Waste Minimization and Cleaner Production

EV20001 – Environmental Science

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What does "Sustainable Design" mean?

- Designing objects that are from renewable sources
- Designing for need and function
- Designing objects that have a positive long term social impact
- Understanding whole earth negative impacts that a product may have and turning them to positive

Why is sustainable design good?

- We live in an ever changing world, looking after our planet is important for the generations that will follow
- Reducing our carbon waste helps promote the growth in our planet's ozone layer
- Reducing our carbon emissions means that our planet is more likely to continue to exist in its current form
- Changing our attitudes to what we buy and how we design can help
- Using materials that are from resources that won't run out and will benefit the planet

Developing our design ideas.

- By developing our design ideas and finding ways to reduce the carbon footprint of our products we can help our planet
- We can improve our designs in many ways....

There are some simple ways to develop our design ideas to reduce the products impact on the environment.....they are.....

Re-duce, Re-use, Re-cycle

These are the 3Rs

They are in this order because re-duce is the most important. You must re-duce as much as you can when you are designing as this will benefit the planet immediately. There are many things you can re-duce from the materials and components you use through to the energy and time it takes to manufacture your product.

Re-duce

- Reduce the amount of materials
- Reduce components
- Reduce waste
- Reduce manufacturing time

Mark Liu is a fashion and textile designer who has produced a range of garments that are cut from a single piece of fabric with absolutely no waste.

Examples of Eco products. (Re-duce)





These products and buildings have been designed to reduce waste, energy use, components, materials or manufacturing time and energy.

Re-use

- Re-use materials
- Re-use components
- Re-use existing objects

A light that re-uses egg cartons.

Foot stool made of old trainers.

Examples of Eco products. (Re-use)


All these products are made from re-using existing products.




Recycle

- Use recycled materials
- Design products so they can be recycled

Smile Plastics make sheet plastic from recycled coloured bottles.

This bag is made of recycled tyres

Examples of Eco products. (Re-cycle)


These products are all made from materials that have been recycled. From tyres through to milk cartons.



Life Cycle

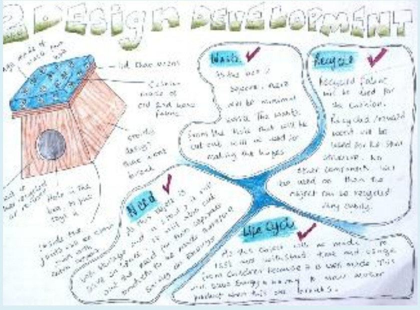
Understand the life cycle of your product.
How can you improve its life cycle and make it last longer?

- Make it strong
- Use materials that will last
- Choose the best joining methods you can for the materials that you have chosen
- Try not to mix materials. If you have components in another material find a way for them to be separated easily once the product becomes waste
- Think seriously about what will happen to your product when it is at the end of its lifecycle and how to reduce its effect on the environment

Material Properties

- Embodied Energy – this is the energy that any material uses to be made. Glass has a high embodied energy (it uses a lot of energy to be made), wood has a low embodied energy (it uses less energy to be made). When using a material think about where it has come from and how did it get to be in front of you.
- Understand material properties. What are the properties of the materials that you have chosen. Do they match the requirements of the product?

Develop Your Own Design



Designs need to be developed to reduce their impact. Think about ways in which you can change and develop your design to make it better for the environment.

Examples of sheets to show sustainable development of your product.

What is Sustainability ?

Sustainability is…

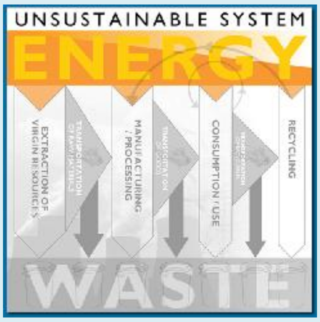
"development that meets the needs of the present without compromising the ability of future generations to meet their own needs"

– the Brundtland Report, 1987
World Commission on Environment and Development

What is Sustainability ?

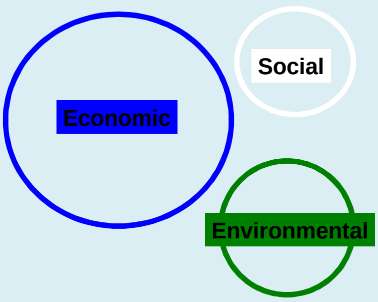
Industrial Revolution:

- Releases billions of pounds of toxic waste into air, water and soil every year
- Creates materials that cause concern by future generations to their quality of life
- Produces large amounts of waste
- Requires endless regulations to simply regulate the rates of damage of points above



What is Sustainability ?

Economic Model of the Industrial Revolution:

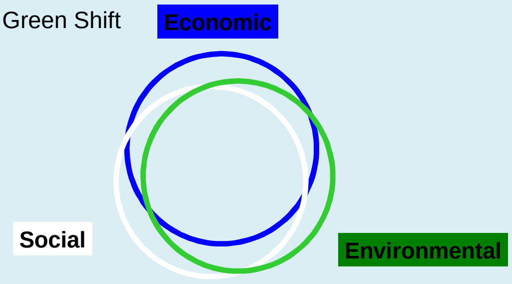


What is Sustainability ?

A Sustainable System:
Cyclical

What is Sustainability ?

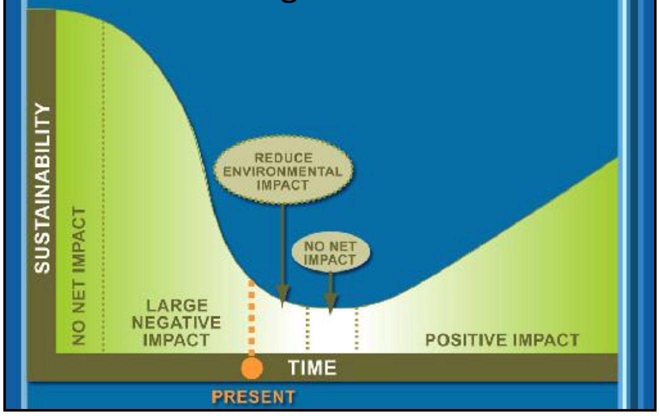
The Green Shift



What is Sustainability ?

1. The quality of life on earth
2. Efficient Use of the Earth's Materials
3. The Protection of our Global Commons
4. The Management of Human Settlements
5. Chemicals and Management of Waste
6. Sustainable Economic Growth

How do we get there from here?



Sustainability Drivers

- Informed public demand
- Positive recognition for leaders
- Best long-term solution
- Environmental legislation
- Increasing prices for resources
  (i.e. energy, water, fuel, wood etc.)

Defining Traditional Engineering

What changed?

In Traditional Engineering…

- required to solve problems they are presented with to the best of their knowledge
  - within constraints of approval authorities
  - within schedule and financial constraints
- Engineers search for methods that maximize function, and minimize cost to clients

Traditional Engineering:

Maximizing utility while minimizing the cost to the client

Shift in Engineering Mindset:

Maximize social benefit while minimizing ecological impact

But…How do We Track Progress?

- **SOCIAL EFFECT:**
  Community activities, employment rates, immigration…
- **ECONOMIC ACTIVITIES:**
  Business growth, employment rates, inflation…
- **ENVIRONMENTAL EFFECTS:**
  Beach closures, smog warnings, environmental contaminations, endangered wildlife…
  - Birth defects, death rates, severe asthma attacks…

How do we track changes to these factors?

As Keyplayers, what can we do?

Designing Towards Sustainable Development

- Be aware of issues and impacts
  Inherently includes well-being of environment
- Comply and go beyond minimum requirement
- Involve public and communities in decision-making
- Set our mindset to doing what is right
- Even when appears to be a more difficult process - it is a step in the right direction

Must change the way people think about sustainability!

Designing Towards Sustainable Development

- Step back from "business as usual"
- Find ways to work with nature
- Lessen environmental impact
- Save energy, resources
- Build on Small Successes – piloting
- Spread the word - Market your capabilities to both existing and new clients

The Challenge… goes beyond just the money!

What Professionals Can Do

Design project to:

- Reduce material and energy use
- Use renewable energy resources
- Maximize lifespan of structure
- Reduce construction waste generated
- Reduce/eliminate hazardous waste generation
- Minimize maintenance and services required

Engineering Design for Sustainability

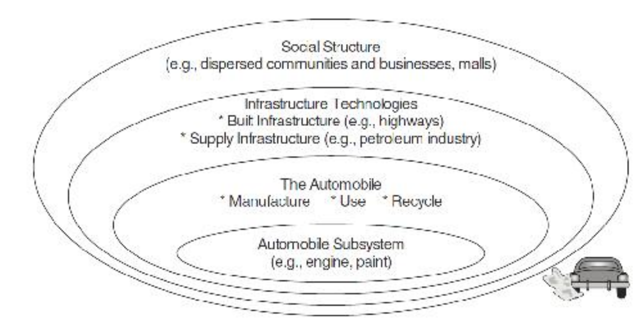
- Engineers play an important role in global sustainable development by designing production systems for materials, minerals, chemicals, energy, electricity generation and distribution, transportation, buildings and other structures, and consumer products
- These designs have impacts on the environment, economies, and societies at spatial scales that vary from local to global and at temporal scales that vary from minutes to decades
- As engineers create designs, they not only evaluate their designs at multiple spatial and temporal scales, they also embed their designs in complex systems

Example from Transport sector

- The field of transportation provides an illustration of the multiple layers of systems in which engineers create designs
- Among the most visible products designed by engineers are automobiles
- Engineers design engines, and improvements to the design of a fossil-fuel-powered engine for an automobile can increase fuel efficiency and reduce the environmental impacts of emissions associated with burning fuels, while simultaneously reducing the cost of operating the vehicle

- The size, power, and fuel efficiency of the engine must be balanced with the weight of the vehicle, however, so changes in engine design must be considered within the entire vehicle system
- Further reductions in emissions and operating costs might be possible by lowering the weight of the vehicle
- The use of materials and fuels by automobiles are embedded in complex fuel and material supply systems

- Developing systems to recycle the materials that make up the automobile at the end of its useful life might improve the environmental and economic performance of global material flows
- Use of alternative power sources, such as biofuels or electricity, can impact global flows of fuels, which, in turn, might impact global flows of materials such as water
- Finally, the design of cities that reduce the need for personal transportation could dramatically reduce the environmental impacts of transportation systems and would also transform social structures



Engineering design for sustainability can consider a variety of system scales, as shown for the automobile: gate-to-gate (subsystem), cradle-to-grave (the automobile), inter industry/infrastructure, and extra-industry/societal

- The point of this example is to illustrate that sustainable design of engineered systems will lead to consideration of multiple spatial and temporal scales and will require that the engineer interact with professionals with many different backgrounds both within and outside of engineering
- These sustainable design challenges are complex, and the tools for addressing these problems are still emerging

Sustainable Engineering Design Principles

- Brundtland Report
- The Hannover Principles – Human systems must be designed to co-exist with natural systems
- The Augsburg Materials Declaration (2002):
  - Integration of environmentally benign design, materials and manufacturing over all stages of the life cycle
  - Optimization and exploitation of raw materials and natural resources
  - Energy efficient production technology and product distribution
  - Regenerative energy sources
  - Durability, Recyclability and closed loops

Sandestin Sustainable Engineering Principles

1. Engineer processes and products holistically, use system analysis, and integrate environmental impact assessment tools
2. Conserve and improve natural ecosystems while protecting human health and well-being
3. Use life cycle thinking in all engineering activities
4. Ensure that all material and energy inputs and outputs are as inherently safe and benign as possible
5. Minimize depletion of natural resources

Sandestin Sustainable Engineering Principles

6. Strive to prevent waste
7. Develop and apply engineering solutions, while being cognizant of local geography, aspirations, and cultures
8. Create engineering solutions beyond current or dominant technologies; improve, innovate and invent technologies to achieve sustainability
9. Actively engage communities and stakeholders in development of engineering solutions

Principles of Green Engineering

Principle 1: Designers need to strive to ensure that all material and energy inputs and outputs are as inherently nonhazardous as possible

Principle 2: It is better to prevent waste than to treat or clean up waste after it is formed

Principle 3: Separation and purification operations should be designed to minimize energy consumption and materials use

Principle 4: Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency

Principles of Green Engineering

Principle 5: Products, processes, and systems should be "output pulled" rather than "input pushed" through the use of energy and materials

Principle 6: Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition

Principle 7: Targeted durability, not immortality, should be a design goal

Principle 8: Design for unnecessary capacity or capability (e.g., "one size fits all") solutions should be considered a design flaw

Principles of Green Engineering

Principle 9: Material diversity in multicomponent products should be minimized to promote disassembly and value retention

Principle 10: Design of products, processes, and systems must include integration and interconnectivity with available energy and materials flows

Principle 11: Products, processes, and systems should be designed for performance in a commercial "afterlife"

Principle 12: Material and energy inputs should be renewable rather than depleting

What does it mean to be Green??
What is Sustainability??

Sustainability

- Environmentally Friendly
- Sustainable Products
- Green product
- Environmentally Preferable

United Nations World Commission on Environment and Development (1987)
Sustainable Development definition:

"… development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

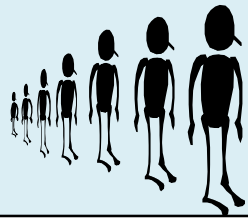
- Biodegradable
- Recyclable
- Ozone friendly
- Eco-design
- Greenwashing

wwblog.miragestudio7.com

What Can the Earth Handle?

- The estimate of Earth's Maximum supportable population is 13.4 billion.
- Looking at the population statistics, where are we headed?

Renewable Energy Source Will Limit Our Growth!



World Population Statistics
UN Population Division

Population (2007)	Annual Growth	Rate (00 – 07)
World	6.7 Billion	1.24%
LDC	5.4 Billion	1.44%
MDC	1.2 Billion	0.36%
US	301 Million	1.03%

Average per capita energy consumption is 3 kW/person
- US 12 kW/person
- Industrialized 7.5 kW/person
- Denmark 5.1 kW/person
- Developing 1kW/person

Being Green is Trendy . . . .
What Does Science Say?

- Industry is looking for ways to green their products and manufacturing processes.
- Individuals and Families are looking to green their homes and lifestyles.
- How can you tell if something really is green??
- What is currently happening to achieve this goal?
- Scientists perform a Life Cycle Assessment (LCA)

www.scienceinthebox.com

Life Cycle Assessment

A Scientific Way to Look at Going Green!

Life Cycle Assessment

Definition:

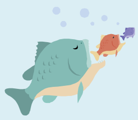
"Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle"

This establishes an environmental profile of the system!

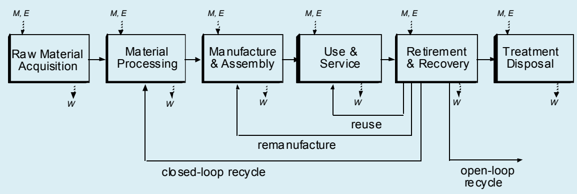
ISO = International Organization for Standardization
Ensures that an LCA is completed in a certain way.

WHAT CAN BE DONE WITH LCA?

1. Product or project development and improvement
2. Strategic planning
3. Public policy making
4. Marketing and eco-declarations



Product Life Cycle



M, E = Material and Energy inputs to process and distribution
W = Waste (gas, liquid, or solid) output from product, process, or distribution

Material flow of product component

What Makes Up LCA

- Goal & Scope Definition

  What is the purpose of the LCA and who is the audience?

- Inventory Analysis (LCI)

1. What is the function & functional unit?
2. Where are the boundaries?
3. What data do you need?
4. What assumptions are you making?
5. Are there any limitations?

- Impact Assessment (LCIA)

  What are the environmental, social, and economic affects?

- Interpretation

  Ways to reduce environmental impacts.

  What conclusions can you draw from the study?

  What recommendations can be made?

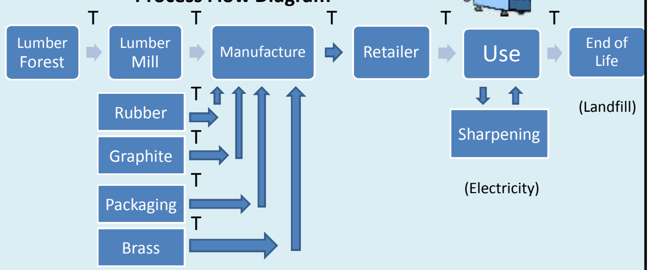
Goal and Scope

Wooden Pencil vs. Mechanical Pencil

Goal = Compare 2 writing utensils for classroom use.

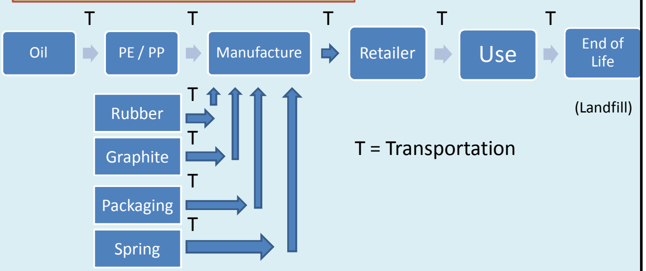
Scope: Wooden Pencil (T = Transportation)

Process Flow Diagram



Scope: Mechanical Pencil

PE = Polyethylene
PP = Polypropylene
Both materials are **plastic polymers** (large molecules) used to make many products.



T = Transportation

Function & Functional Unit

Function

- Service provided by a system
- What it does!

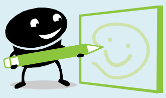
Functional Unit

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

Example

Wooden Pencil vs. Mechanical Pencil

- Function = "Writing"
- Functional Unit = "1 meter of writing"



Items To Consider??

Inputs

What is needed to make the substance!

1. Energy
2. Materials
3. Labor

Outputs

What comes out of the system!

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

Data Collection

Life Cycle Inventory Analysis

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

Never Forget . . . .

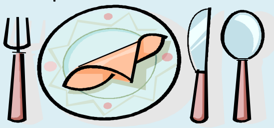
Precision:
The consistent reproducibility of a measurement

Completeness:
Covers all the areas outlined in the scope

LCA in Action: Think About It!

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

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



Data Analysis

Environmental Impact Categories

Global Warming Potential

- Gases in the atmosphere that absorb and emit radiation
- Trap heat from the sun
- Water vapor, CO_2 , CH_4 , ozone, NO_2

Abiotic Depletion

- Consumption of non-living resources

Human Toxicity Potential

- Value that shows harms to humans from chemicals

Land Use

- How much land is needed

Environmental Impact Categories

Continued . . . . .

Eutrophication

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

Water Use

Mercury

Acidification

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

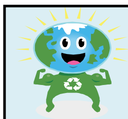
Smog (Winter or Summer)

Energy Use

Solid Waste

Oil

. AND MANY MORE!!



Where Do We Go From Here?

- What is the purpose of all this data??
- Scientists can make recommendations of choices that are less impactful
- Scientists can analyze a particular impact and focus on a solution

- Industry & Individuals can take a closer look at how they can make a difference

Let's look at another example

Comparison of light bulbs

Compact fluorescent	Incandescent

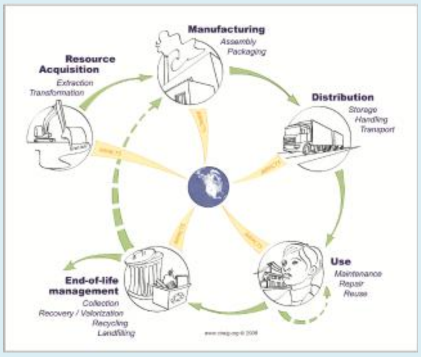
Compact fluorescent light bulb is worse, equal or better?

LCA study consist of 4 steps

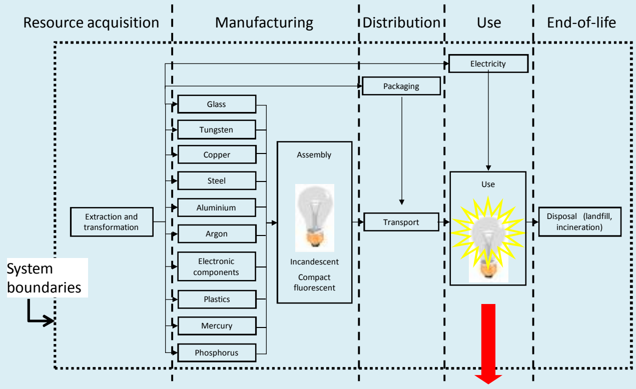
- Define goal and scope
- Life cycle inventory stage - all environmental input and output
- Life cycle impact assessment – understanding the environmental relevance of all the inputs and outputs
- The interpretation of the study

The life cycle of a product

All processes associated with the product, **wherever** and **whenever** they might occur



Life cycle of a light bulb



Bulb's function = Lighting

LCA = An accounting exercise

Environmental impacts	=	Perturbations of natural cycles by environmental interventions
Environmental intervention	=	Change in state of natural environment due to human activities
LCA	=	Accounting for all environmental interventions associated with life cycle of product

Life cycle inventory

Inputs

Natural resource extractions

Iron ore
Crude oil
Water
Wood
Solar energy
Land use

Resource Acquisition
↓
Manufacturing
↓
Distribution
↓
Use
↓
End-of-Life

Outputs

Emissions in

Air : CO_2, SO_2, PM, VOC
Water : PO_4, NO_3
Soil : pesticides, metals

Other environmental interventions

Radiations
Heat
Noise

Functional unit
= given « amount » of function to which all inputs and outputs are related to

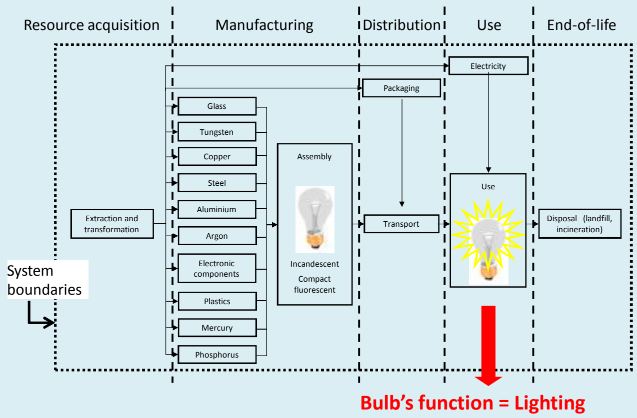
Functional unit and reference flow

- Product comparison is the functional unit or comparison basis
- In many cases, one cannot simply compare product A and B, as they may have different performance
- For example, comparing milk cartoon and a returnable milk bottle (can be used many times)

Functional unit and reference flow

- Product comparison is the functional unit or comparison basis
- In many cases, one cannot simply compare product A and B, as they may have different performance
- For example, comparing milk cartoon and a returnable milk bottle (can be used many times)
- May be comparing two ways of packaging and delivering 1000 litres of milk is a better option

Life cycle of a light bulb



Defining the functional unit

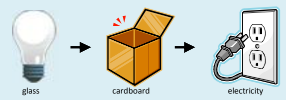
Products	Primary function	Secondary functions
Incandescent light bulb	Lighting	Heating Creating an ambiance
Compact fluorescent light bulb		

Products	Functional unit = « service provided »	Reference flows = « what is needed »	Key parameters
Incandescent light bulb	Providing 700 lumens	10 bulbs	Lifetime Watt/lumen ratio
Compact fluorescent light bulb		1 bulb	

Inventory for a light bulb

1° **Product system** (modeled by analyst)

Lighting needs :



2° **Functional unit (FU)** — ***Providing 700 lumens for 10000 hours***

3° **Referece flows** (data collected by analyst) — ***Providing 700 lumens for 10000 hours needs :*** 228 g glass; 232 g cardboard; 600 kWh

4° **Unit processes** (measured, calculated or estimated data, specific (primary) or generic (secondary) data)

	For 1 kg glass	For 1 kg cardboard	For 1 kWh
Inputs	94 g crude oil 1.0 g iron ore 1300 l water	77 g crude oil 16 g iron ore 3200 l water	1.3 g crude oil 0.29 g iron ore 19000 l water
Outputs	0.52 kg CO2 0.26 g PM2.5 1.6 mg benzene	1.1 kg CO2 0.32 g de PM2.5 8.7 mg benzene	23 g CO2 5.8 mg de PM2.5 0.61 mg benzene

5° **Elementary flows inventory**

	Per FU	Per FU	Per lFU
Inputs	21 g crude oil 0.23 g iron ore 300 l water	18 g crude oil 3.7 g iron ore 740 l water	780 g crude oil 170 g iron ore 11 000 000 l water
Outputs	0.11 kg CO2 59 mg PM2.5 0.36 mg benzene	0.26 kg CO2 74 mg PM2.5 2.0 mg benzene	14 kg CO2 3.5 g PM2.5 370 g benzene

Life cycle inventory

Elementary flows

Inputs:
Iron ore
Crude oil
Water
Wood
Solar energy
Land use
…

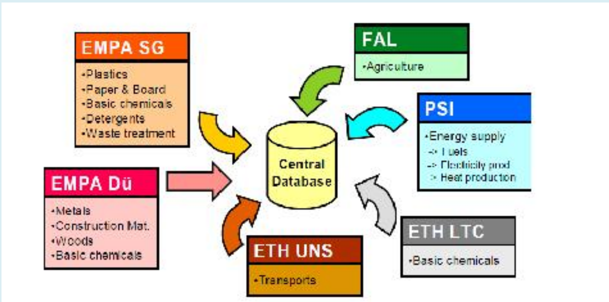
Outputs :
CO_2
SO_2
PM
VOC
PO_4
NO_3
Pesticides
Metals
…

Inventory may count hundreds of different elementary flows

➔ Very hard to interpret

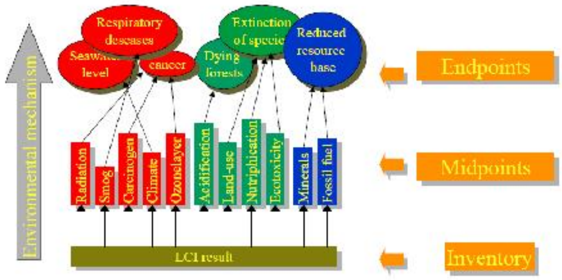
➔ Brain can simultaneously consider only up to 7 independent parameters

Neglecting processes in the process tree which contributes to less than 0.1% of environmental load



The figure above shows the Swiss organisations that joined forces to create the Ecoinvent database. See www.ecoinvent.org for more information.

Figure 3: The choice of the impact assessment method depends largely on the audience addressed.



General overview of the structure of an impact assessment method. The LCI results are characterised to produce a number of impact category indicators. According to ISO, one must document the environmental relevance of each indicator by describing the link to the endpoints. Endpoints can be selected by the practitioner, as long as the reasons for including or excluding endpoints are clearly documented.

Life cycle impacts

Elementary flows

Inputs:

Iron ore
Crude oil
Water
Wood
Solar energy
Land use
...

Outputs :

CO_2
SO_2
PM
VOC
PO_4
NO_3
Pesticides
Metals
...

Impact categories

Global warming
Ozone layer depletion
Land use
Natural resource depletion
Acidification
Eutrophication
Photochemical ozone generation
Human toxicity
Ecotoxicity

Single score

IMPACT2002+ = A combined approach

Elementary flows

Impact categories

Human toxicity
Respiratory effects
Ionizing radiations
Ozone layer depletion
Photochemical oxydation
Aquatic ecotoxicity
Terrestrial ecotoxicity
Terrestrial acidification/nutrification
Land occupation
Aquatic acidification
Aquatic eutrophication
Global warming
Non-renewable primary energy
Mineral extraction

Damage categories

Human health

Ecosystem quality

Climate change

Resources

From Jolliet et al. (2003) IMPACT2002+

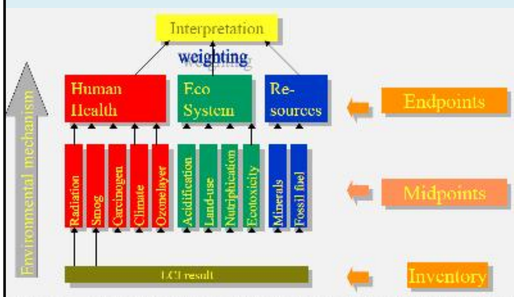
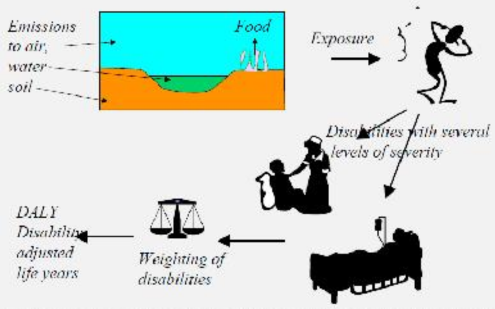
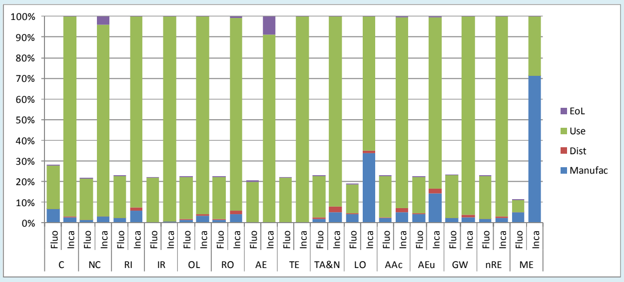


Figure 5: Schematic overview of the methodology proposed by Goedkoop & Spriensma. The environmental models for each impact category are extended up to endpoint level, as the impact category indicators that relate to the same endpoint have a common unit, these indicators can be added. In the case of Ecotoxicity, the endpoint is Ecosystem Quality, expressed as Potential Disappeared Fraction of plants.

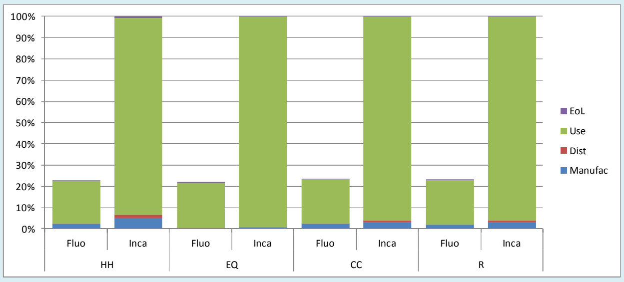


Schematic representation of the environmental model used for human toxicity. For other substance types other fate models are used.

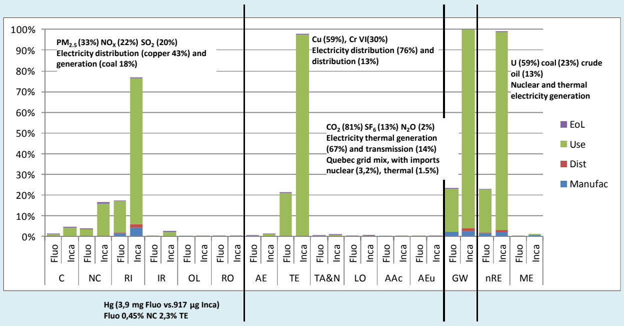
Light bulbs indicator results



Light bulbs indicator results



Light bulbs indicator results



Evolution of environmental preoccupation

Restauration (*Clean-up*)

Emissions reduction (*End-of-pipe*)

Pollution prevention

Cleaner Production

DfE / DfS

Green Chemistry

Life Cycle Management

Environmental assessment tools

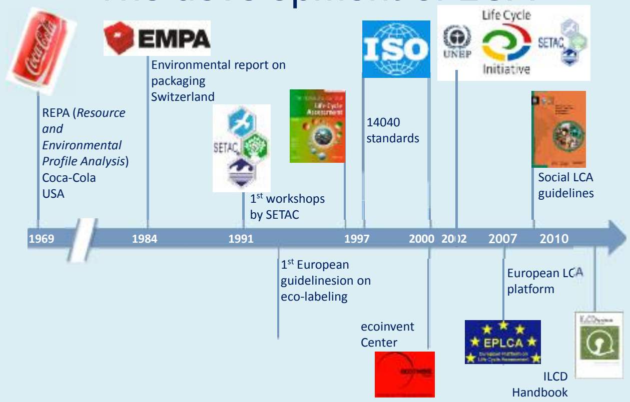
Tool	Object analysed	Scale	Aspects considered
RA (Risk Assessment)	Installation, substance	Local or regional	(Eco-)Toxicity
EIA (Environmental Impact Assessment)	New activity	Local	Variable
SFA (Substance Flow Analysis)	Substance	Regional or global (Life cycle of substance)	No effects
LCA (Life Cycle Assessment)	**Product, service** (= system)	**Global** (Life cycle of product/service)	**Multiples effects**

From O Jolliet, M Saadé, P Cretaz (2005) Analyse du cycle de vie, Comprendre et réaliser un écobilan, Presses Polytechniques et universitaires romandes, 242 p.

LCA = Modeling of reality

System definition	*Inventory*	*Impact assessment*
Function → Product system	Production inventory → Elementary flows inventory	Impact category indicators → Single score
Economic models	*Technological models*	*Environmental models*

The development of LCA



The ISO framework

Framework (*ISO-14040*)

1) Goal & scope definition (*ISO-14044*)	↔	**4) Interpretation (*ISO- 14044*)**
2) Life cycle inventory (LCI) (*ISO-14044*)	↔	
3) Life cycle impact assessment (LCIA) (*ISO-14044*)	↔	

Applications

Iterative method

- The collected data may lead to the modification of the scope of the study
- The goal itself can also be revised