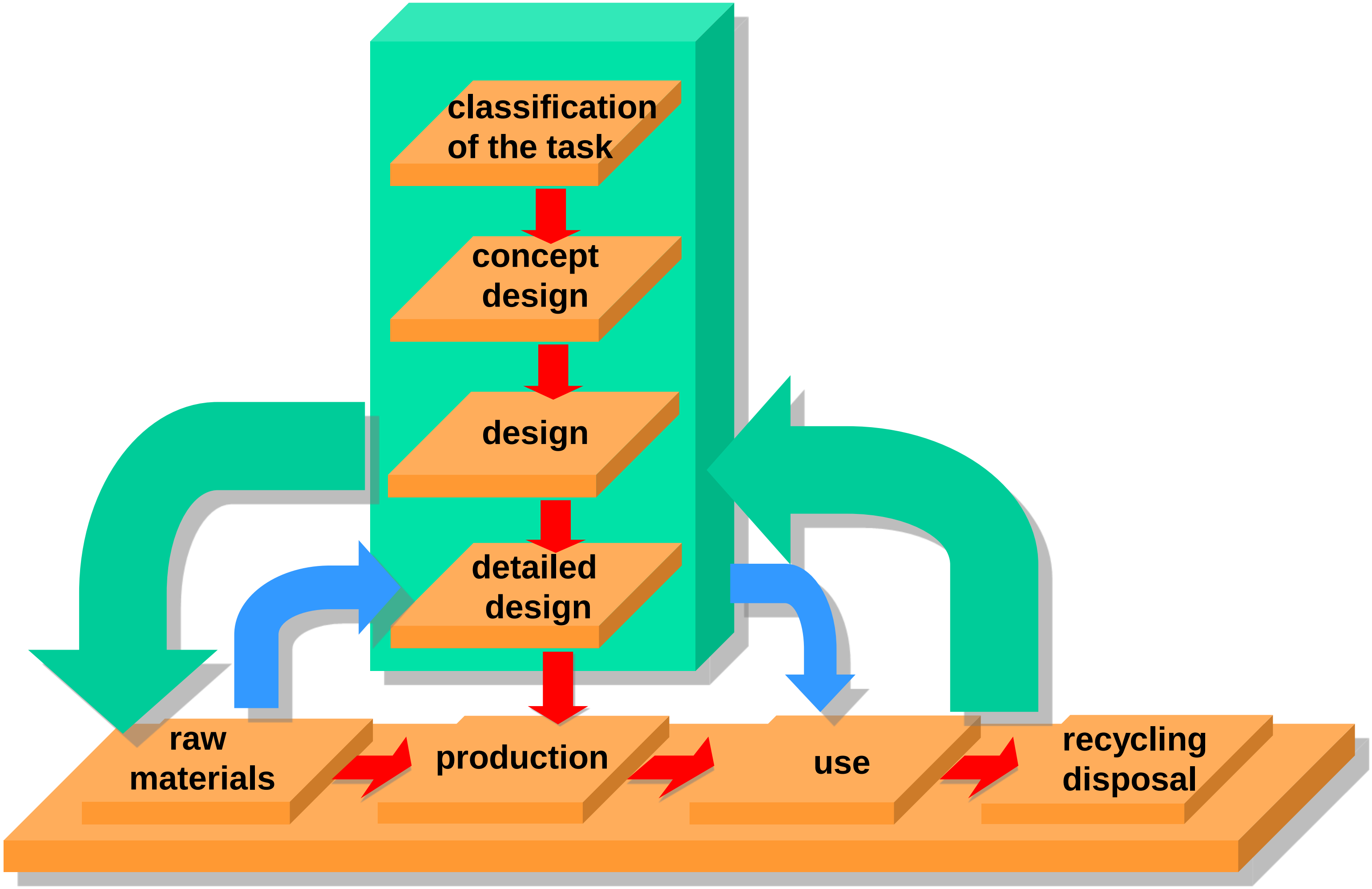
- Three Categories of Evaluation Criteria
    - **Energy** Consumption during the Entire Life Cycle
    - **Material** Utilization & Selection
    - **Process** Improvement & Selection

- Tools
    - Life Cycle Assessment Tools
    - CAD/Material/Process Selection Tools
    - Disassembly Modeling and Analysis Tools
    - Simulation Tools

Integrated Product Development



Design for Environment



Eco-Design

Eco-Design considers the relation between a product and the environment.

Common propositions:

- Environmental impacts from products have continued to rise relative to production processes
- A life-cycle perspective on the environmental impacts of a product captures the whole production-consumption chain
- Of the (life-cycle) impacts from products, 60% to 80% are determined at the design stage
- A focus on products is a better way to engage business interest and action because it focuses on the products' market vulnerability

Cradle-to-Cradle Design – A New Paradigm

- *True change*: Designing industrial processes so they do not generate toxic pollution and "waste" in the first place

Cradle-to-Cradle Design – “Environmentally Intelligent”

New paradigm modeling human industry on nature’s processes in terms of which

WASTE = FOOD

Materials are viewed as nutrients circulating in healthy, safe metabolisms:

1) *Nature's* biological metabolism *should be protected and enriched*

all waste = food for biological system (biodegradable)

2) Technical metabolism *enhanced through circulation of mineral and synthetic materials*

All waste = food for another industrial system

Cradle-to-Cradle by William McDonough & Michael Bragnaurt

Cradle-to-Cradle Design – Benefits

- *Design for life-time customers – products leased again & again to customer base*
- *Risk management – risks to environmental and human health are reduced by eliminating the concept of waste & selecting materials that are safe to both human and natural systems*
- *Cost reduction – dramatically reduce legal & material costs*
- *Product differentiation – products that offer customers excellence by all measurements*

“Cradle-to-Cradle designs have positive effects extending beyond the client company to its suppliers, customers, communities, and the natural world ”

William McDonough

Product Stewardship

A product-centred approach to environmental management, where manufacturers – either voluntarily or under pressure from government – take responsibility for the entire life-cycle impacts of a product and its packaging

Benefits:

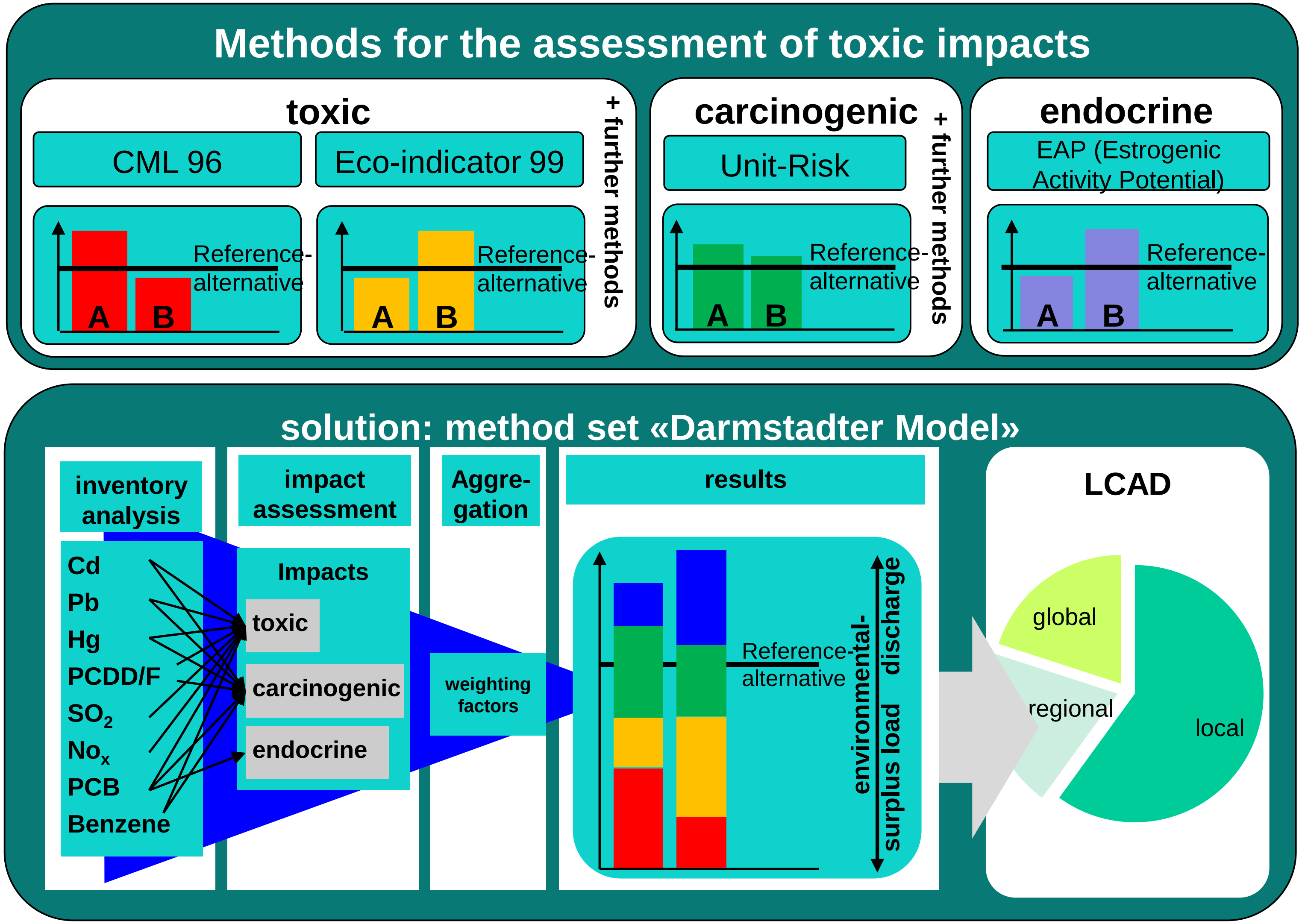
- **Green marketing opportunities**
- **Avoids regulation**
- **Achieves environmental goals**

The objective of product stewardship is to encourage manufacturers to redesign products with fewer toxins, to make them more durable, reusable, recyclable, and using recycled materials.

Tools of Product Stewardship include:

- Take-back programs
- Leasing
- Life-cycle management
- Shared responsibility
- Extended producer responsibility
- Manufacturer responsibility

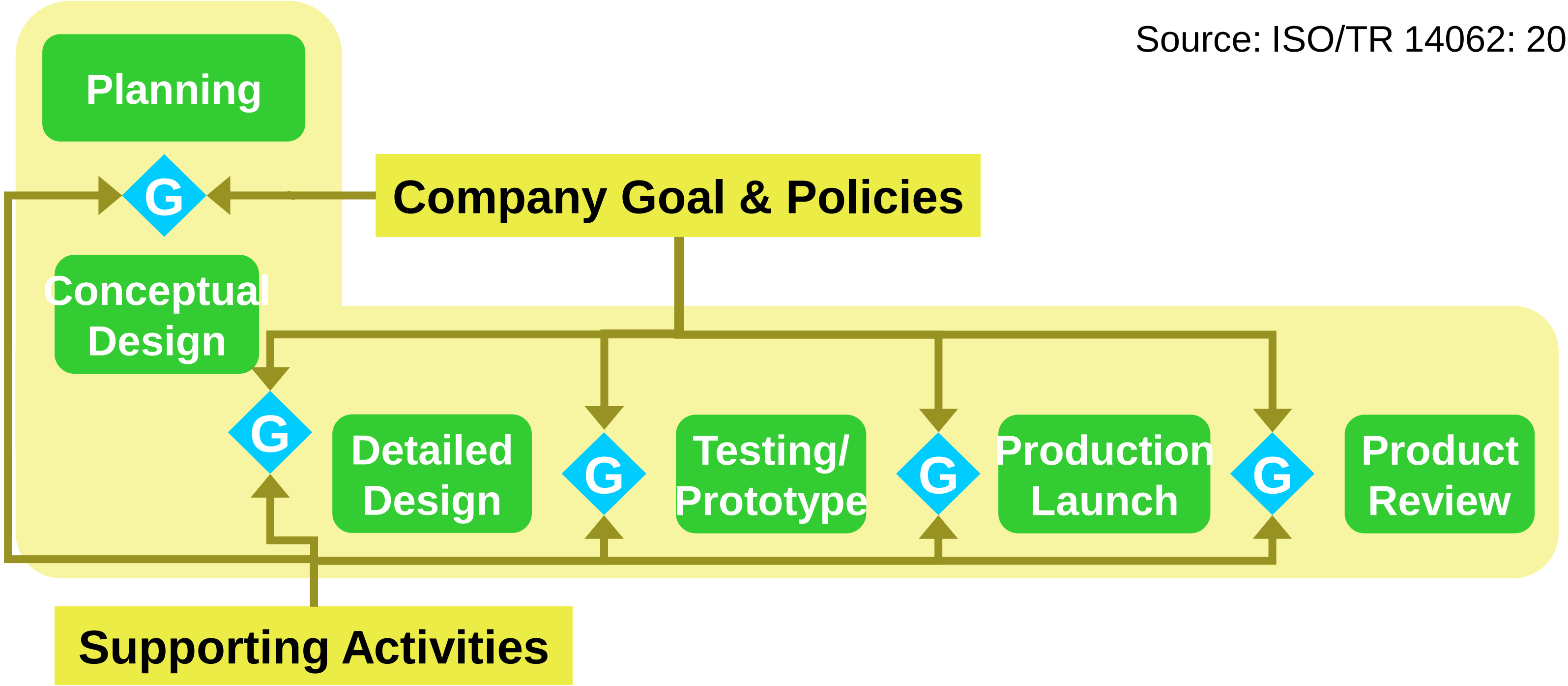
Assessment of Toxic Impact



Surfactant Criteria Snapshot Chemical Green Card

	Aquatic Tox	Ult. Biodegradable	EU- Enviro Classif.	Acute Human Tox
Best (3)	Class 3, Preferred • LC50/EC 50> 1mg/L • 3 or more species tested	Class 3 • Readily biodegradable (OECD 301) >60% w/in 10 d	Class 3 (Best) • Aquatic tox 100mg/L	**Class 3** • **LD50 >2000 mg/kg**
Better (2)	Class 2 • LC50/EC 50> 1mg/L • 1/2 species tested	Class 2 • >60% w/in 28 d	Class 2 (Better) • No adverse classification • Readily biodegradable • Aquatic tox >1mg/L	**Class 2** • **LD50 between 500 -2000 mg/kg**
Acceptable (1)	Class 1 • LC50/EC50 < 1mg/L	Class 1 • <60% w/in 28 d	Class 1 (Acceptable) • Any EU classification (N, R50; N, R50-53; N, R51-53; R52-53, R52 or R53)	**Class 1** • **LD50 < 500 mg/L**

Gate New Product Development Process



Source: ISO/TR 14062: 2002

stage

- A set of tasks that generate information, typically in the form of deliverables such as drawings, reports, etc. needed to support key business decisions

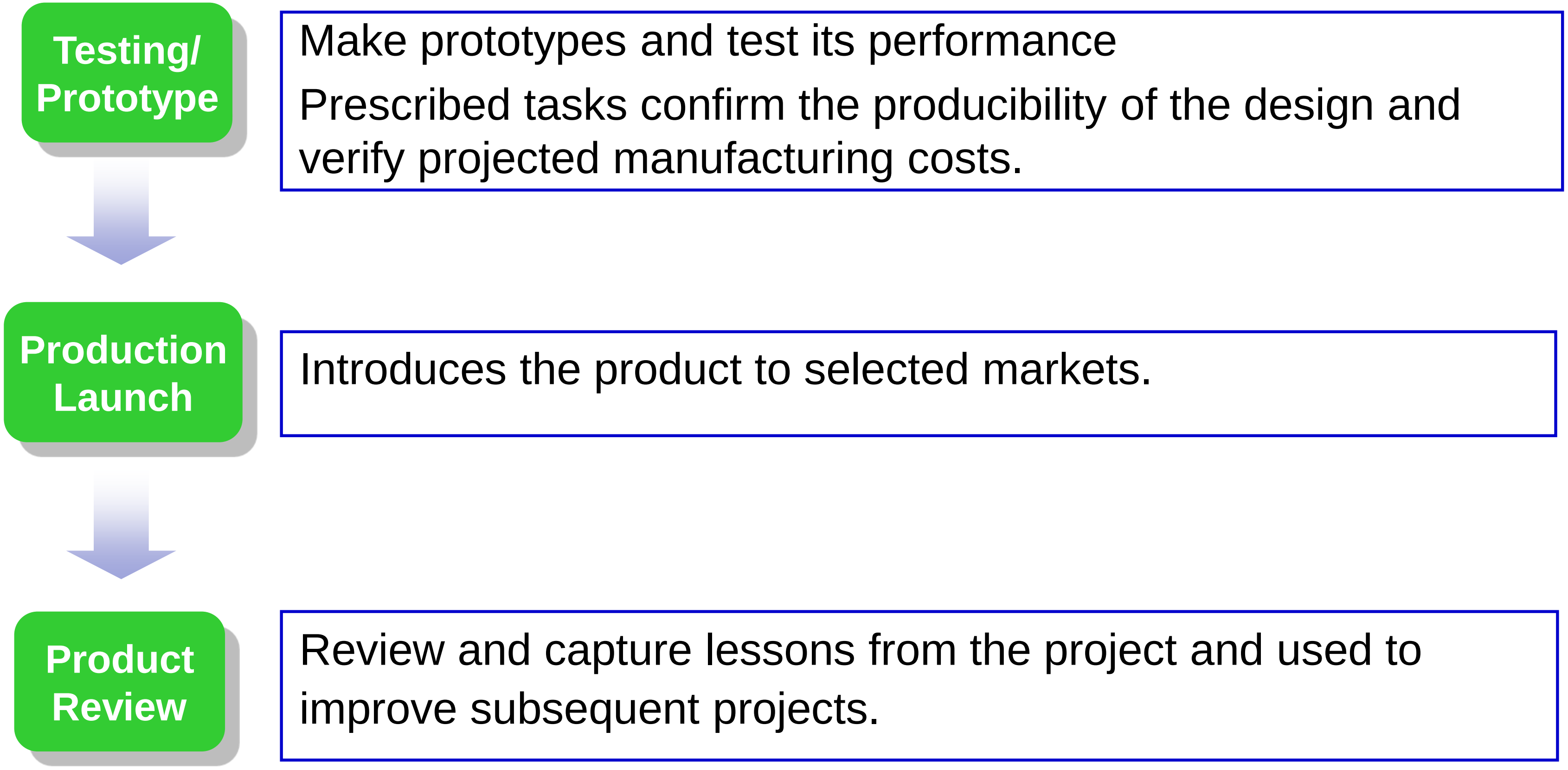
gate

- A point for review where a decision to continue investment in the project or terminate is made

Stage - Details

Planning	Surveys external pressures, public expectations, customer needs, and industry trends to define the requirements for a successful product offering
Conceptual design	Assesses the strategic fit of the identified business opportunity with company capabilities and objectives. Develop product concept
Detailed Design	Develops complete bill-of-material, drawings, manufacturing plans, etc. that meets technical specifications and enables design of the manufacturing and support processes consistent with project cost and quality goals

Stage - Details



Testing/ Prototype

Make prototypes and test its performance

Prescribed tasks confirm the producibility of the design and verify projected manufacturing costs.

Production Launch

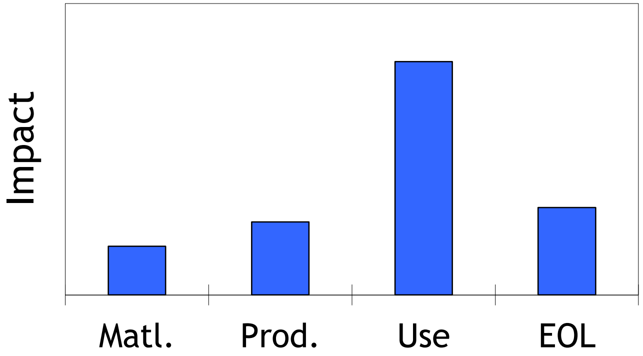
Introduces the product to selected markets.

Product Review

Review and capture lessons from the project and used to improve subsequent projects.

Examples of Product Life Cycle Profiles

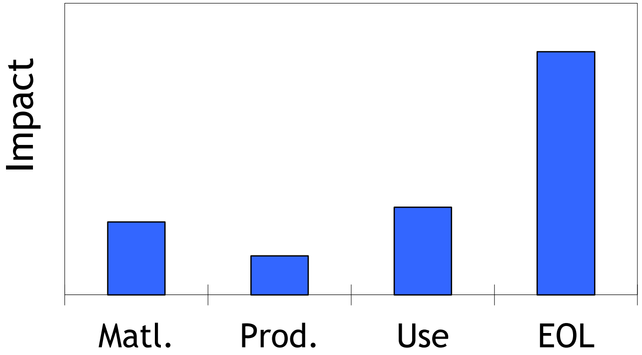
- Durable goods, (e.g. appliances)



Eco-design strategies

- energy conservation
- elimination of toxic and other minor constituents that complicate maintenance and upgrades

- Single-use, (e.g. diaper)



- biodegradability
- elimination of any problematic materials after its disposal

Eco-design Approach

Product (System) Definition

Environmental Assessment

Life cycle Perspective

Stakeholder Perspective

Eco-design

Environmental Communication

- Defines a product to be improved environmentally
  - ✓ Identifying product components, parts, and materials, plus life cycle stage information of the product.
- **Output**
  - ✓ The product composition, product system, life cycle stage data and, technical parameters of the product relevant to the significant environmental aspects or environmental parameters

Environmental Assessment – Stage II

Life cycle Perspective

- Assess the environmental aspects of a product system based on the environmental impact caused by the product system.
- Tools: Life cycle thinking & LCA

Stakeholder Perspective

- Assess the environmental aspects of a product based on the stakeholders view such as legal requirements, market demands, and competitor's products.
- Tools: EQFD & EBM

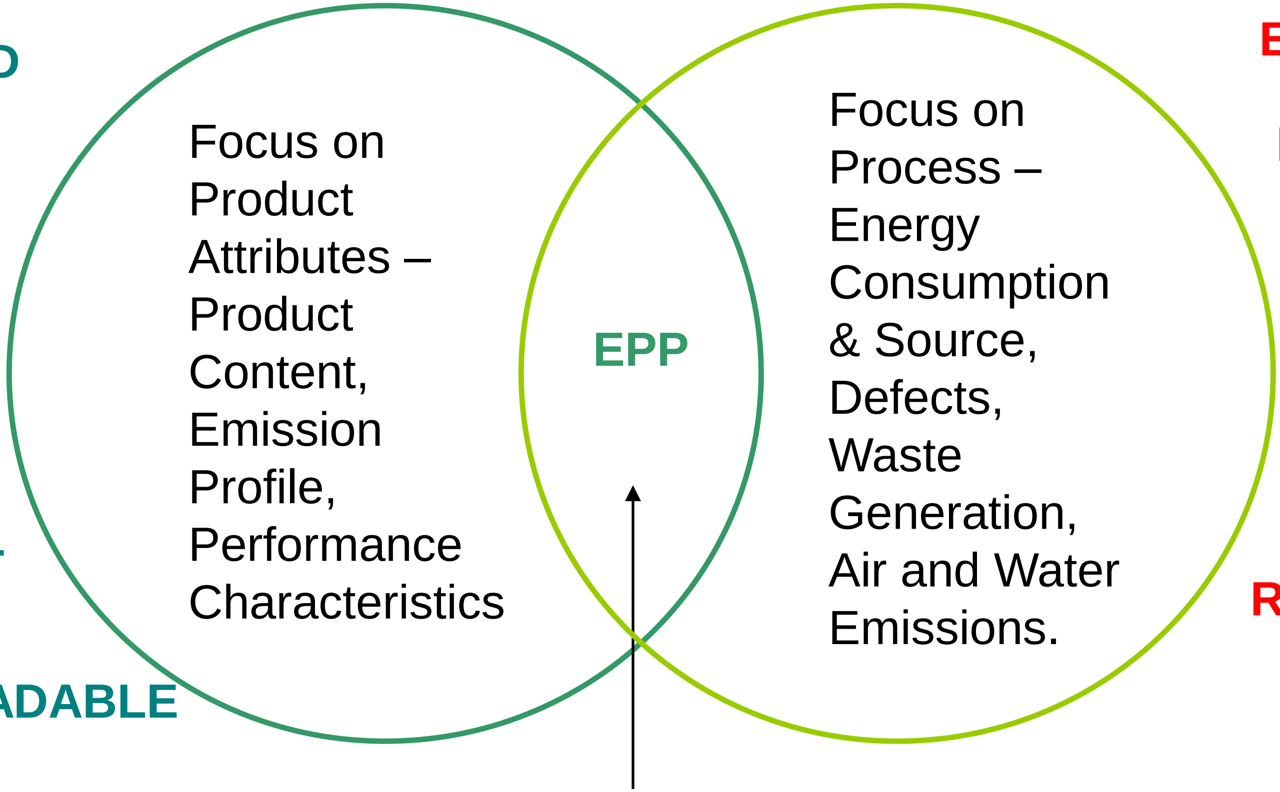
Output

- A set of significant environmental parameters of a product on the environment

Eco-design – Stage III

- Link the significant environmental parameters to relevant environmental strategies
- Identify relevant implementation measures for the improvement of the environmental parameters belonging to a certain environmental strategy
- Develop redesign tasks for the chosen implementation
- Develop product specification. It consists of fixed and wish specification
- Identify function of the reference product and then add new function and/or modify existing function based on the product specification
- Generate ideas to realize the function
- Generate variants. Assembling idea corresponding to each function of the newly improved product generates the variants
- Develop product concept by selecting variant. Variants are evaluated against criteria such as economic, technical, social and environmental ones
- Continuing detailed embodiment design, layout, testing, prototype, production and market launch

Blend LCA, 13101 and Beyond



RECYCLED CONTENT

ORGANIC

LOW EMITTING

ENERGY EFFICIENT

BIODEGRADABLE

Focus on Product Attributes – Product Content, Emission Profile, Performance Characteristics

EPP

Focus on Process – Energy Consumption & Source, Defects, Waste Generation, Air and Water Emissions.

RENEWABLE ENERGY

ISO 14000

ISO 9000

LCI/LCA

GHG REGISTRY

Where we are heading – Environmentally Preferable, Well Managed, Sustainable

Communication of Life Cycle Information

Distinguish communication tools vs. target stakeholders

- Final consumers
- Business clients
- Financial stakeholders
- Public administrators and policy makers
- Other society stakeholders

- ISO-type I labels as communication tool to final consumers

However, important limitations of eco-labels

- other communication tools increase awareness and foster better use of products
- Simplification of complex life-cycle information into ISO-type II claims
- ISO-type III declarations for B2B
- Combination of tools

Final Consumers 1 – ISO-type I Labels

- Diffusion of ISO-type I labels
- Number of product groups, firms and products for the main ISO-type I labeling schemes as of end of 2002.

Country	**Year of establishment**	**Product group**	**Firms**	**Products**
Japan1	1989	64	2107	5152
Germany	1978	94	995	3114
Nordic countries	1989	55	658	2872
Sweden (Falcon)	1992	14	617	1226
Spain/Catalunya (DGQA)	1994	16	79	864
Austria	1991	44	334	645
EU_2	1992	19	128	576
France	1992	15	47	443
The Netherland	1992	69	257	360
Spain (AENOR)	1994	13	71	77

Comparison of the main key performance indicators from 2001 to 2012 (EU Ecolabel)

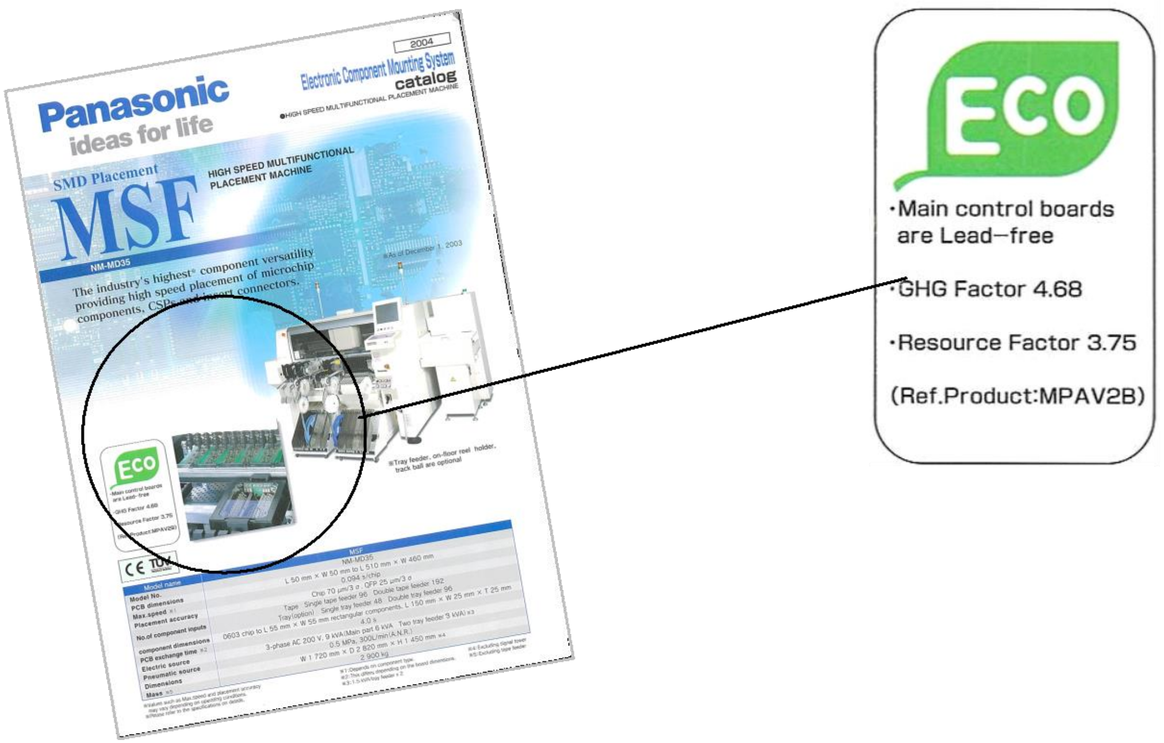
KPIs	2001	2005	2011	2012
No of companies	83	250	887	~ 1000
No of licenses	95	279	1357	1671
No of products	(no stats)	(no stats)	17935	17176
No of people who have seen/heard of or bought Ecolabel products	(no stats)	11% (in 2006)	37% (in 2009)	(no stats)

EU Ecolabel Work Plan for 2011 – 2015
http://ec.europa.eu/environment/ecolabel/about_ecolabel/pdf/work_plan.pdf

Final Consumers 3 – ISO-type II Claims

Example: ISO-type II labels in Japan

Panasonic: Factor X provides concise information about the improvement of new products with respect to old ones



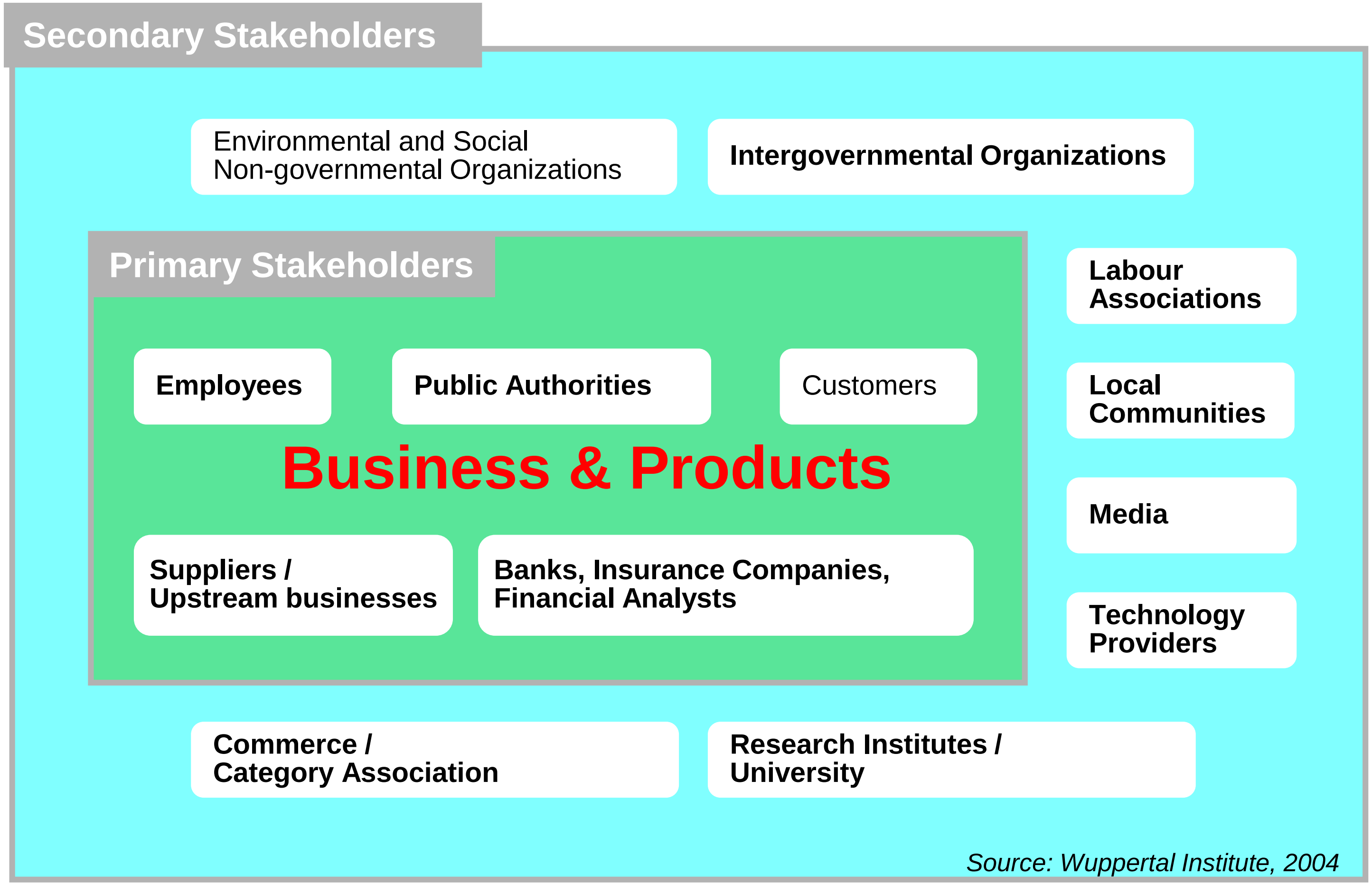
GHG factor = (GHG efficiency of the new product) / (GHG efficiency of the old product), where

GHG efficiency = (Product life x Product functions) / (GHG emissions over the entire life cycle)

Business Clients 1 – ISO-type III Declaration

COUNTRY	NATIONAL SCHEME	SETTORIAL SCHEME
Denmark	Pilot project EPD *(DEPA – Danish Envir. Protection Agency)*	
France	Experimental standard on type III environmental declarations *AFNOR – Ass. Francaise de Normalisation)*	AIMCC *(construction)*
Finland		RTS *(construction)*, paper
Germany		AUB *(construction)*
Italy	Program *ANPA 2000-2001* EU-LIFE INTEND - EPD (2003/05)	
Netherland		MRPI *(construction)*
Norway	Project NHO Type III *NHO – Conf. Norwegian Industry*	
Sweden	program EPD (SWEDAC - *Swedish Environmental Management Council)*	Volvo cars EPDs (*automotive*) Volvo trucks EPDs (*automotive*) IT Eco Declaration (*IE and Telecom*) Byggvarudeklaration (*construction*) Teko Environ. Declar. (*textile*)
United Kingdom	-	BRE environmental profile (*constr.*)

Stakeholder Relationships



Secondary Stakeholders

Environmental and Social
Non-governmental Organizations

Intergovernmental Organizations

Primary Stakeholders

Employees

Public Authorities

Customers

Business & Products

**Suppliers /
Upstream businesses**

**Banks, Insurance Companies,
Financial Analysts**

**Labour
Associations**

**Local
Communities**

Media

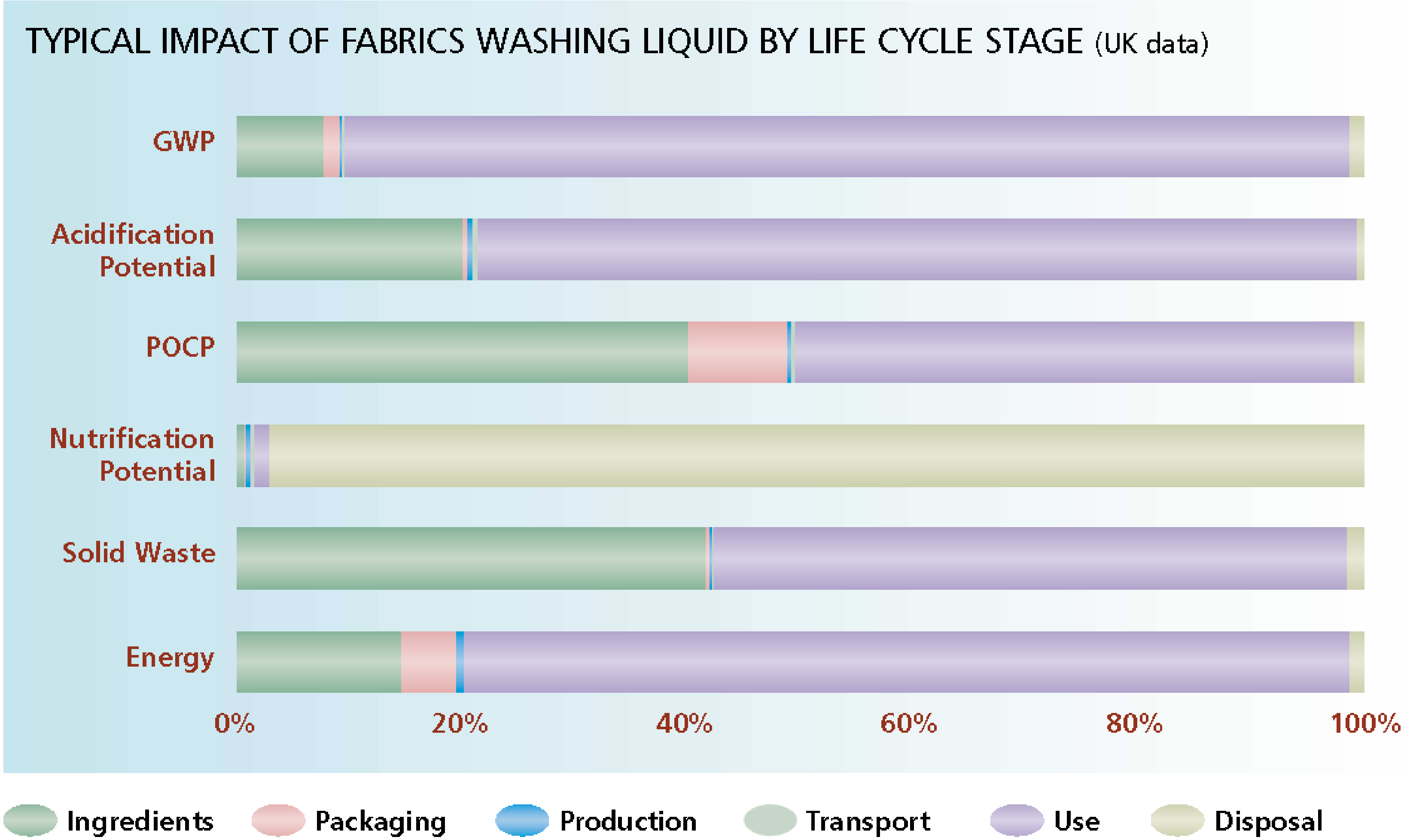
**Technology
Providers**

**Commerce /
Category Association**

**Research Institutes /
University**

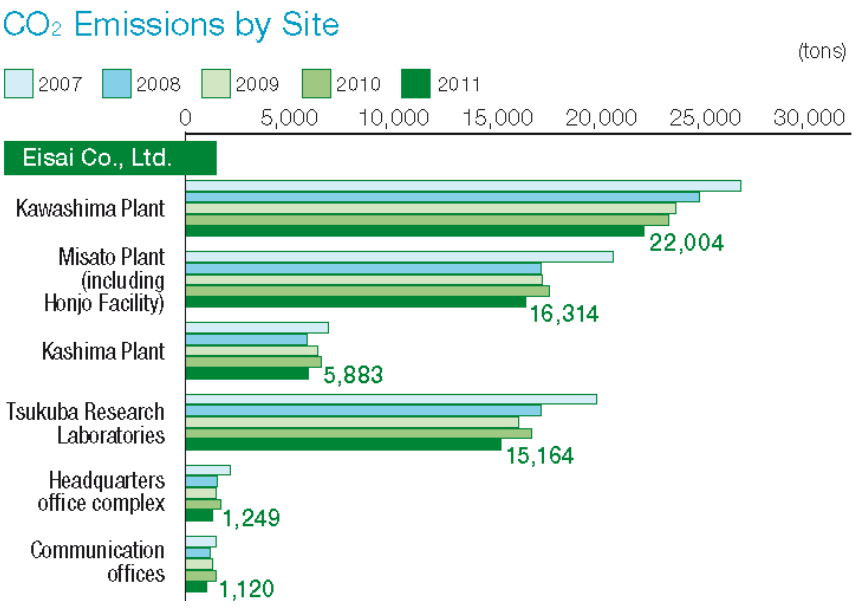
Source: Wuppertal Institute, 2004

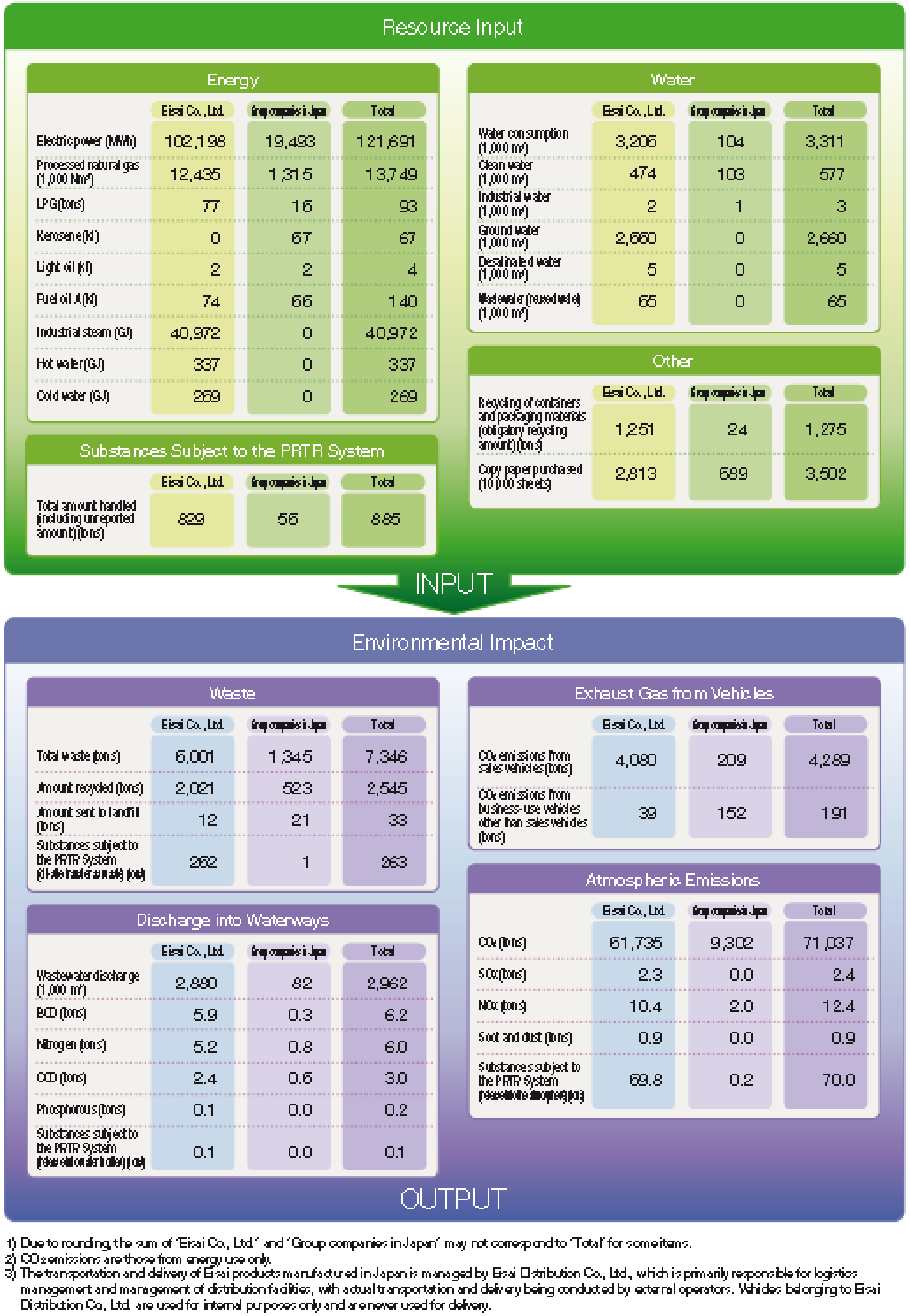
Communication – Information Brochures (i.e. liquid fabric washing)



Source: Unilever

Communication: Report on Environmental Inventory





Resource Input

Energy

	Eisai Co., Ltd.	Group companies in Japan	Total
Electric power (MWh)	102,198	19,493	121,691
Processed natural gas (1,000 Nm³)	12,435	1,315	13,749
LPG (tons)	77	16	93
Kerosene (kl)	0	67	67
Light oil (kl)	2	2	4
Fuel oil A (kl)	74	66	140
Industrial steam (GJ)	40,972	0	40,972
Hot water (GJ)	337	0	337
Cold water (GJ)	269	0	269

Substances Subject to the PRTR System

	Eisai Co., Ltd.	Group companies in Japan	Total
Total amount handled (including unreported amount) (tons)	829	56	885

Water

	Eisai Co., Ltd.	Group companies in Japan	Total
Water consumption (1,000 m³)	3,206	104	3,311
Clean water (1,000 m³)	474	103	577
Industrial water (1,000 m³)	2	1	3
Ground water (1,000 m³)	2,660	0	2,660
Desalinated water (1,000 m³)	5	0	5
Wastewater (reused water) (1,000 m³)	65	0	65

Other

	Eisai Co., Ltd.	Group companies in Japan	Total
Recycling of containers and packaging materials (obligatory recycling amount) (tons)	1,251	24	1,275
Copy paper purchased (10,000 sheets)	2,813	689	3,502

INPUT

Environmental Impact

Waste

	Eisai Co., Ltd.	Group companies in Japan	Total
Total waste (tons)	6,001	1,345	7,346
Amount recycled (tons)	2,021	523	2,545
Amount sent to landfill (tons)	12	21	33
Substances subject to the PRTR System (off-site transfer amount) (tons)	262	1	263

Discharge into Waterways

	Eisai Co., Ltd.	Group companies in Japan	Total
Wastewater discharge (1,000 m³)	2,880	82	2,962
BOD (tons)	5.9	0.3	6.2
Nitrogen (tons)	5.2	0.8	6.0
COD (tons)	2.4	0.6	3.0
Phosphorous (tons)	0.1	0.0	0.2
Substances subject to the PRTR System (release into public waters) (tons)	0.1	0.0	0.1

Exhaust Gas from Vehicles

	Eisai Co., Ltd.	Group companies in Japan	Total
CO_2 emissions from sales vehicles (tons)	4,080	209	4,289
CO_2 emissions from business-use vehicles other than sales vehicles (tons)	39	152	191

Atmospheric Emissions

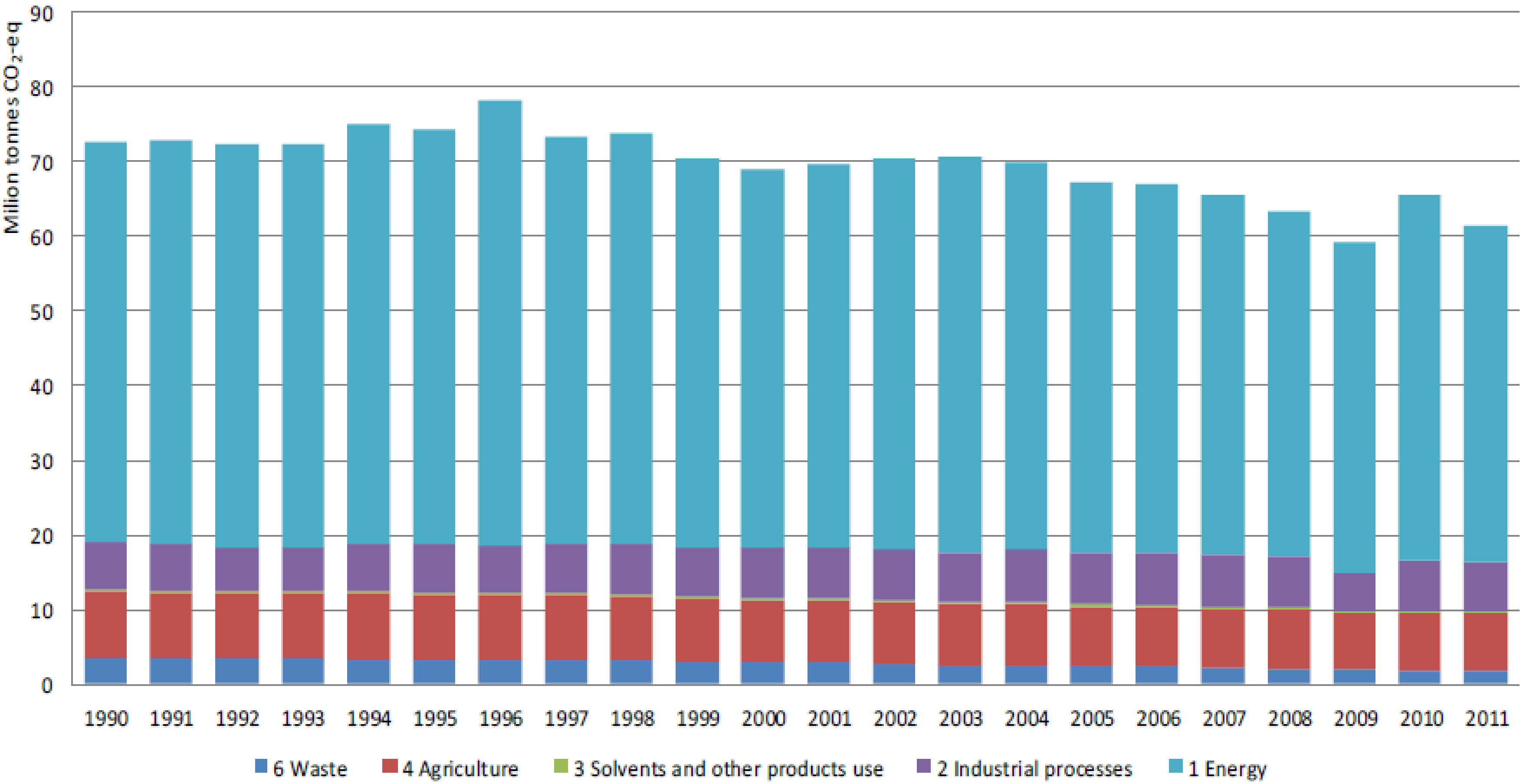
	Eisai Co., Ltd.	Group companies in Japan	Total
CO_2 (tons)	61,735	9,302	71,037
SO_x (tons)	2.3	0.0	2.4
NO_x (tons)	10.4	2.0	12.4
Soot and dust (tons)	0.9	0.0	0.9
Substances subject to the PRTR System (release into the atmosphere) (tons)	69.8	0.2	70.0

OUTPUT

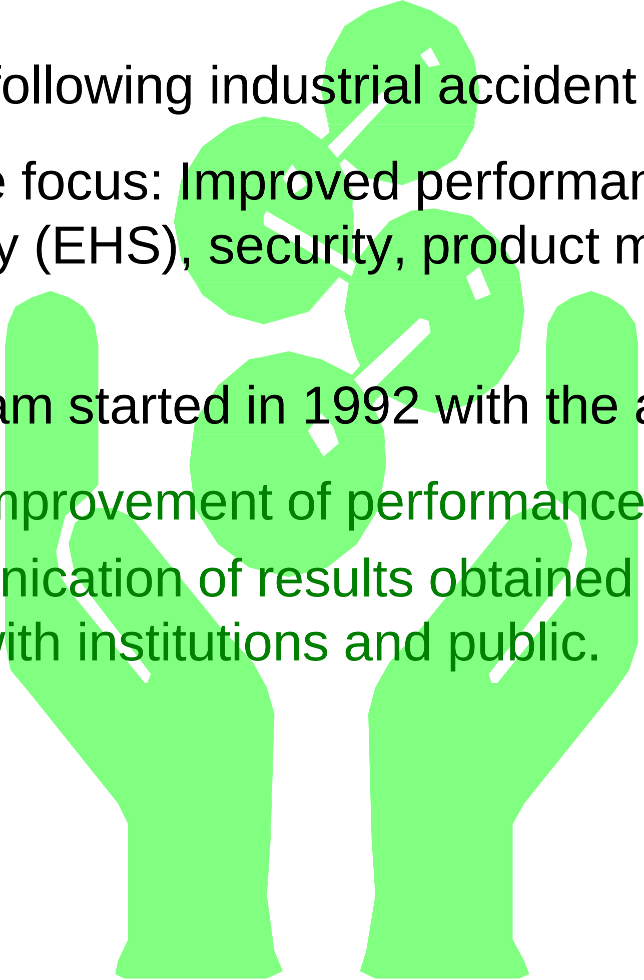
1) Due to rounding, the sum of 'Eisai Co., Ltd.' and 'Group companies in Japan' may not correspond to 'Total' for some items.
2) CO_2 emissions are those from energy use only.
3) The transportation and delivery of Eisai products manufactured in Japan is managed by Eisai Distribution Co., Ltd., which is primarily responsible for logistics management and management of distribution facilities, with actual transportation and delivery being conducted by external operators. Vehicles belonging to Eisai Distribution Co., Ltd. are used for internal purposes only and are never used for delivery.

Eisai Co., Ltd. (2012)

Report example: Trend of Wastes in Sweden



Responsible Care (a voluntary program)



- An obligation for membership to the American Chemistry Council (ACC)
- Initiated in 1988 following industrial accident in Bhopal, India
- Inherent negative focus: Improved performance in Environment, Health and Safety (EHS), security, product management issues, and value chain
- In Italy the program started in 1992 with the aim to reach:
    - Continuous improvement of performances of above issues
    - Good communication of results obtained supporting a transparent relationship with institutions and public.

School of Industrial and Information Engineering

Course 096125 (095857)

Introduction to Green and Sustainable Chemistry

POLITECNICO DI MILANO

Examples of LCA

Prof. Attilio Citterio
Dipartimento CMIC “Giulio Natta”
http://iscamap.chem.polimi.it/citterio/education/course-topics/

Examples of Life-Cycle Assessment

(1) **Chemical Product** From raw material and intermediates chemical transformations provide the product with defined composition, to be used as is.

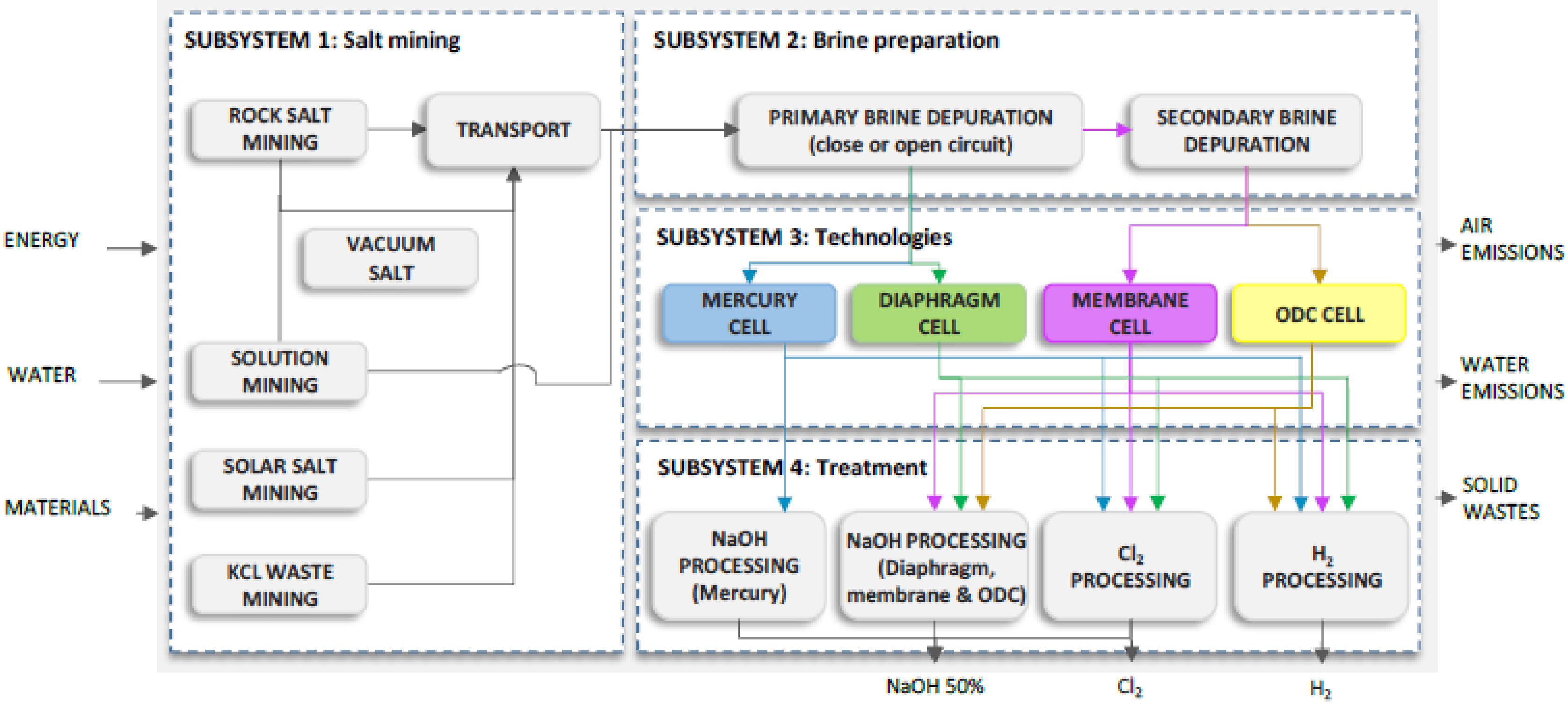
(2) **Formulated**. Mixture of compounds with a defined service.

(3) **Component of a product - Part of a more complex product but made through an independent production and finally assembled (car fender)**

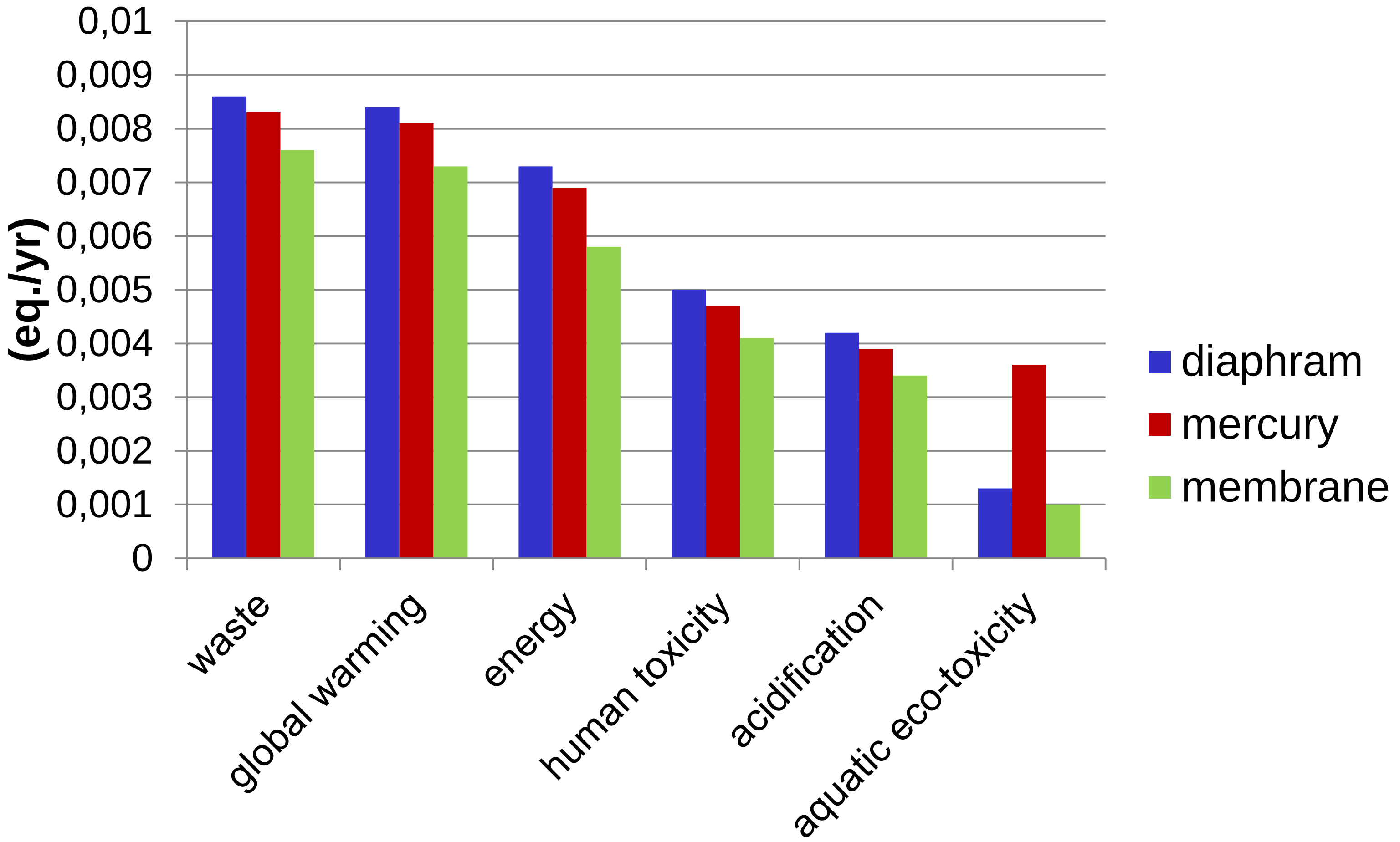
(4) **Industrial sector**. Sphere of transformations in which there is a series of activities to achieve a target, e. g. publishing, textile, car making, etc.

Example 1:
LCA of Chlor-Alkali Industry

The chlor-alkali industry sector produces chlorine, sodium/potassium hydroxide and hydrogen by electrolysis of brine. Nowadays, three different electrolysis techniques are applied: mercury, diaphragm, and membrane cell technology. From all these technologies, the European Commission labels the membrane process as the Best Available Technique (BAT). Here the LCA to support this.

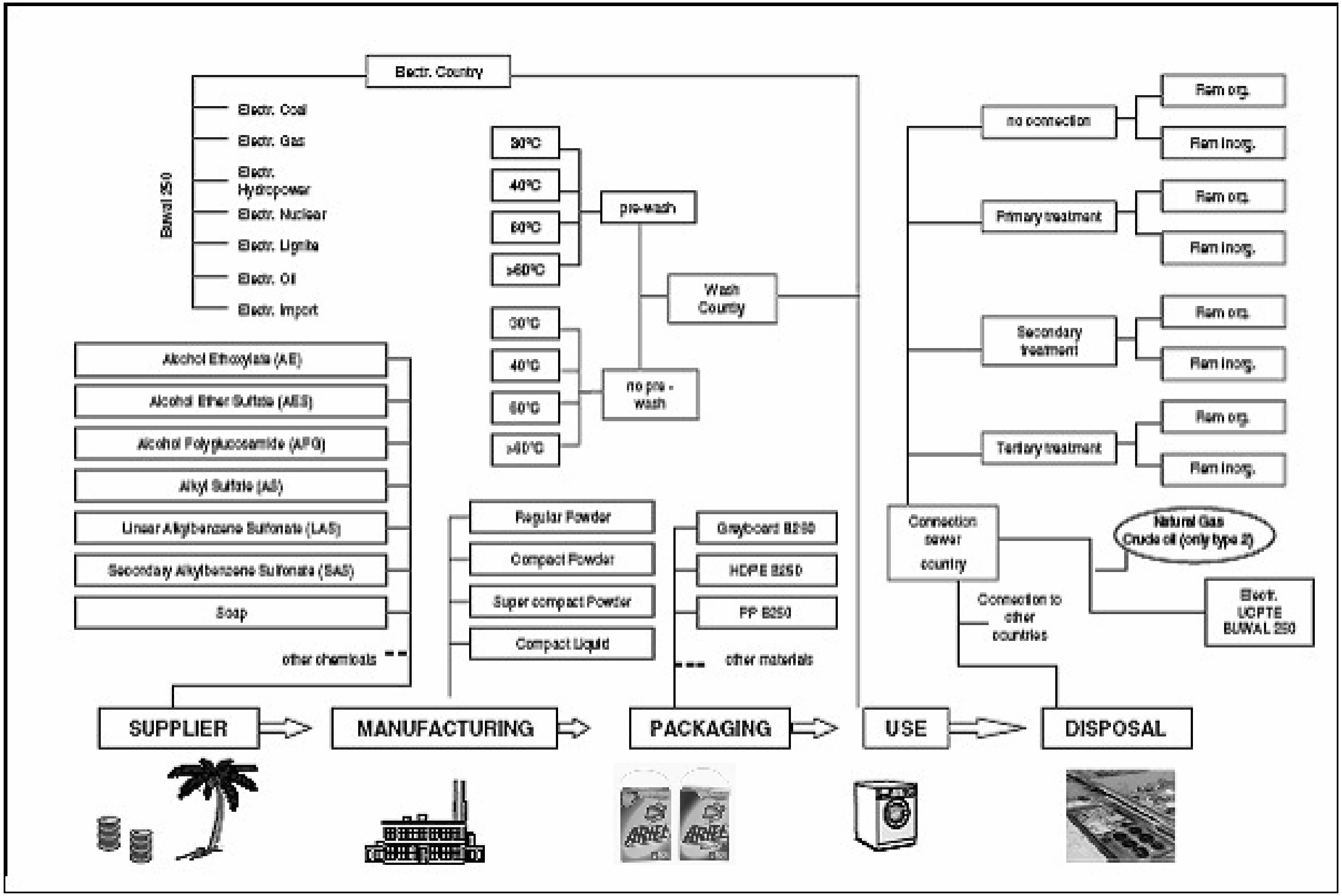


Chlor-Alkali Production Processes



Normalized environmental profile of the three choralkali production processes. Normalization is based on a comparison with the total annual environmental burden of western Europe

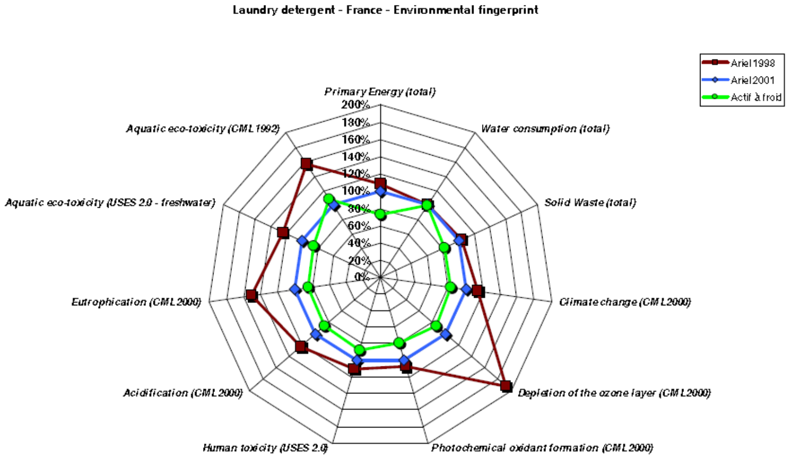
Example 2 - home laundering in Europe – Structure of the life cycle of Ariel 2001 (Formulation)



LCIA indicators of Ariel 2001 regular powder detergent (Formulation)

LCIA indicator	Units	Total	Formulation	Manufacturing	Packaging	Distribution	Use	Water treatment
Climate change	g eq. CO2	298	50,40%	5,44%	1,99%	1,15%	27,80%	13,21%
Depletion of ozone layer	g. eq. CFC-11	0,000049	75,79	0	1,6	5,23	10,95	6,43
Photochemical oxidants	g eq. C2H4	0,029	44,70%	0,68%	0,81%	1,22%	40,86%	11,73%
Human toxicity	g 1,4-DCB eq	26,42	51,75%	0,00%	0,91%	1,11%	42,09%	4,14%
Acidification	g eq. SO2	0,58	72,24%	3,45%	2,31%	3,34%	16,90%	1,77%
Eutrophication	g eq. PO4 3-	0,46	31,29%	1,19%	0,83%	1,11%	5,75%	59,83%
Aquatic eco-tox (USES 2,0)	g 1,4-DCB eq	27474	38,58%	0,00%	0,32%	1,30%	25,16%	34,63%
Aquatic eco-tox (CML1992)	m 3 poll. wat	0,032	49,32%	0,00%	1,22%	0,43%	3,88%	45,16%

Procter & Gamble (2001)



Ingredients in Laundry Detergents and Stain Removers

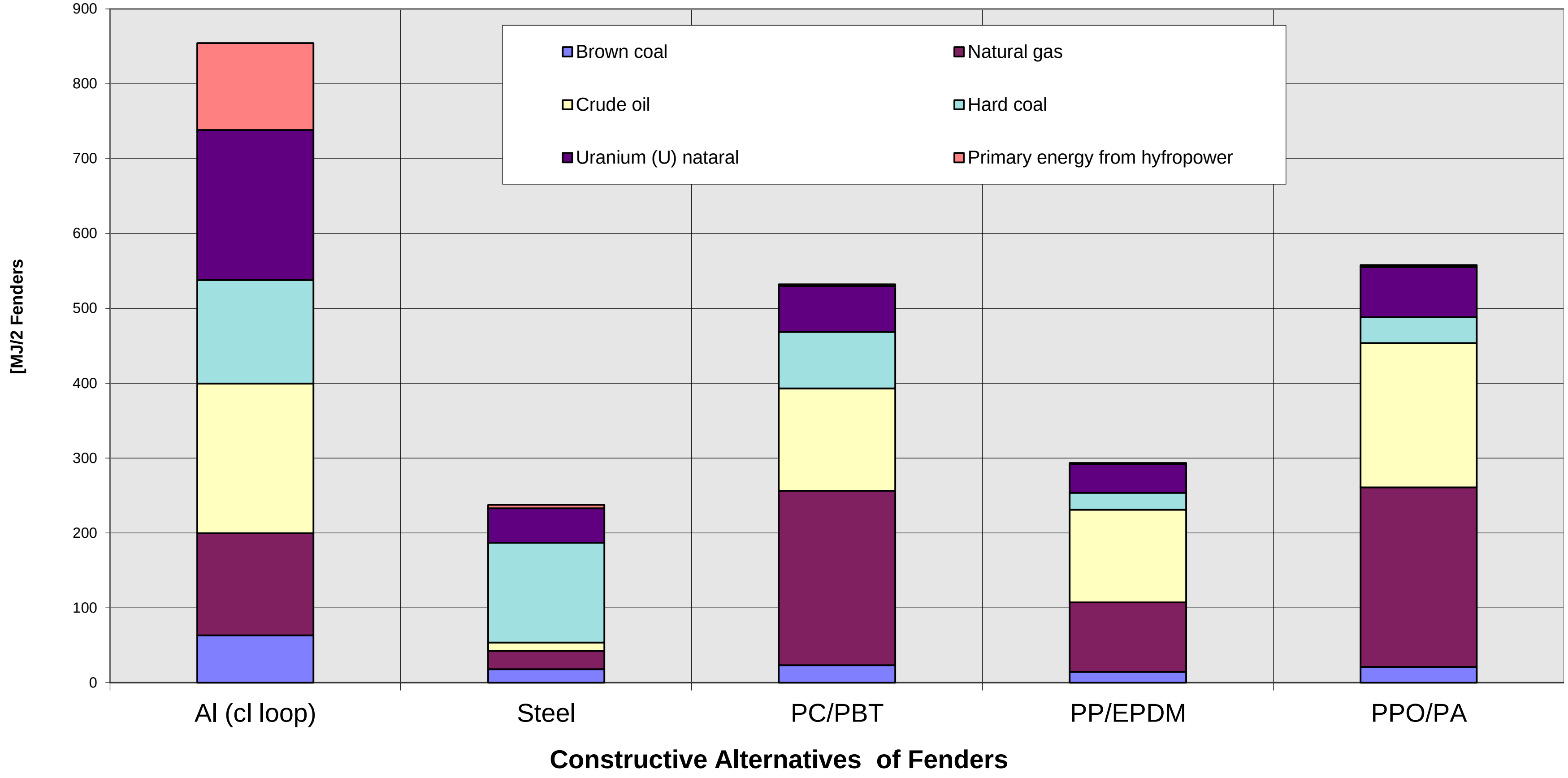
Ingredient type	Function	Examples
Anti-redeposition agents	Prevents dissolved dirt to reattach to textiles and greying.	CMC, CEC, polymers, starch
Bleaching agents	Removes or decolorizes (whitens or lightens) stains that are not removed by surfactants	Perborate, percarbonate, hydrogen peroxide, peracids, sodium hypochlorite
Bleach activators	Activates the bleaching agent. Peracid precursors.	TAED
Bleach catalysts	Makes H_2O_2 or O_2^1 more effective. Enables bleaching at lower T, complexing organic molecules with a metallic center.	Manganese complexes
Buffering agents	Stabilizes the pH of the wash water to maintain the cleaning efficiency. Cleaning is reduced under acidic conditions	Carbonate, citrate, citric acid
Builders (co-builders)	Binds Ca^{2+} in water and soil on the clothing. Allow better access to the soil for surfactants and thus improves cleaning	Phosphate, phosphonate, zeolite, silicates, X_2CO_3, citrate, polycarboxylates
Colorants	Aesthetic / marketing value	Various coloring agents
Corrosion-inhibitors	Protects the washing machine against corrosion	Silicates
Dye-transfer inhibitors	Prevents transfer of dyes from one textile to another	Polymers, co-polymers (PVP or PVPI)
Enzymes	Specific stain removal, biodetergency, whiteness, color	Proteases, lipases, amylases, cellulases, mannanase, pectinase
Optical brighteners	Reflect ultra-violet sunlight as white, visible light. Impression.	FWA-1, FWA-5
Fillers	Adds structure	Na_2SO_4 (In liquid products: water)
Fragrance	Aesthetic / marketing value	Various fragrance mixtures
Hydrotropes	Increases the solubility of other ingredients in liquid products. Regulates viscosity.	Cunene/xylene/toluene sulphonates, urea, ethanol
Preservatives	Prevent growth of microorganisms in liquid products	Various types of preservatives
Soap	Cleaning agent. Reduces surface tension and loosens/disperses/ suspends the soil.	Soluble sodium or potassium salts of fatty acids (C8-C22)
Solvents	Dissolution of ingredients (in liquid products)	Alcohols
Suds inhibitors	Reduces the quantity of suds (foam) in the washing machine	Soap, low foaming surfactants, silicones
Surfactants	As soap (Alkyl ether sulfates, alkyl sulfates)	alcohol ethoxylates, alcohol alkoxylates

Example 3 - Fender Case Study - Description of the Fender Designs

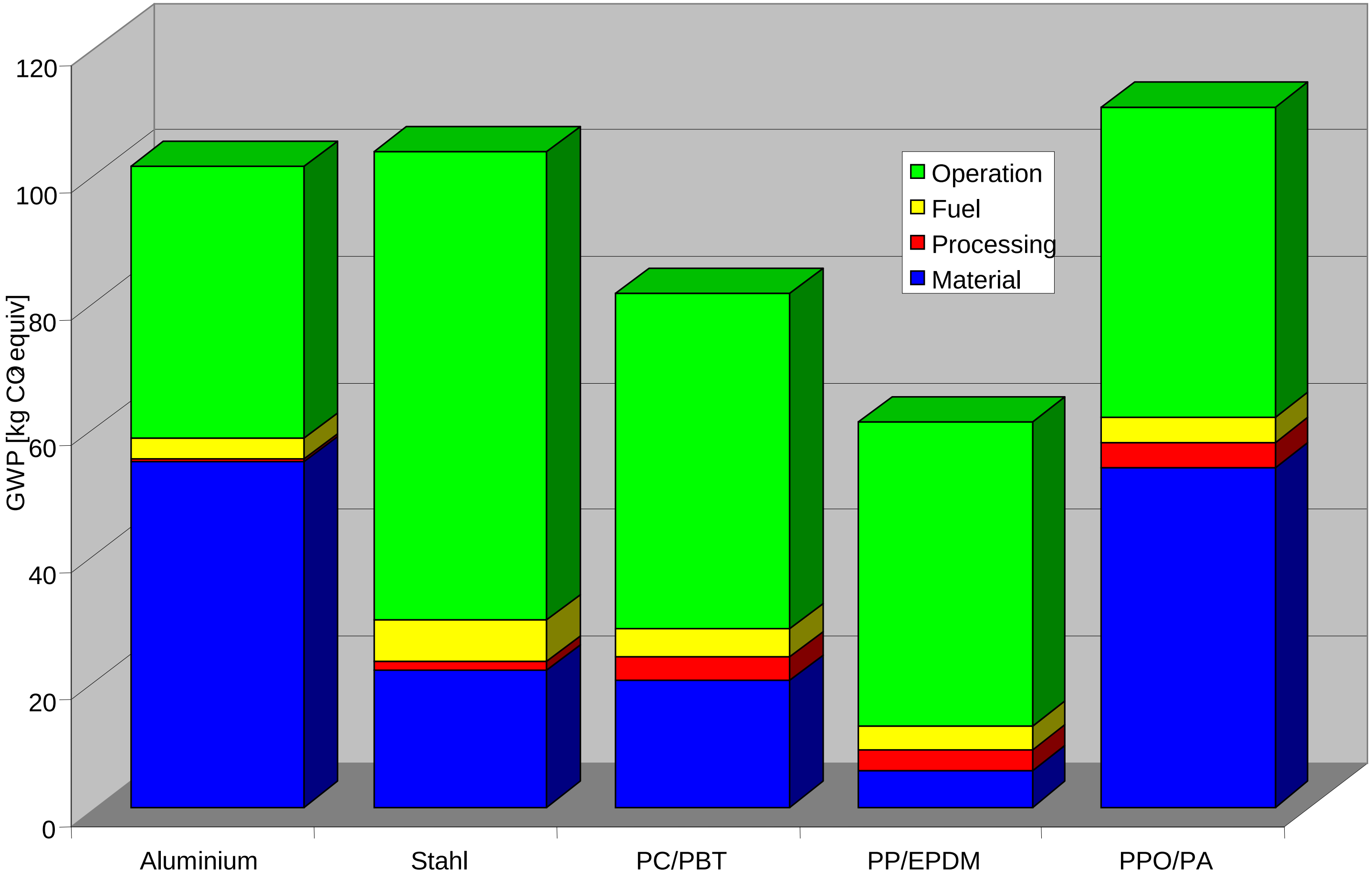
Fender Design	**Thickness**	**Weight**	**Weight**
		2 Fenders	**Semi-finished**
	[mm]	**[kg]**	**[kg]**
Steel	0.75	5.6	11.16
Alluminum	1.1	2.77	5.63
PP/EPDM T10	3.2	3.21	3.37
PPO/PA	3.2	3.35	3.52
PC/PBT	3.2	3.72	3.9

Symbols: PP polypropylene, PPO polyphenylenether, EPDM polyethylene-propylene
PA polyamide, PC polycarbonate, PBT polybutylenterephthalate

Primary Energy Demand for the Production of Fenders

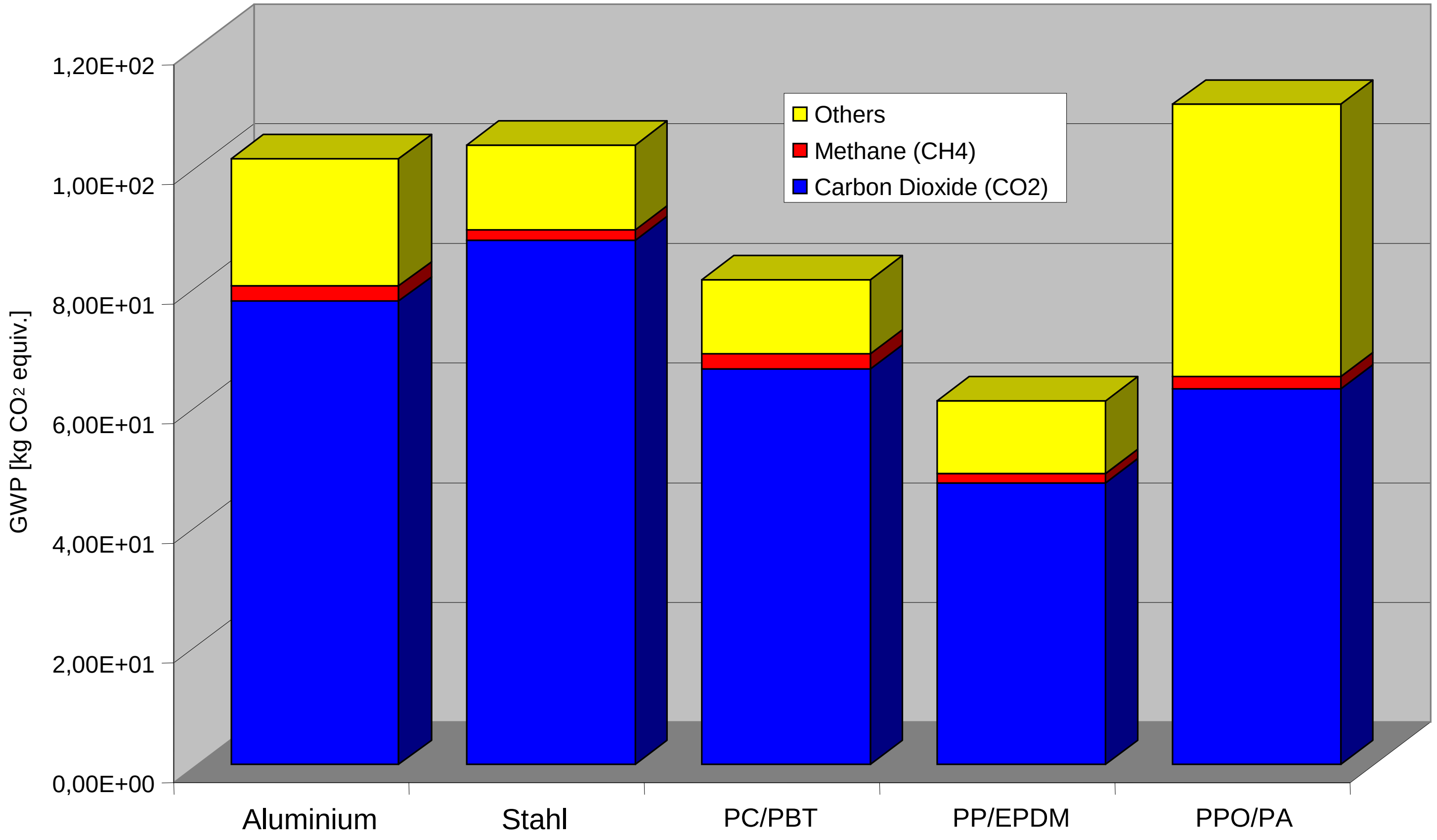


Impact Assessment - GWP I



- Use-Phase is dominant; lightweight design is of advantage
- Material-Profiles are decisive (Al, PPO/PA)
- Data-quality from the Material-Profiles are important (PPO/PA)

Impact Assessment - GWP II



- CO_2 is the dominant Emission
- PPO/PA is dominated by the N_2O Emission from PA

Fender Case Study - Impact Assessment results - total

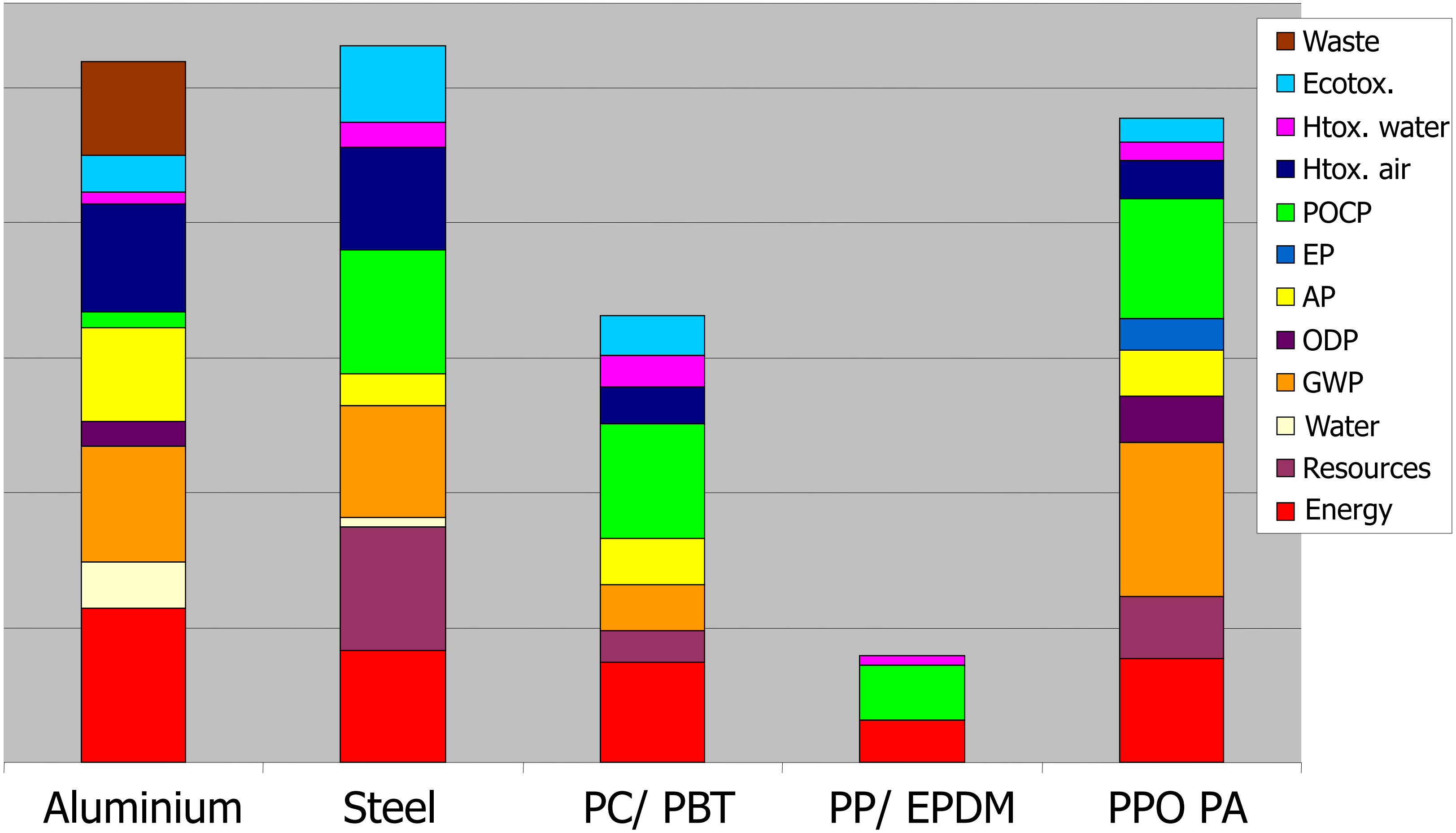
	Aluminum	Steel	PC/PBT	PP/ EPDM	PPO/PA
energy	**1290**	***1120***	1060	810	1080
resources	15	**25**	18	***14***	21
water	**36**	27	22	**17**	25
GWP	104	105	83	**62**	**115**
ODP	1	**0.1**	0.4	0.2	**1.2**
AP	**28**	19	20	***16***	20
EP	4.4	4.2	3.9	***3.5***	**7.2**
POCP	**6.7**	**9.2**	8.7	8	9.1
Htox. Air	**3.8**	3.7	2.5	***1.9***	2.5
Htox. Water	0.66	0.92	**0.99**	**0.62**	0.74
Eco tox.	2.9	**3.4**	2.7	**1.9**	2.4
waste	**3.7**	1.2	1	**0.25**	**0.25**

Fender Case Study - *Environmental results* - total

	Aluminum	Steel	PC/ PBT	PP/ EPDM	PPO/PA
Score	168,5	164,2	234,9	322,3	183,0
result	48,1%	46,9%	67,1%	92,1%	52,3%
order	**4**	**5**	**2**	**1**	**3**

- PP/EPDM seems by far to be the most favorable design.
- PC/PBT follows with significant distance.
- PPO/PA, Aluminum and Steel are not competitive for this design.

Fender Case Study - *weighting results*



Weighting results have been inverted to demonstrate the environmental burdens.

Fender Case Study - *Economic Characterization*

Material	Steel	Alluminum	PP/ EPDM	PPO/ PA	PC/ PBT
Score	7,09	4,53	7,05	5,76	4,74
Share	70,9%	45,3%	70,5%	57,6%	47,4%
Rank	1	5	1	3	4

- PP/EPDM and steel are economically very advanced.
- PPO/PA is about to become competitive.
- PC/PBT is not yet in a competitive area.
- Aluminium is the least favourable solution

Fender Case Study - *Technical Characterization*

Design	Steel	Aluminum	PP/ EPDM	PPO/ PA	PC/ PBT
Score	7,23	5,18	7,94	7,19	6,91
Share	72,3%	51,8%	79,4%	71,9%	69,1%
Rank	2	5	1	2	3

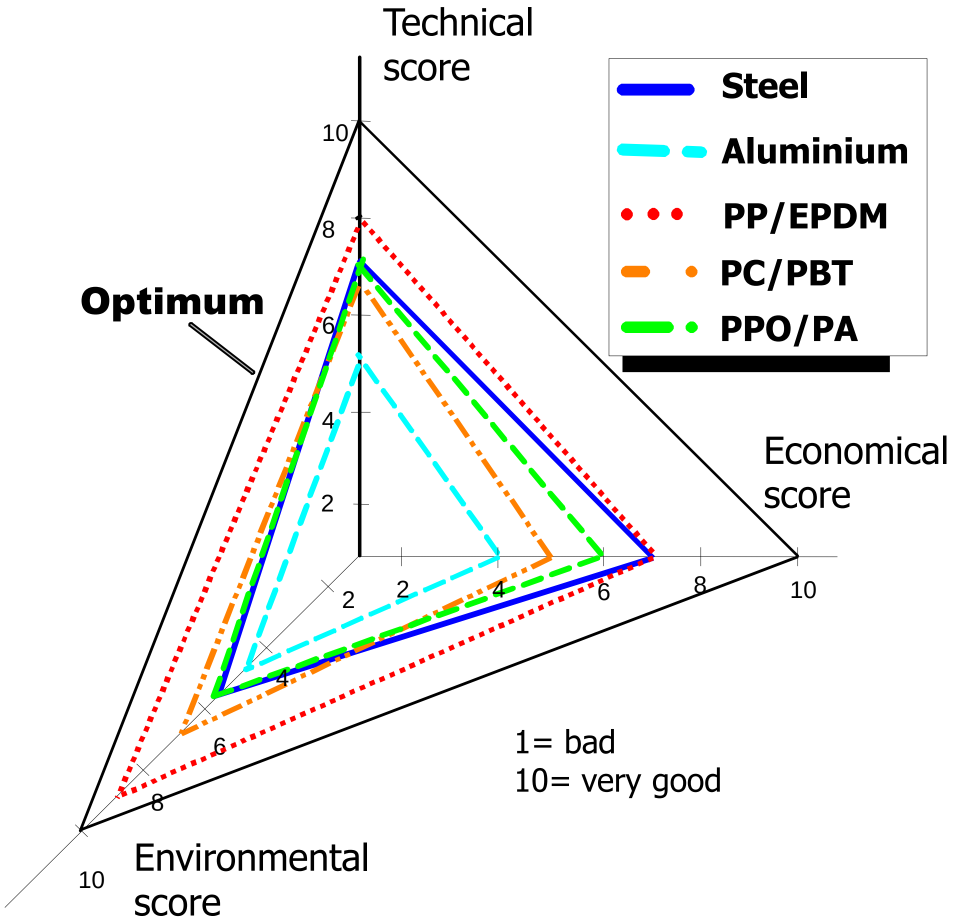
- PP/EPDM is the technically most favorable design.
- Steel and PPO/PA follow closely.
- PC/PBT has some technical disadvantages.
- Aluminum is the least favorable solution

Fender Case Study - *Overall Valuation*

	Steel	Alum.	PP/ EPDM	PPO/ PA	PC/ PBT
technical	7.2	5.2	**7.9**	7.2	6.9
economical	**7.1**	4.5	**7.0**	5.8	4.8
environmental	4.7	4.8	**9.2**	4.7	6.7

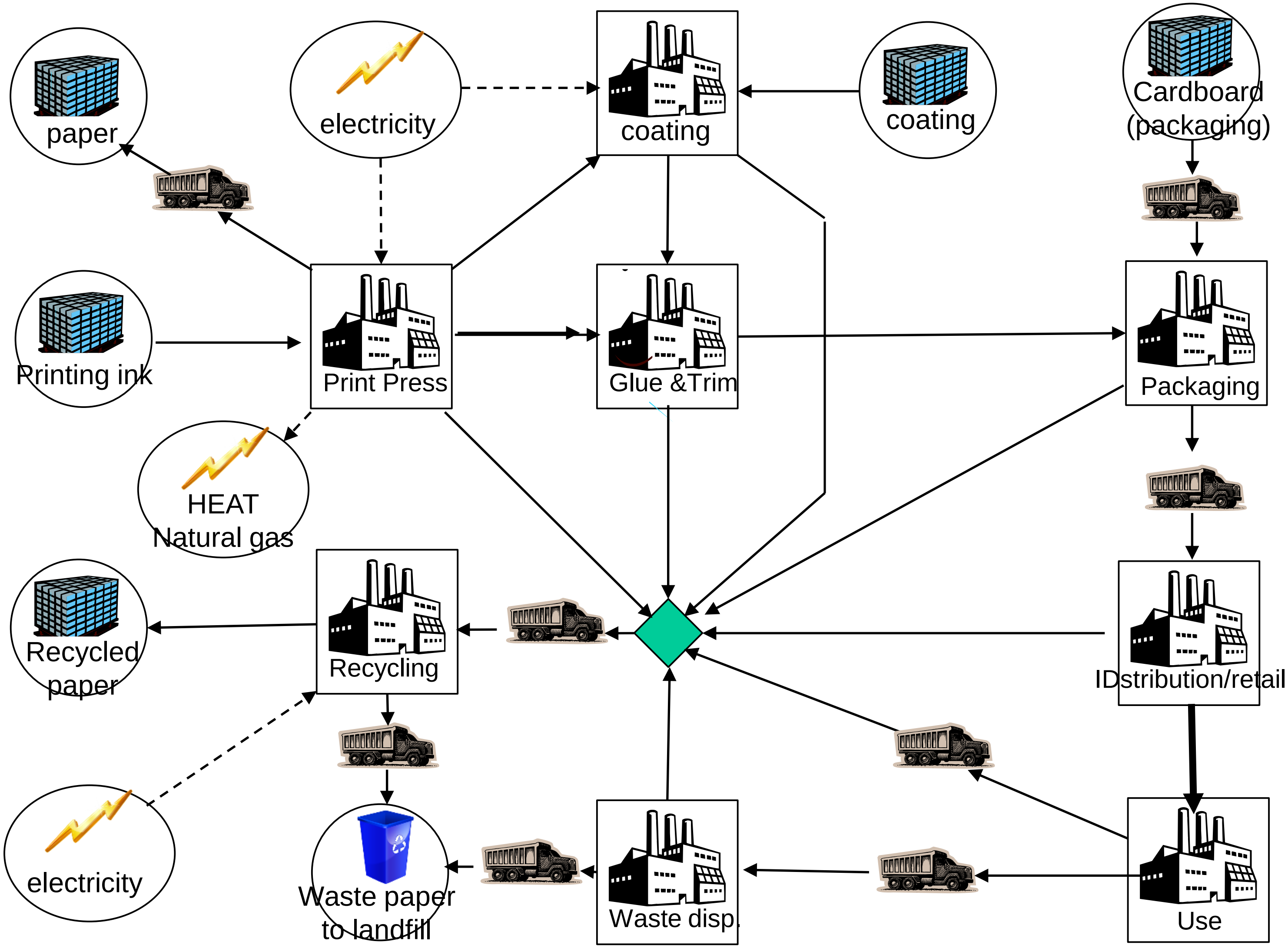
- PP/EPDM is the most favorable solution.
- Aluminum is the worst design here.
- Steel still is competitive.
- PPO/PA and PC/PBT are not yet competitive.

Fender Case Study - *Overall Valuation*



- Steel has economic advantages, but strong environmental disadvantages technically good.
- Aluminium is not desirable from all viewpoints.
- PP/EPDM is the best solution for all dimensions.
- PC/PBT is technically and environmentally strong, but has economic disadvantages.
- PPO/PA is technically good, but has environmental and economic disadvantages.
- Material Selection is still difficult and depends on the related design.
- Competition is good for an overall improvement.

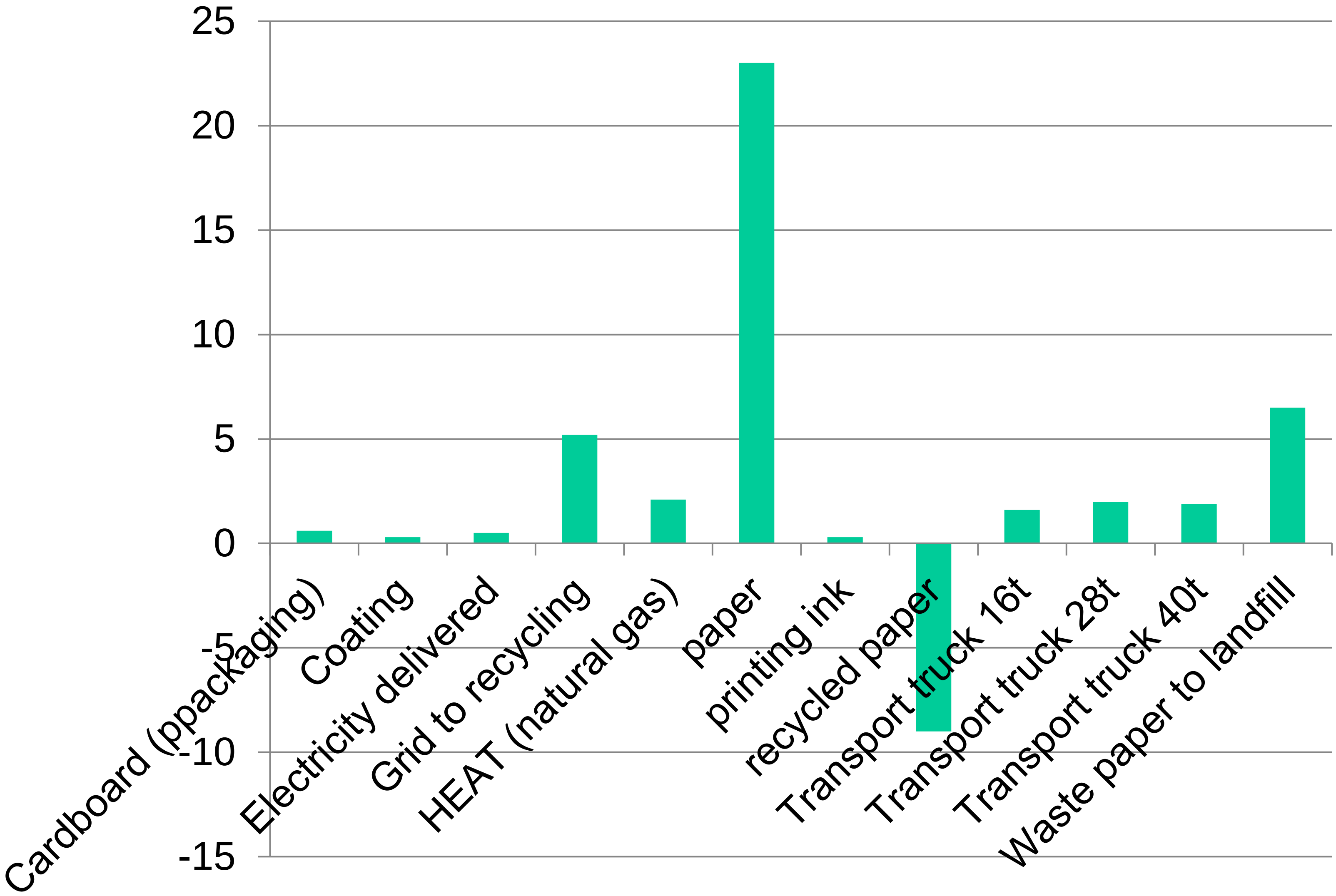
Example 4 - Printing Industry / Flow Diagram (Inventory)



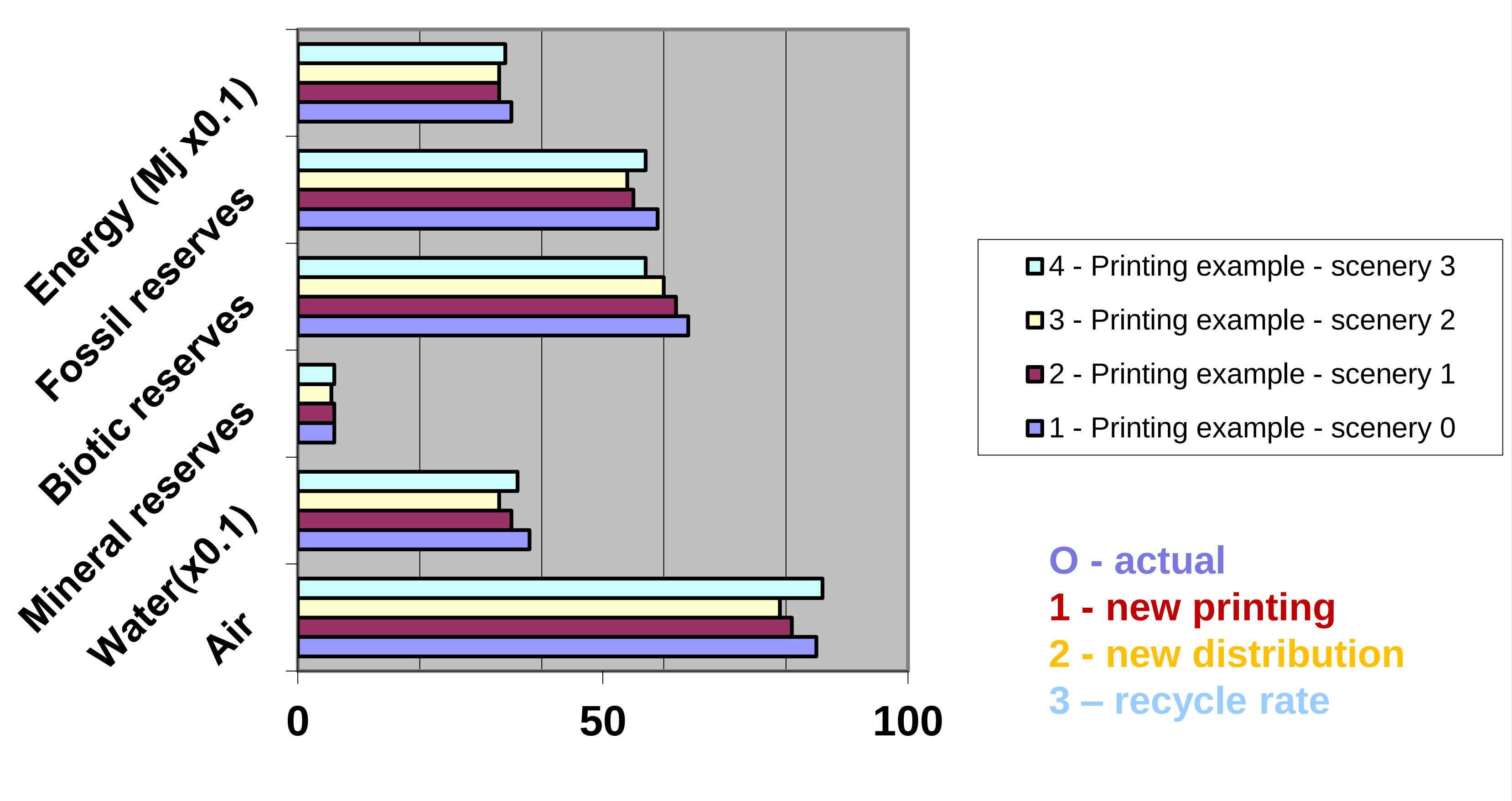
Indicators for Printing Industry

Indicator, for product weight	Unit	Interval
Materials		
Material use	kg/ ton	1130–1390
Not renewable materials	kg/ ton	0.498–12.7
Dangerous materials	kg/ ton	0–0.529
Printing paper, total	kg/ ton	1110–1370
Printing paper, not Swan	kg/ ton	0–1370
Energy		
Energy consumption	kWh/ ton	520–550
Not-renewable energy	kWh/ ton	130–330
Transports		
Total transports	tonkm/ ton	200–960
Transport (diesel)	tonkm/ ton	18–880
Waste		
Waste, total	kg/ ton	127–422
Landfill	kg/ ton	0–6.32
Dangerous wastes	kg/ ton	1.13–9.44
Emissions		
VOC (internal)	kg/ ton	0.17–0.45
VOC (prod/transp. Energy)	kg/ ton	0.034–0.099
Carbon dioxide	kg/ ton	33–55

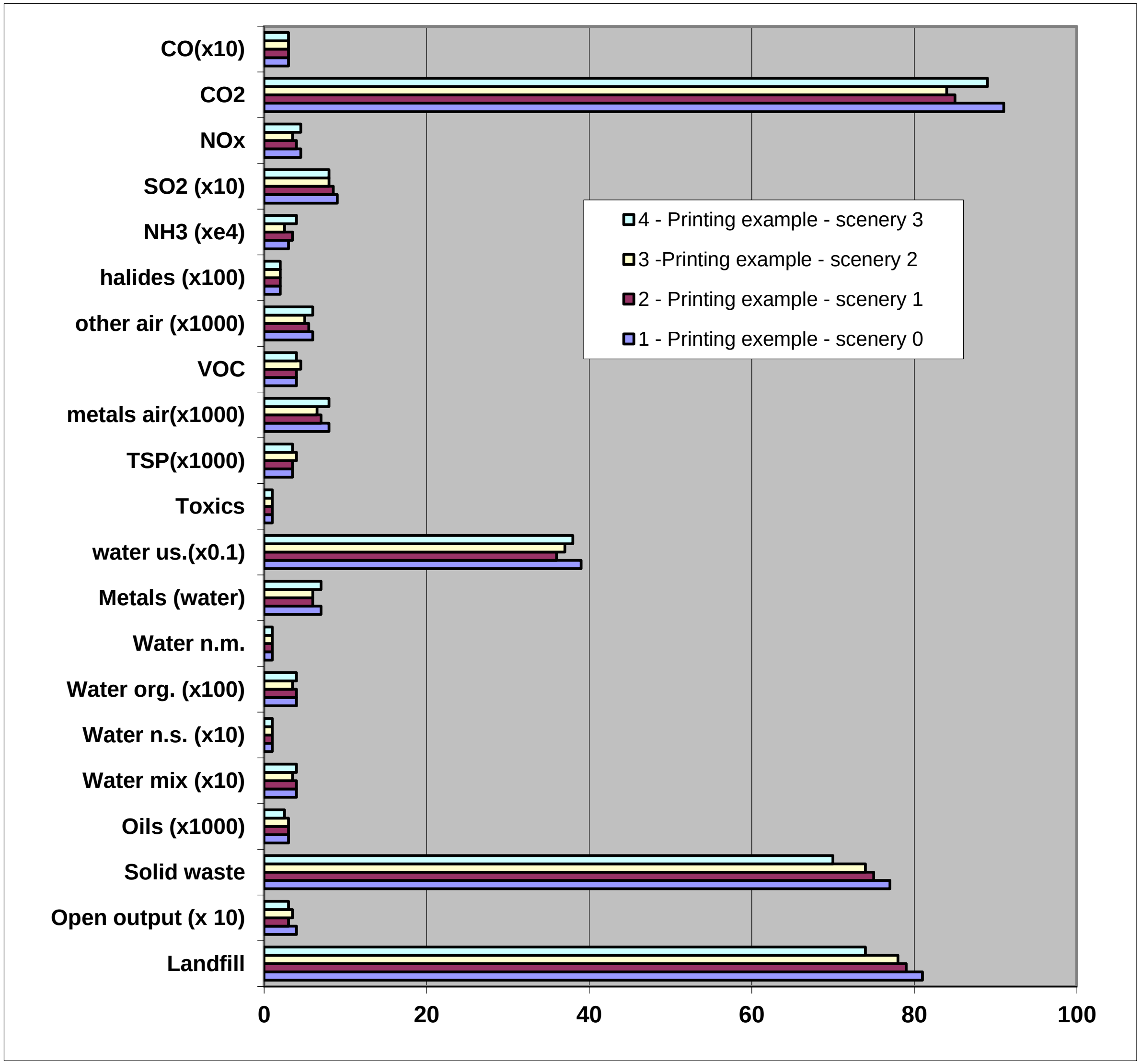
Relative Environmental Results for Life Cycle Assessment of Printing Paper



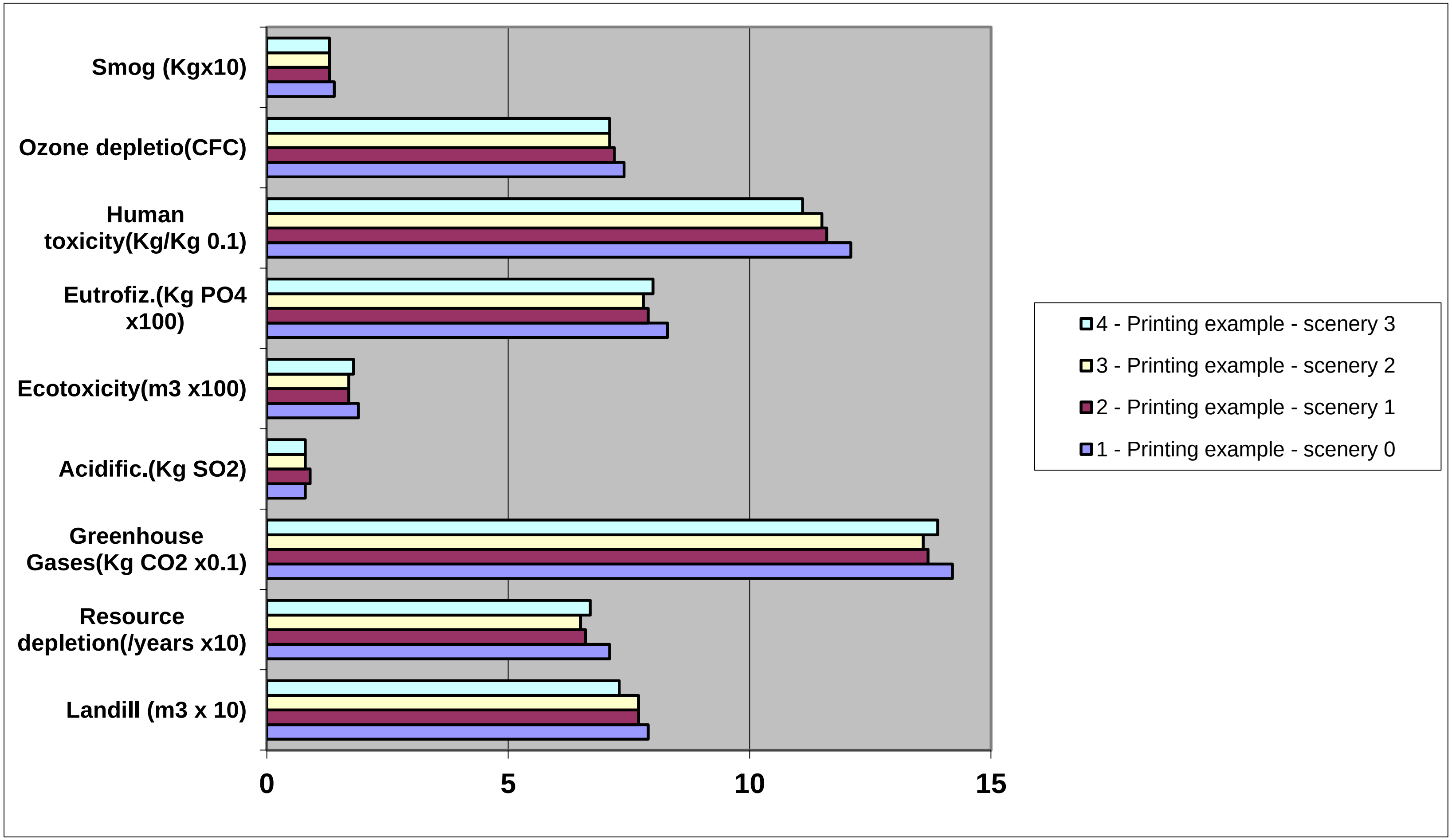
Inventory Results – Summary of Input in kg/ Functional Unit



Inventory Results – Summary of Wastes for kg/functional Unit

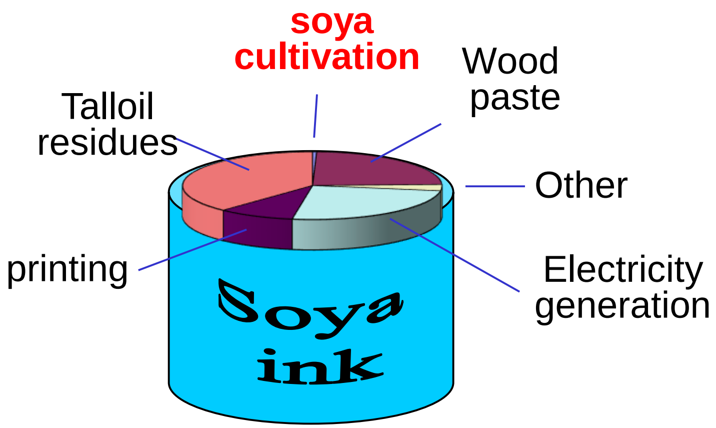


Impact Assessment – Scenary Comparison



Soya Ink

Introduced in 1987, it was used in newspaper trade industry. Made up of soya oil instead of petrol.



- Soya agriculture accounts less than 1 % of the energy involved in the life cycle of this oil.
- Talloil residues (38 %) can be replaced by soya oil derivatives
- The energy involved in the life cycle is mainly coming from petroleum but alternative sources are under investigation.

Ecological Criteria and Ecological Labeling

- This is a requirement to be respected by a product or by a producer to prove that the product or productive process shows a lower environmental impact than a different product or process absolving the same function.
- For instance, the European Union Committee for Ecological label (CUEME) defines the ecologic criteria to which a product must adapt to obtain the Ecolabel.
- Similarly, public administrations can introduce ecological criteria in their notices to orient selections to purchase products/services at a reduced environmental impact.

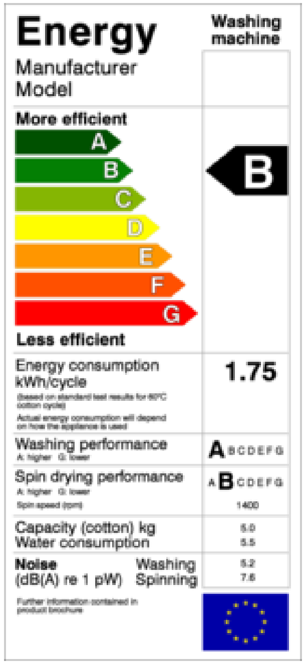
Environmental Labels

- They are labels directly applied on a product or a service to inform on its overall environmental “performance”, or on one or more specific environmental aspects. Allows consumers to make informed decisions about what they are buying. Shows commitment to reduced environmental impact. Third party verification gives credibility
- There are several environmental labels on the market. The main types are:
  - TYPE I: Voluntary label verified by independent part, awarded to products fulfilling criteria corresponding to the best environmental performance within each particular product group.
  - TYPE II: Self-certified labels used by manufacturers to indicate the environmental aspects of a product or service. The label may take the form of statements, symbols or graphics on product or packaging labels, product literature, advertising or similar.
  - TYPE III: Label censed by independent organizations, serving as a report card and providing information on the possible environmental impact of a product, leaving it to the consumer to decide which product is best. Also known as an Environmental Product Declaration.

See http://www.globalecolabelling.net/

Compulsory Labels

- Compulsory labels in U.E. apply to different sectors and bind producers, users, distributors and other parties to comply to legislative regulations.
- This labeling type “command and control” contributes a lot to reach some fundamental environmental objectives arranged to European and national level, so that in some cases it represents a strong stimulus for industry to activate voluntary environmental initiatives (program agreements, EMAS, etc.)
- Compulsory labels apply to the following product types:
  - **Toxic and dangerous substances** (directive 93/21/EEC)
  - **Household appliance - Energy Label** (directive 92/75/CEE)
  - **Food products**
  - **Packaging - Packaging Label**
  - **Electricity from renewable sources – Green Certification**



Energy

Washing machine

Manufacturer

Model

More efficient

Less efficient

Energy consumption kWh/cycle 1.75

Washing performance A

Spin drying performance B

1400

Capacity (cotton) kg

Water consumption

Noise (dB(A) re 1 pW) Washing Spinning

Voluntary Labels

Energy Star: U.S.

ISO Type I – ISO 14024, 1999

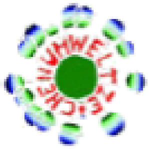
third party certification labels: claims are based on criteria set by a third part. Criteria take into account the overall life cycle of the product. It points to better environmental services of a product belonging ta a specific category. Examples include the EC Eco-Label, Nordic Swan and the German Blue Angel.

Between environmental labels of product can be found some national labels for a long time on the market. Typical are labels for agriculture products

Blauer Engel: Germany from 1978

White Swan: from 1989 in Denmark, Sweden, Finland and Iceland

Green Seal: USA



Umweltzeichen: Austria from 1991

NF Environnement: France from 1992

Environmental Labels of Products

- An environmental label (i.e. "ecolabel") can be considered a ” guarantee" for environmentally compatible products and is attractive for commercial purpose.
- The general aim of a national and upper-national environmental label schemes is to supply products with less environmental impacts easily recognized to purchasers. Therefore, the success of a environmental label scheme is to a some extent dependent on the product classes number with that label.

- **EU label Ecolabel (”Il fiore”)**
  EU regulation (No 882/92) intend to:
  - Promote the design, production, commercialization and use of products having a low environmental impact along the overall life cycle
  - Supply consumers with better information on environmental impact of products, without, however, compromise products or worker health and alter significantly properties which make them ready to use.

ISO 14000 International Standard

Benefits:

- **Improve environmental performance**
- **Reduce costs**
- **Establish a system and process standard in the direction:**
  - **Integrate with other management systems**
  - **Increase the credibility towards public**
  - **Competitivity**
  - **Improve relationships with Control Agencies**

ISO 14000 Standard Package on Life Cycle Assessment

ISO 14001 – Environmental management systems — Specification with guidance for use
ISO14004 – Environmental management systems — General guidelines on principles, systems and supporting techniques
ISO 14010/11/12 – Substitute of ISO 19011 standard – Guidelines for quality and/or EMS auditing
ISO 14015 – Environmental management – Environmental assessment of sites and organizations
ISO 14020 – Environmental labels and declarations — General principles
ISO 14021 – Environmental labels and declarations — Environmental auto certification (Environmental labels Type II)
ISO 14024 – Environmental labels and declarations — Type I environmental labeling — Principles and procedures
ISO TR 14025 – Environmental labels and declarations —Type 111 Environmental declaration
ISO 14031 – Environmental management — Environmental performance evaluation — Guidelines
ISO 14032 – Environmental management — Environmental performance evaluation — Examples of ISO 14031 use
ISO 14040 – Environmental management — Life cycle assessment — Principles and framework
ISO 14041 – Environmental management — Life cycle assessment — Goal and scope definition and inventory analysis
ISO 14042 – Environmental management — Life cycle assessment — Life cycle impact assessment
ISO 14043 – Environmental management - Life cycle assessment - Life cycle interpretation
ISO TR 14047 – Environmental management - Life cycle assessment – Examples of application of ISO 14042
ISO 14048 – Environmental management - Life cycle assessment – Data format for documentation of life cycle assessment
ISO TR 14049 – Environmental management - Life cycle assessment – Examples of application of ISO 14041 to the definition of targets and spheres and inventory analysis
ISO 14050 – Environmental management — Vocabulary
ISO 14060 – Guide for inclusion of Environmental Aspects in Product Standard
ISO TR 14061 – Information to assist external organizations in the use of ISO 14001 and ISO 14004 standard of Environmental Management System
ISO TR 14062 – Environmental management – guidelines to integrate environmental aspects in the product development
ISO 14063 – Environmental management – Environmental Communications – Guidelines and examples
ISO 14064 – Guide for the inclusion of environmental aspects in product standards
ISO-14065 – Guide to compliance of national and international programs

Systems oriented and product oriented standards within the ISO 14000 family

Year	**Standard Published**
1997	ISO 14040: LCA: Principles and Framework
1998	ISO 14041: LCA: Goal and Scope
2000	ISO 14042: LCA: Impact Assessment
2000	ISO 14043: LCA: Interpretation
2001	ISO 14020: Labels General Principles
2004	CEN TC350 Standardisation Mandate issued
2006	ISO 14025: Labels: Type 3 EPDs
2006	ISO 14040: LCA Principles and Framework updated
2006	ISO 14044: LCA: Requirements and Guidelines updated
2007	ISO 21930: EPDs for Construction Products
2010	CEN TR 15941: Generic Data
2010	EN 15643-1: General Framework
2011	EN 15643-2: Environmental Framework
2011	EN 15878: Building level Calculation methods
2011	EN 15942: EPD B2B Communication Formats
2012	EN 15643-3: Social Framework
2012	EN 15643-4: Economic Framework
2012	**EN 15804 Core Rules for the Product Category Construction Products**

ISO 14000 Route (initial)

Auditing and Evaluation tools

Environmental Performance Evaluation (EPE)

ISO 14031 – Guide to Evaluation of Environmental Service

Environmental Auditing (EA)

14010 – *Guidelines for quality and/or EMS auditing*

14011-1 – *Guidelines for Environmental Auditing – Audit procedures - Part 1: Auditing of environmental management systems*

14012 - Guidelines for per Environmental Auditing – Qualification Criteria for Auditors

Management Systems

ISO 14001 – Environmental Manag. System (EMS)

Specifications and Use Guide

ISO 14004 - Environmental Aspects of Product Standard (EPS)

General guidelines on principles of systems and support techniques

Support tools addressed to Product

Life Cycle Assessment(LCA)

14040 – Life cycle assessment - General principles and Environmental auto certification 1

4041 - Life cycle assessment – Life cycle inventory analysis

14042 - Life cycle assessment – assessment of life cycle impact

14043 - Life cycle assessment - Life cycle interpretation and evaluation of improvements

Environmental Labeling (EL)

14020 – Environmental Labeling – Basic principles for all Environmental Labeling

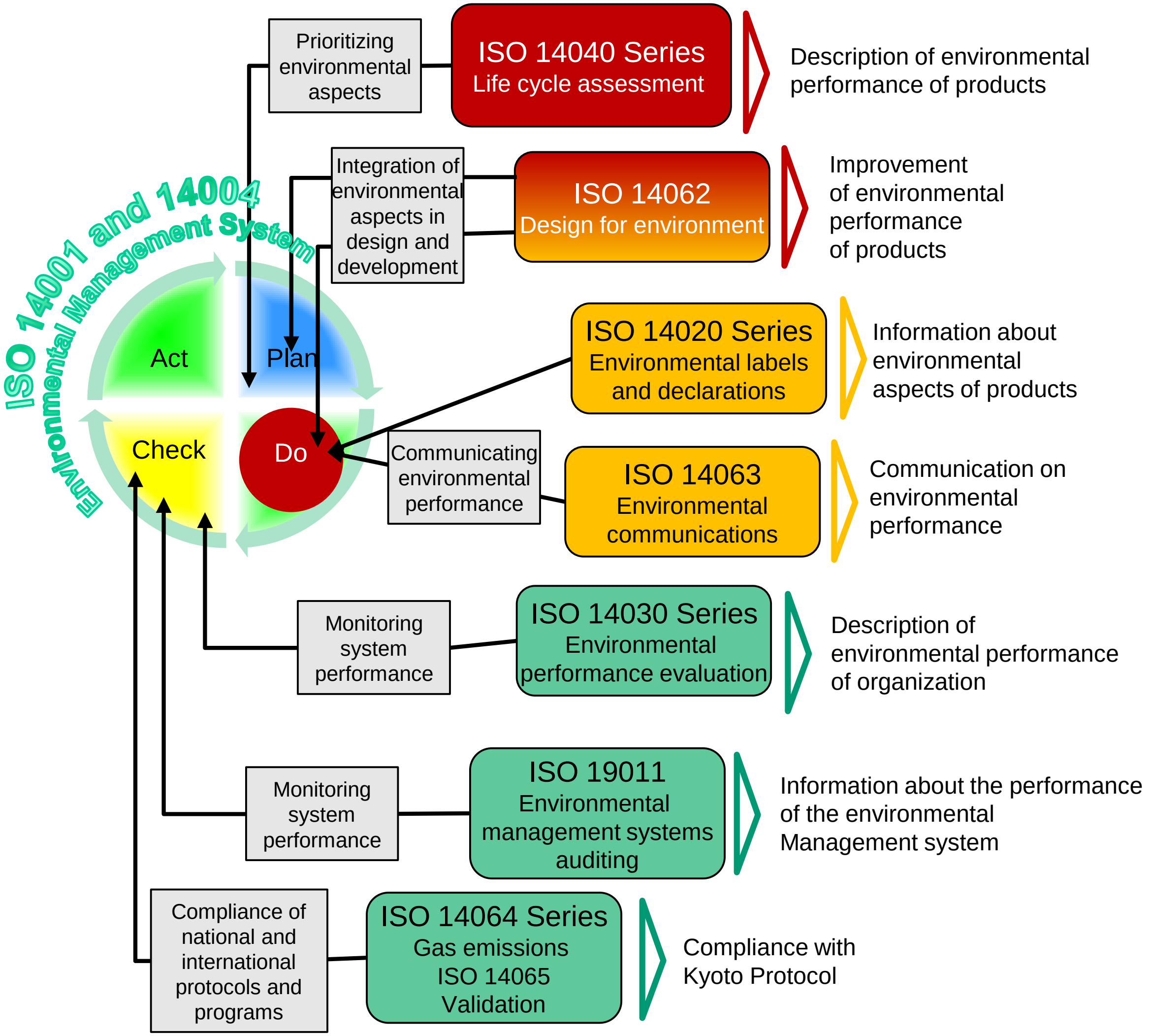
14021 - Environmental Labeling – Environmental auto-certifications and Declarations – Terms and definitions

14022 - Environmental Labeling - Environmental auto-certifications and Declarations – Symbols

14023 - Environmental Labeling - Environmental auto-certifications and Declarations – Test methodologies

14024 - Environmental Labeling – guide principles, Procedures and Criteria for Certification Programs – Guide to Certification Procedures

ISO 14000 Route (actual)



Environmental Management Systems

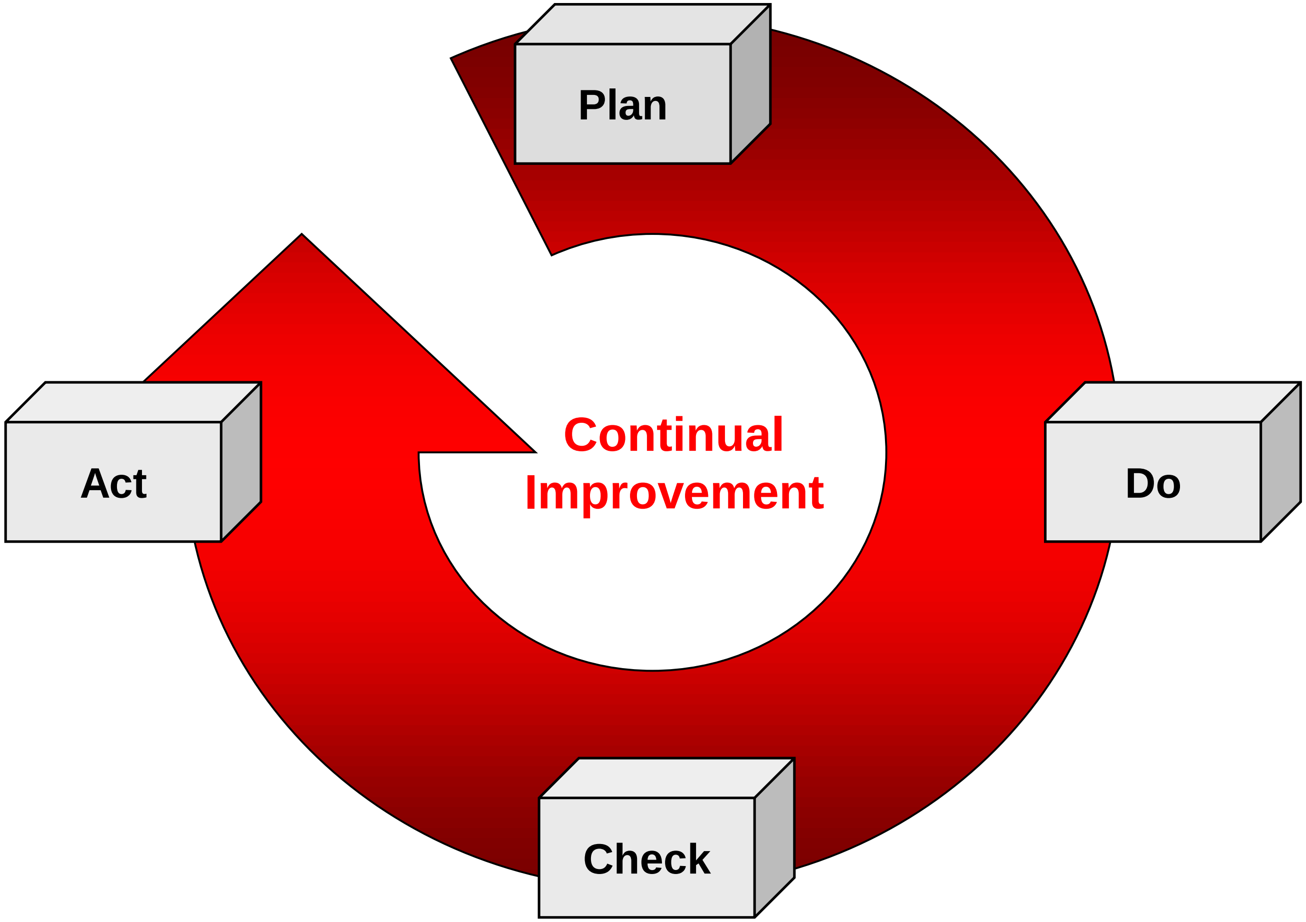
An EMS is the part of the overall management system that includes organizational structure, planning activities, responsibilities, practices, procedures, processes and resources for developing, implementing, achieving, reviewing and maintaining the environmental policy. Key examples include ISO 14001 and EMAS.

EMS are used to:

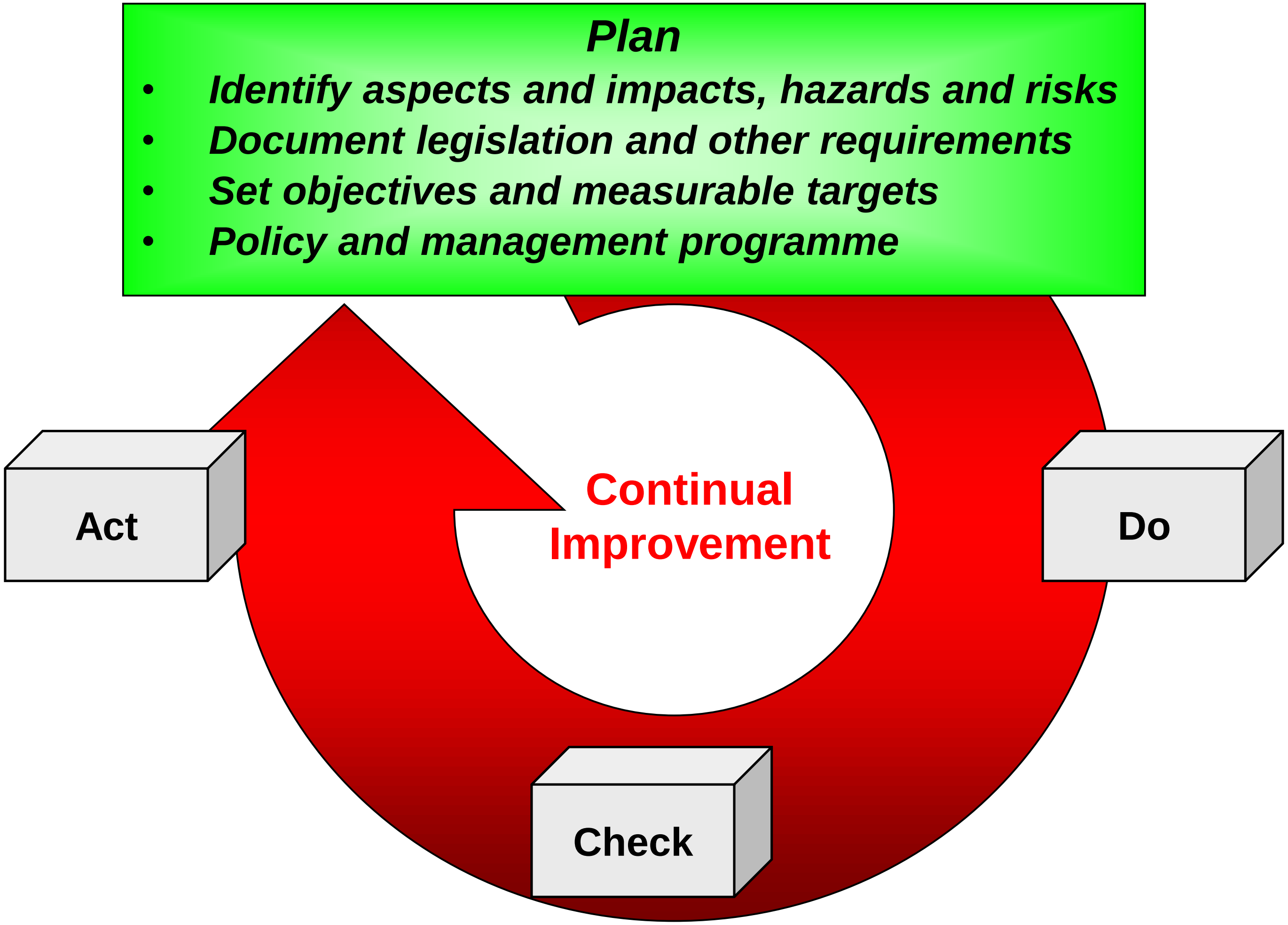
- **Help companies to identify and prioritise their key environmental impacts in a structured and systematic manner**
- **Provide a framework for setting clear objectives and targets for managing these impacts**
- **Ensure that structured processes and procedures are in place for measuring and monitoring performance.**

The type of EMS depends on the nature, size and complexity of the company's activities, products and services.

ISO 14001 Environmental Management System: The Framework



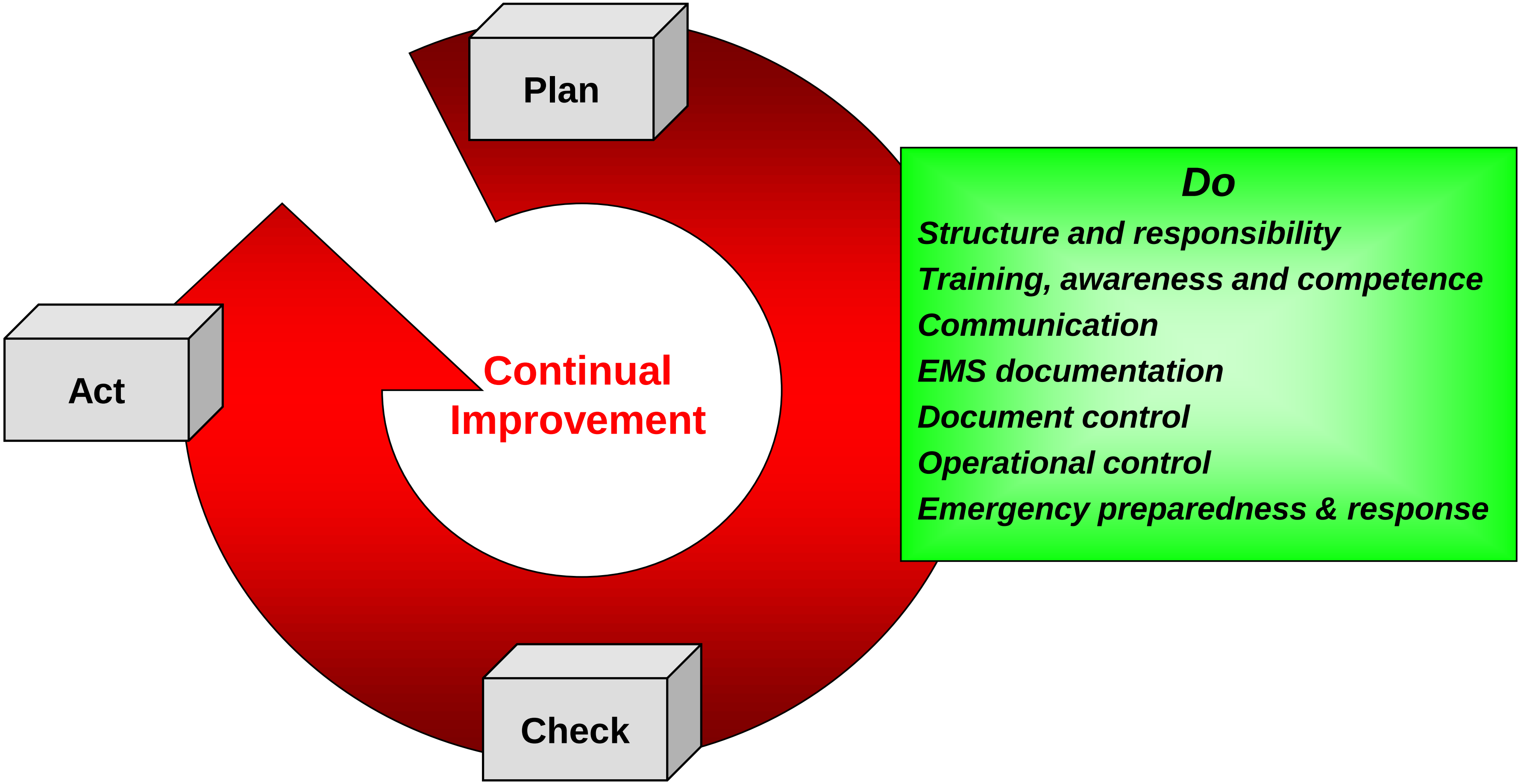
ISO 14001 Environmental Management System



Plan

- ***Identify aspects and impacts, hazards and risks***
- ***Document legislation and other requirements***
- ***Set objectives and measurable targets***
- ***Policy and management programme***

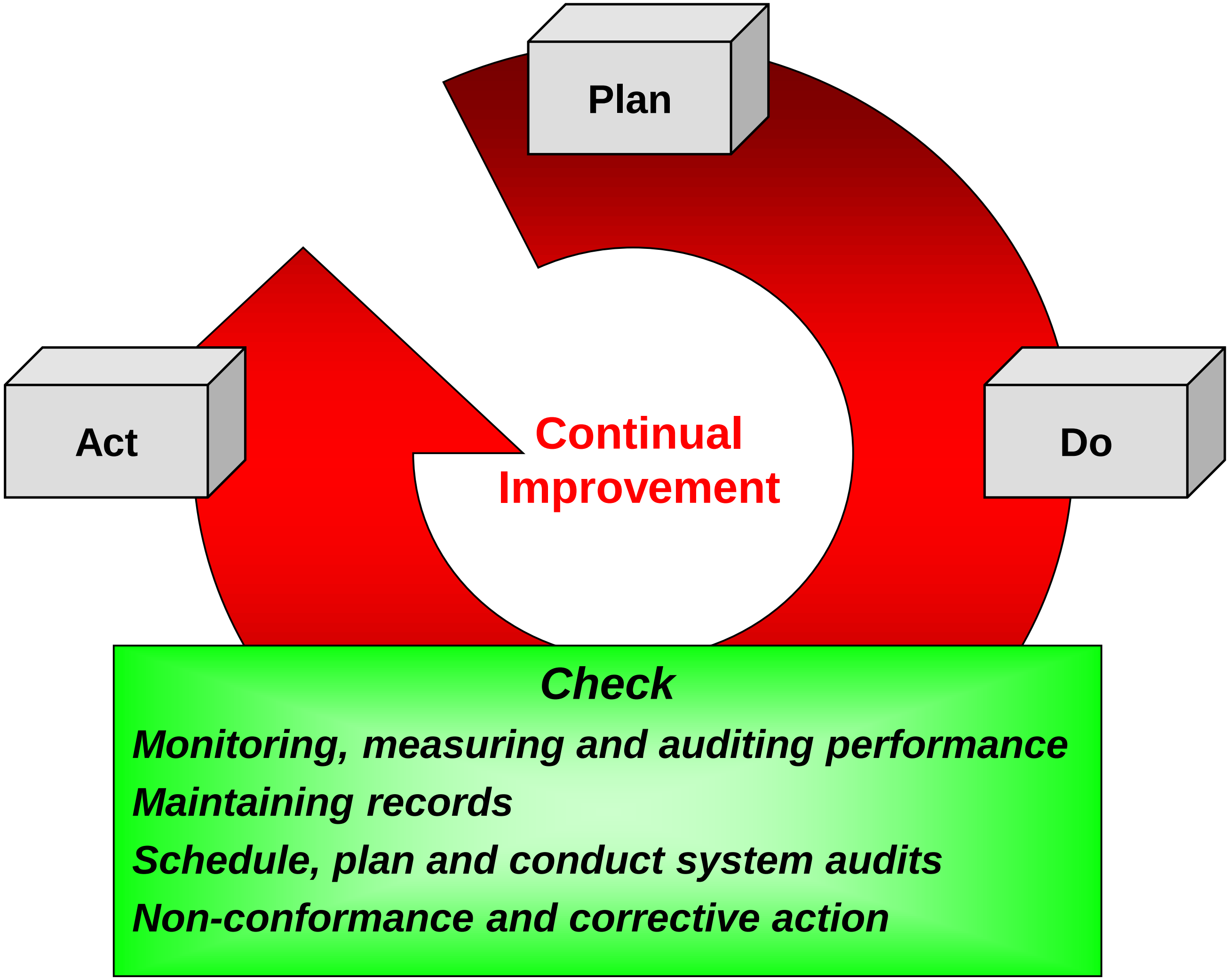
ISO 14001 Environmental Management System



Do

Structure and responsibility
Training, awareness and competence
Communication
EMS documentation
Document control
Operational control
Emergency preparedness & response

ISO 14001 Environmental Management System



Plan

Do

Check

Monitoring, measuring and auditing performance

Maintaining records

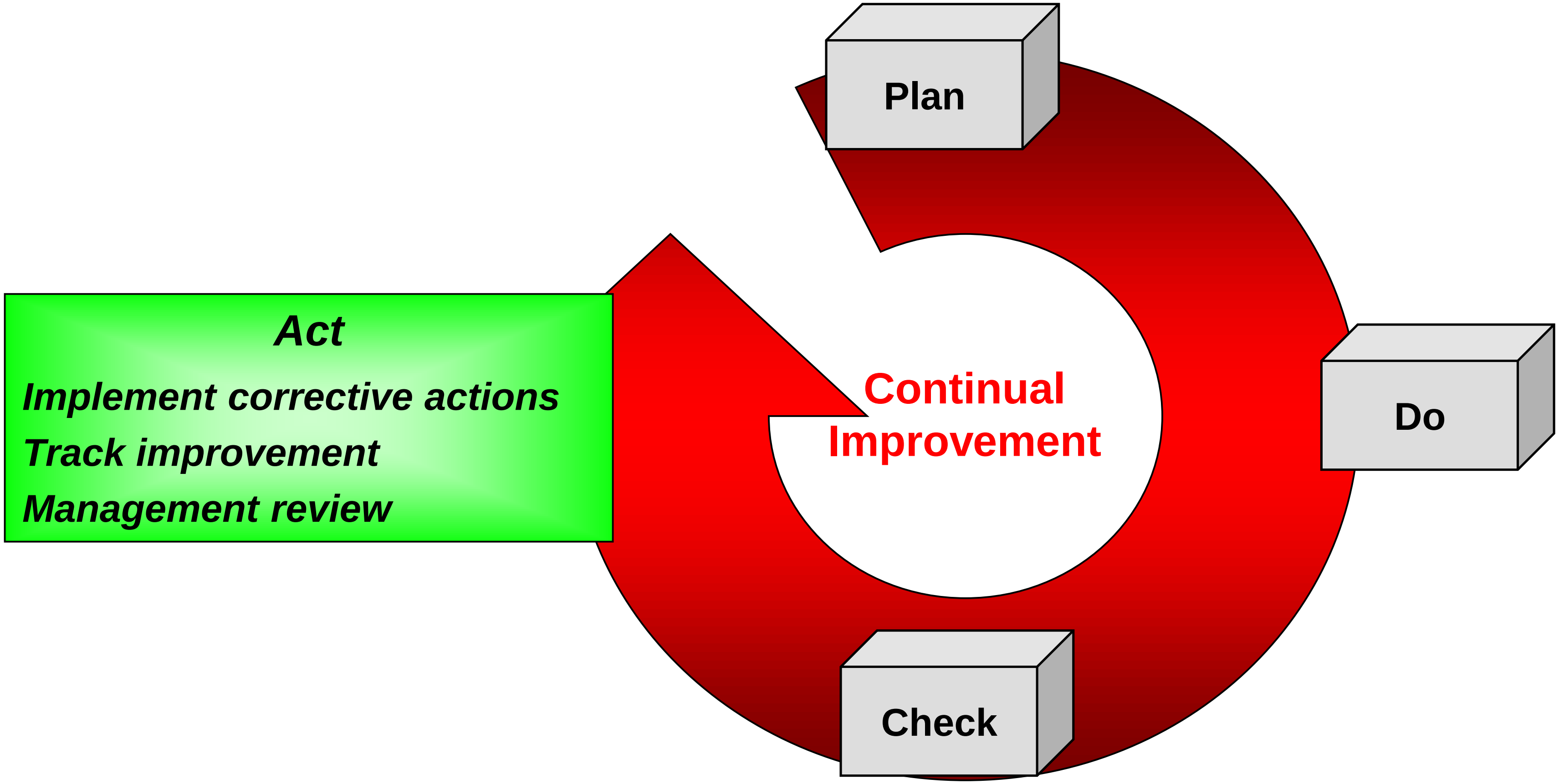
Schedule, plan and conduct system audits

Non-conformance and corrective action

Act

Continual Improvement

ISO 14001 Environmental Management System



Act

Implement corrective actions

Track improvement

Management review

Cleaner Production

"The continuous application of an integrated preventive environmental strategy applied to processes, products, and services. It embodies the more efficient use of natural resources and thereby minimizes waste and pollution as well as risks to human health and safety."

UNEP

- CP promotes the shift of mindset from *corrective* to *preventive* approach
- Endeavors to bring a combination of economic savings and environmental improvements
- CP addresses root *causes* of problems rather than their *effects*.
- CP aims to reduce the utilization of natural resources per unit of production, the amount of pollutants generated and their environmental impact → decoupling production from environmental impacts
- At the same time, it makes alternative products and processes financially more attractive

Cleaner Production (CP) Strategy

For production processes**, CP includes**

- More efficient use of raw materials, water and energy
- Elimination of toxic or dangerous process input materials
- Minimising the volume and toxicity of all emissions and waste

For products**, CP focuses on**

- Reducing impacts through the product’s life cycle
- Adapting design, raw material input, manufacturing, use, and disposal

For services**, CP implies**

- Preventive environmental strategy in the design and delivery of services

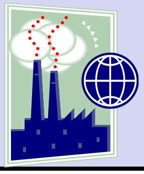
Implementing a CP Management Program

STEP 1: PLANNING

- *Management commitment*
- *Prepare policy statement*
- *Establish project team*
- *Appoint project champion*

STEP 2: PRELIMINARY INVESTIGATION

- *Asses effluent streams (process flow chart))*
- *Obtain regulatory reports*
- *Carry out walk through inspections*
- *Prepare a programme plan*
- *Develop a schedule with milestones*

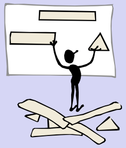


STEP 3: DETAILED ASSESSMENT

- *Review data and sites*
- *Collect input/output data*
- *Prepare material/energy balances*
- *Define ICP options brainstorm)*

STEP 4: FEASIBILITY' ANALYSIS

- *Rank various technical options*
- *Technical analysis*
- *Environmental analysis*
- *Economic analysis*
- *Select most viable options*
- *Prepare report*

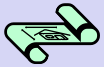


STEP 5: IMPLEMENTATION

- *Plan and schedule*
- *Implement selected CP options*

STEP 6: MONITOR PROGRESS

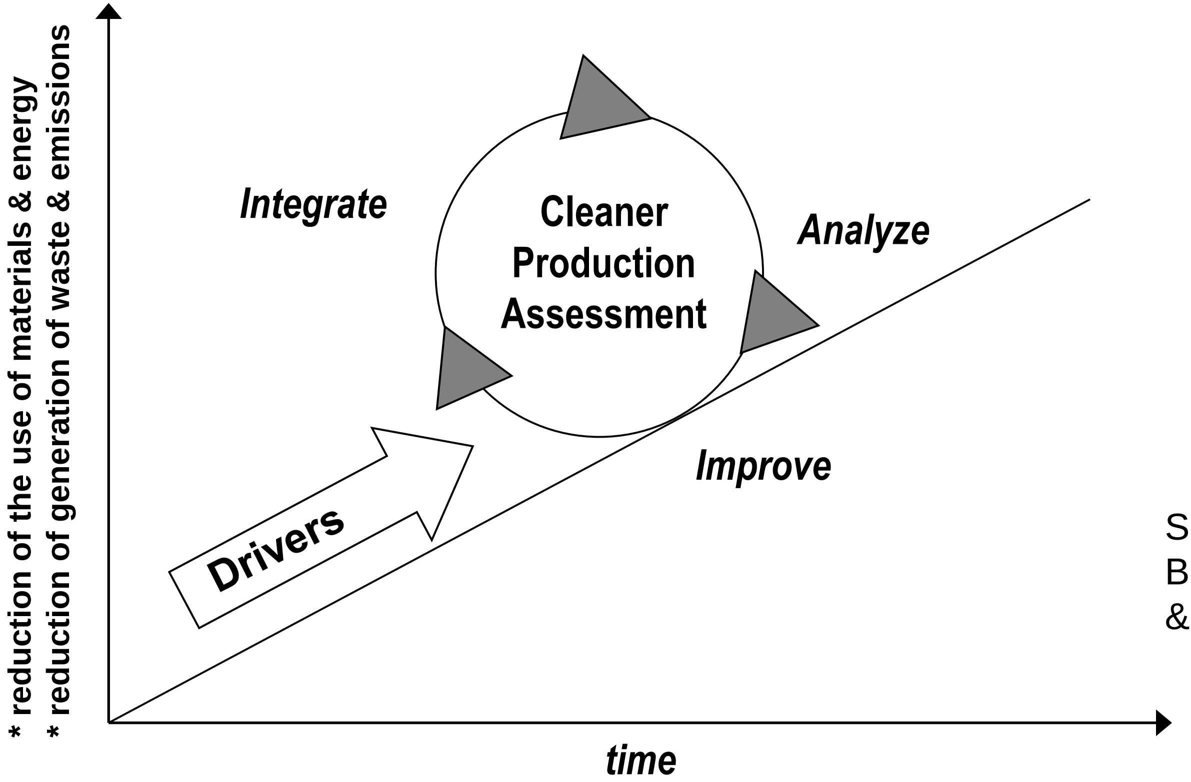
- *Track wastes, material use, cost saving*
- *Document results and savings*



Areas of CP Management

CP covers 3 areas of environmental management:

- Pollution prevention (P2)
- Toxic use reduction (TUR)
- Design for the environment (DfE)



Source: Van Berkel, Willema, & Lafleur, 1997

Environmental Impact Declaration

Definition

- An EIS is a report which draw the potential environmental effects arising from the completion of the proposed action

Aim

- Present EAI conclusions to political, authority which decide law and common in order to prevent environmental burden

Includes:

- Environmental impact of the proposed action
- Unfavorable environmental impacts to be avoided
- Alternatives to the proposed actions
- Relationship between short term use and maintenance/improvement of long term productivity
- Any irreversible and not recoverable ban of resources

Political Approaches

Depending on the level of intervention, and with the aim to attempt to minimize costs of economic activity and environment degradation, governments can adopt three different approaches:

- Regulatory
  - Administrative in nature and fixed
  - Complex and expensive
  - Based on constraints
  - Unwanted *results (i.e. black market of CFC in some countries)*
  - *Promoted in the past, new less* common owing to costs for control and difficulties in applying
- Economic instruments or market based solutions
  - Change of relative prices to influence the resource use system: the price of a good or service must include all externality and environmental costs
- Ban of a substance
  - This is the case of Dioxin and CFC (considered too dangerous to be used by community)

Other Political Approaches

Based on desired effect on producers and consumers

1) Voluntary Programs
   - Common approach
   - Limited success
   - The most successful: “Responsible Care”

2) Direct control, based on laws, taxation and punishment
   - Scarcely imposed (approved in 12 countries - (2000))

3) Economic tools and taxis
   - The more effective
   - Economic measures: green certificates, pollution tax
   - Economic tools : allowance schemes and deposit reimbursement, biomass compensation (carbon sequestration by forest planting)

Software Programs for LCA

1. ECO-it 1.0 PRé Consulting http://www.pre.nl/eco-it.html
2. EcoManager 1.0 Franklin Associates, Ltd. http://www.fal.com/software/ecoman.html
3. EcoPro 1.5 EMPA http://www.sinum.com/
4. GaBi 3.0 IPTS http://www.pe-product.de/englisch/main/software.htm
5. IDEMAT Delft Univ. of Technology http://www.io.tudelft.nl/research/mpo/idemat/idemat.htm
6. LCAD Battelle/DOE http://www.estd.battelle.org/sehsm/lca/LCAdvantage.html
7. LCAiT 2.0 CIT EkoLogik http://www.ekologik.cit.chalmers.se/lcait.htm
8. REPAQ 2.0 Franklin Associates, Ltd. http://www.fal.com/software/repaq.html
9. SimaPro 4 PRé Consulting http://www.pre.nl/simapro.html
10. TEAM 2.0 Ecobalance http://www.ecobalance.com/software/team/team_ovr.htm
11. Umberto 3.0 IFEU http://www.ifu.com/software/umberto-e/
12. BEES 3.0 http://www.nist.gov

http://eplca.jrc.ec.europa.eu/ELCD3/datasetDownload.xhtml

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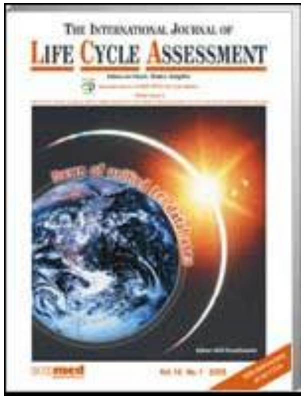
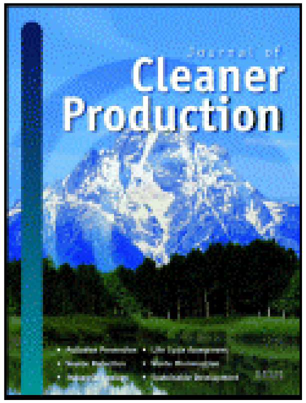
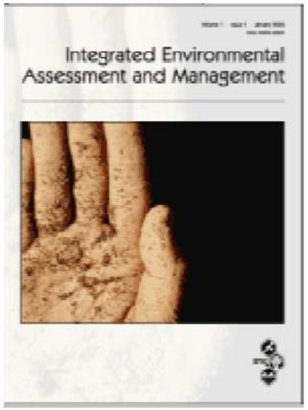
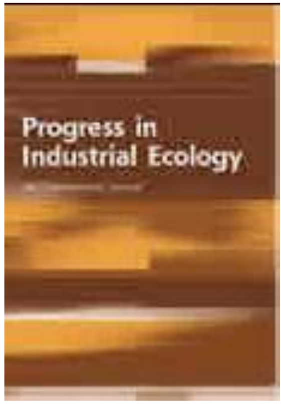
Scientific Journals on LCA

- International Journal of Life Cycle Assessment
- Journal of Industrial Ecology
- Journal of Cleaner Production
- Integrated Environmental Assessment and Management
- Progress in Industrial Ecology









ISO Standards 14040 & 14044 (2006)
U.S. EPA (2006) *Life Cycle Assessment Principles & Practice* EPA/600/R-06/060
Curran, M.A. (ed.) (1996) *Environmental Life Cycle Assessment.* McGraw-Hill, New York
Baumann & Tillman (2004) *The Hitch Hiker's Guide to LCA: An Orientation in Life Cycle Assessment Methodology and Application*
Heijungs R, et al (1992) *Environmental Life Cycle Assessment of Products. Vol. I: Guide, and Vol. II: Backgrounds*, Center for Envir. Studies, Leiden University
International Journal of Life Cycle Assessment; Journal of Cleaner Production; Journal of Industrial Ecology