Life-Cycle Analysis
Or
Life-Cycle Assessment

Pollution Prevention Factors

Environmental impact of a product is not limited to the emissions from the manufacturing line

Example – Common construction nail

- Nail factory probably purchases iron wire of the appropriate size, extrudes it, cuts it to length, sharpen or hammers
- A coating of color may be applied

A more detailed analysis, however finds:

… Only way to FULLY understand the magnitude of these impacts is "LCA"

1. Lubricant during machining stage
2. Water for equipment cooling
3. Electricity needed to run the equipment
4. Waste associated with packaging
5. Energy for transportation; factory--- retailers --- customers
6. Finally, when the useful life ends, the nail must be disposed of in the land fill

Pollution Prevention Factors

Life Cycle Assessment (LCA)

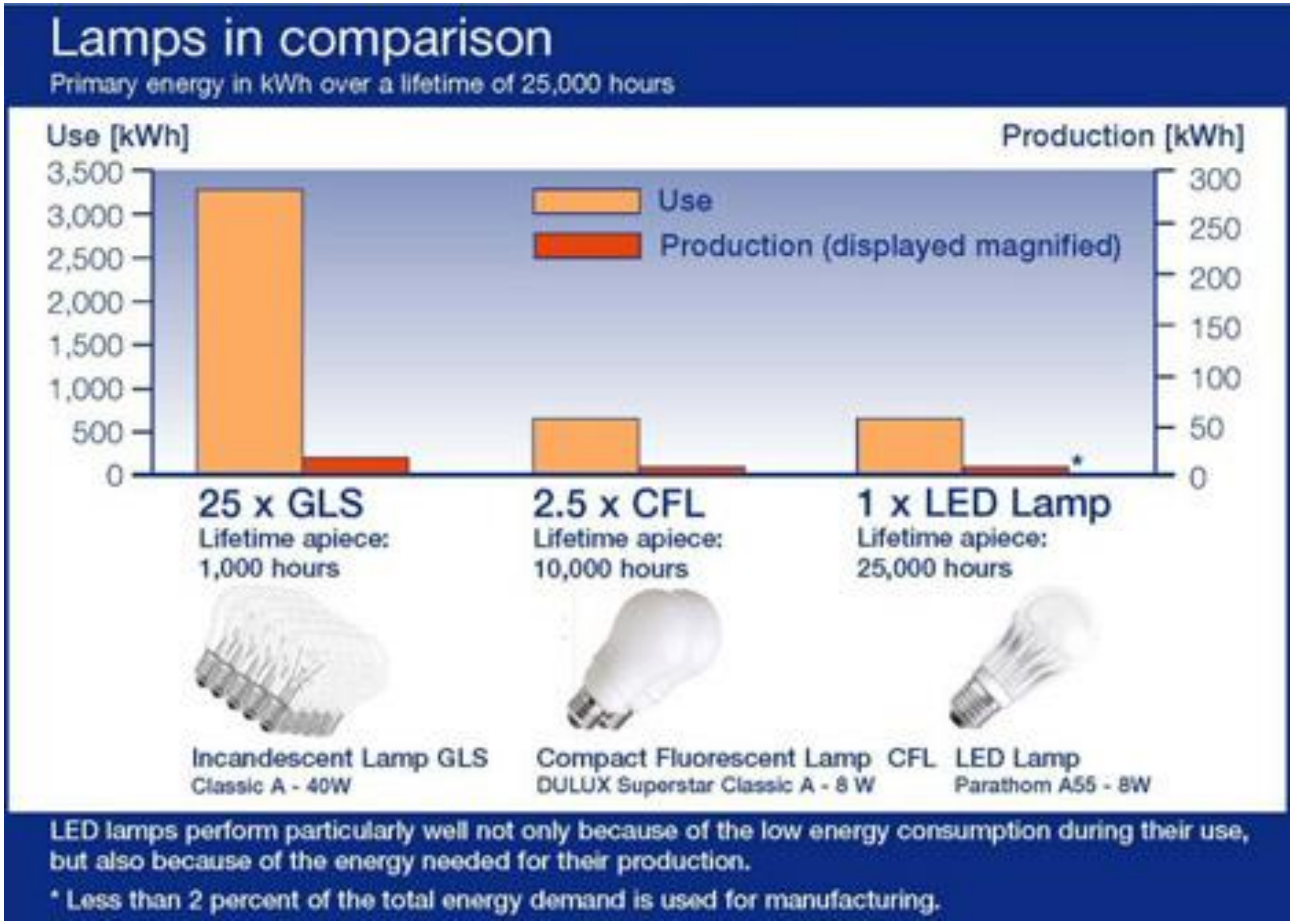
A LCA is an evaluation of the environmental effects associated with any given activity from the initial gathering of raw material from the earth until the point at which all residuals are returned to the earth (Vigon et al. 1993)

This evaluation includes:

- All side stream releases to the air, water and soil from the production of the raw materials (including energy), The use of the product, Final disposal

also known as Cradle to Grave analysis

Example



Life cycle of Lighting Options

GLS : General Lighting Services

(Source: http://www.treehugger.com/files/2009/08/led-lights-vs-cfl-life-cycle-study-energy-efficiency.php)

Objectives of LCA

- LCA is an approach through which manufacturers accept responsibility for the pollution caused by their products from design to disposal.

…… This is a major change from the traditional philosophy that the responsibility begins with the raw material acquisition and ends with the sale of the finished products (Bhat, 1996).

- LCA helps ensure that all environmental impacts are accounted for and to help in the decision-making process to determine which product to use.

…… Ex. – Incandescent light bulb (more energy)	Fluorescent light bulbs (less energy) (contains toxic mercury)

Objectives of LCA (contd.)

1. Product process improvement
2. Cost reduction
3. Decision making
4. Customer requirements
5. Determining obligations
6. Regulatory concerns
7. Setting research priorities
8. Ecolabeling
9. Reducing toxic waste
10. Marketing

Primary drivers (1–2)

2nd tier of motivation (3–4)

Lower tier drivers (5–10)

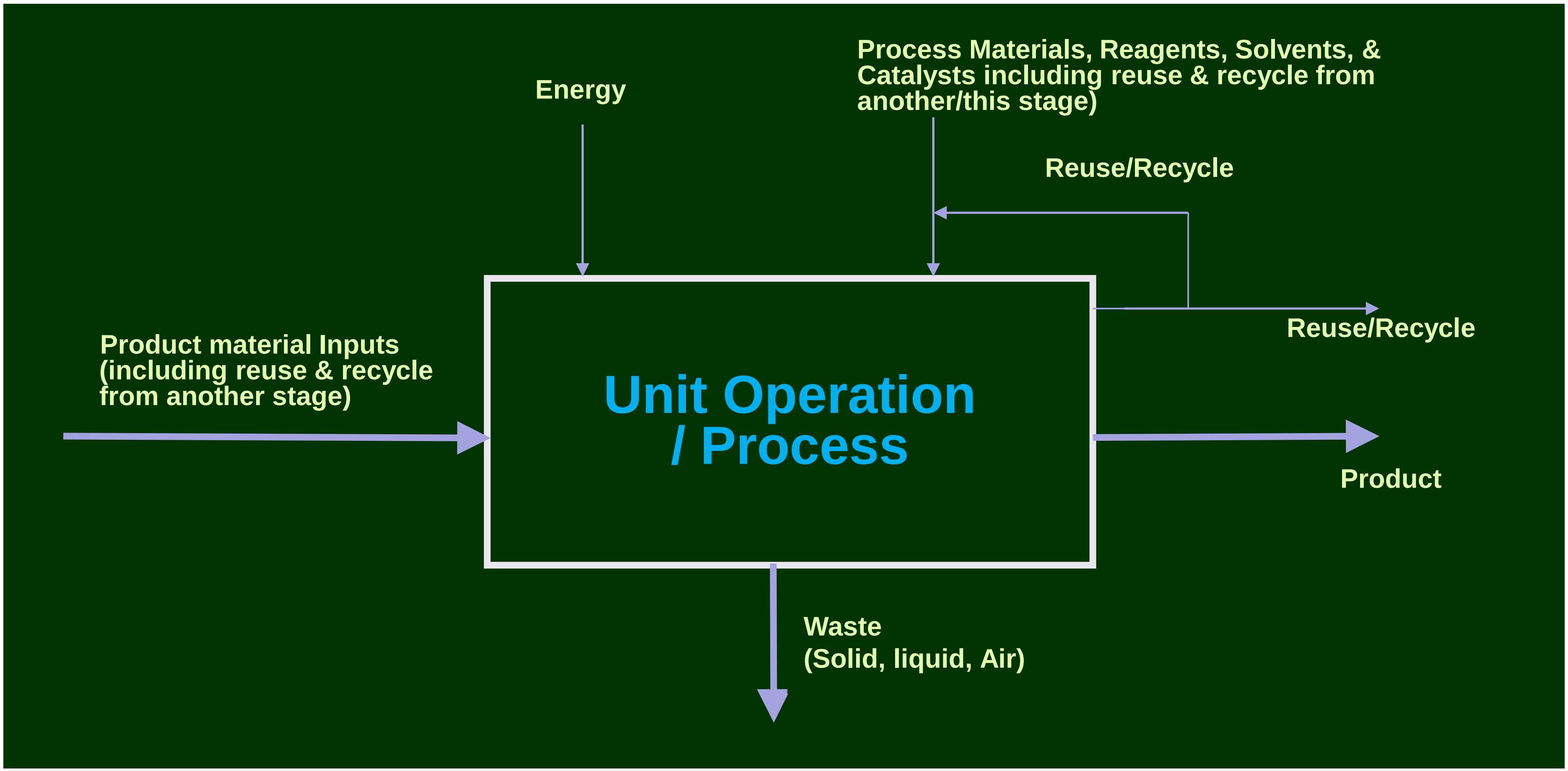
Curran, M. A. “Environmental Life Cycle Assessment, NY: McGraw-Hill (1996)

Code of practice for LCAs

<u>Product Stewardship</u>

is a concept that lays environmental responsibility on the Manufacturers …. Such that minimum impact are posed along the life cycle.

Material balance approach for LCA



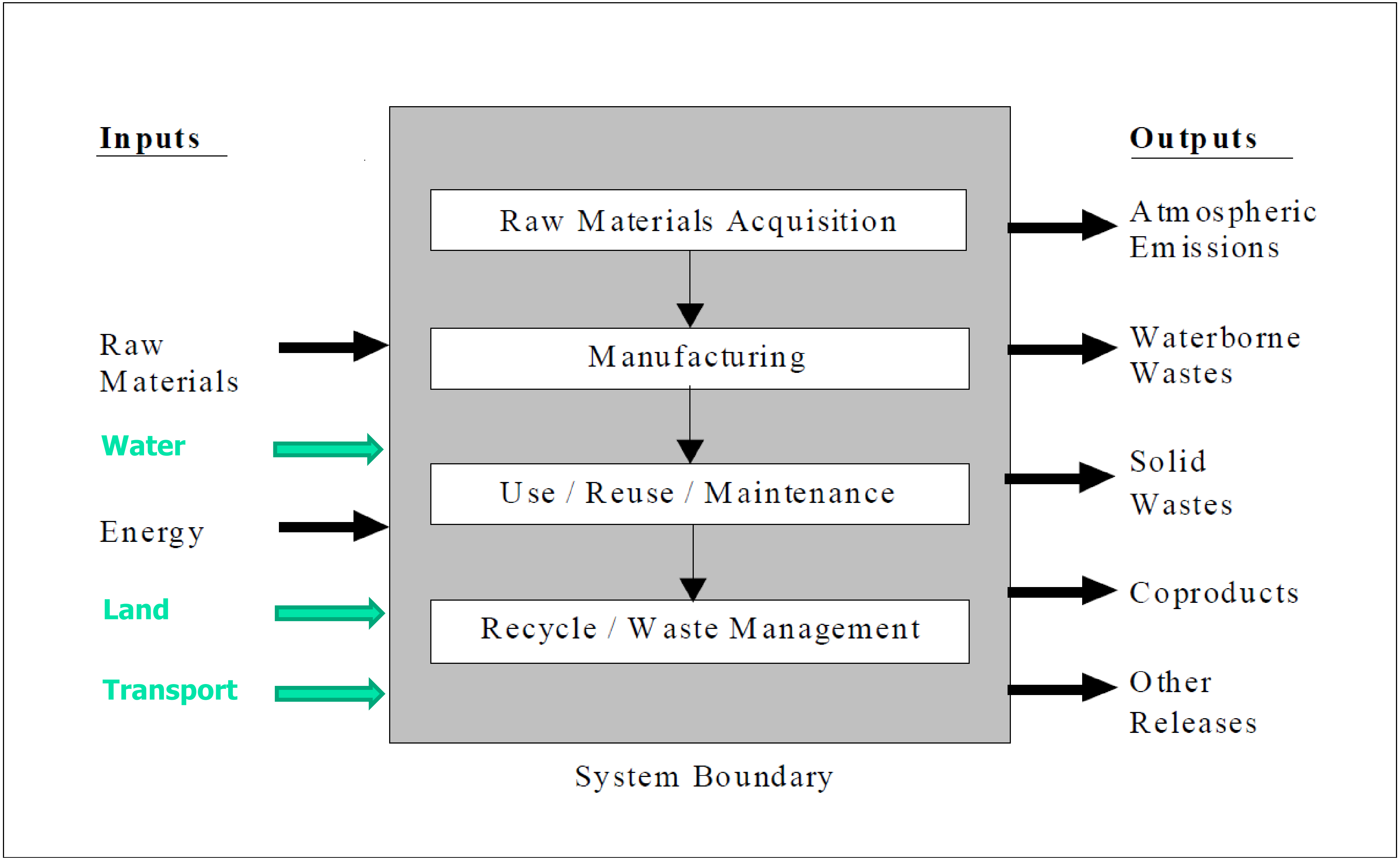
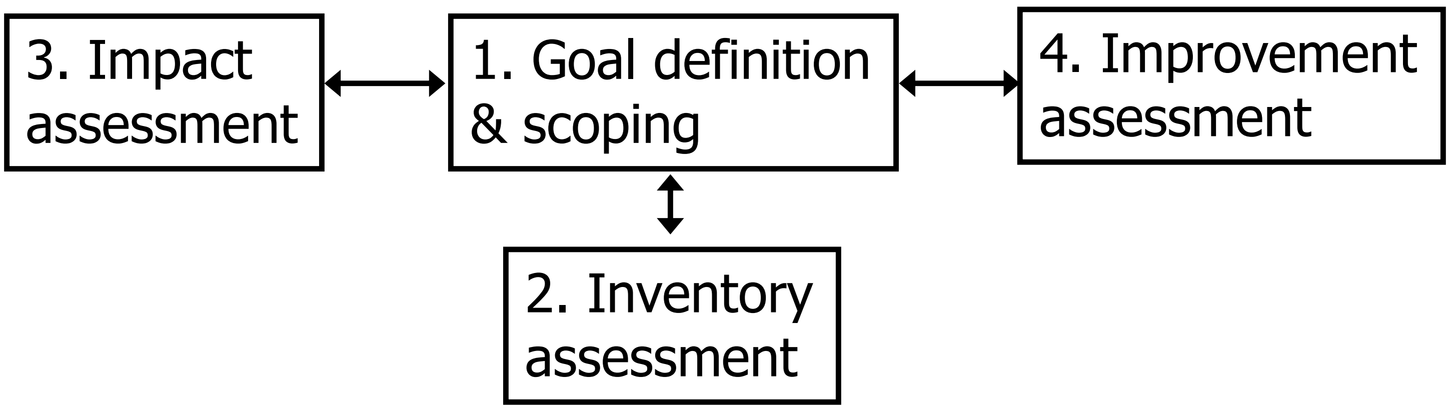


Exhibit 1-1. Life Cycle Stages (Source: EPA, 1993)

System boundary is flexible

Components of LCA: (How to do LCA)



Goal definition & scoping

- The first phase of LCA includes definition of
  - The purpose of the study and its intended use
  - The system and system boundaries
  - The functional unit
  - Data quality, the assumptions and limitations of the study

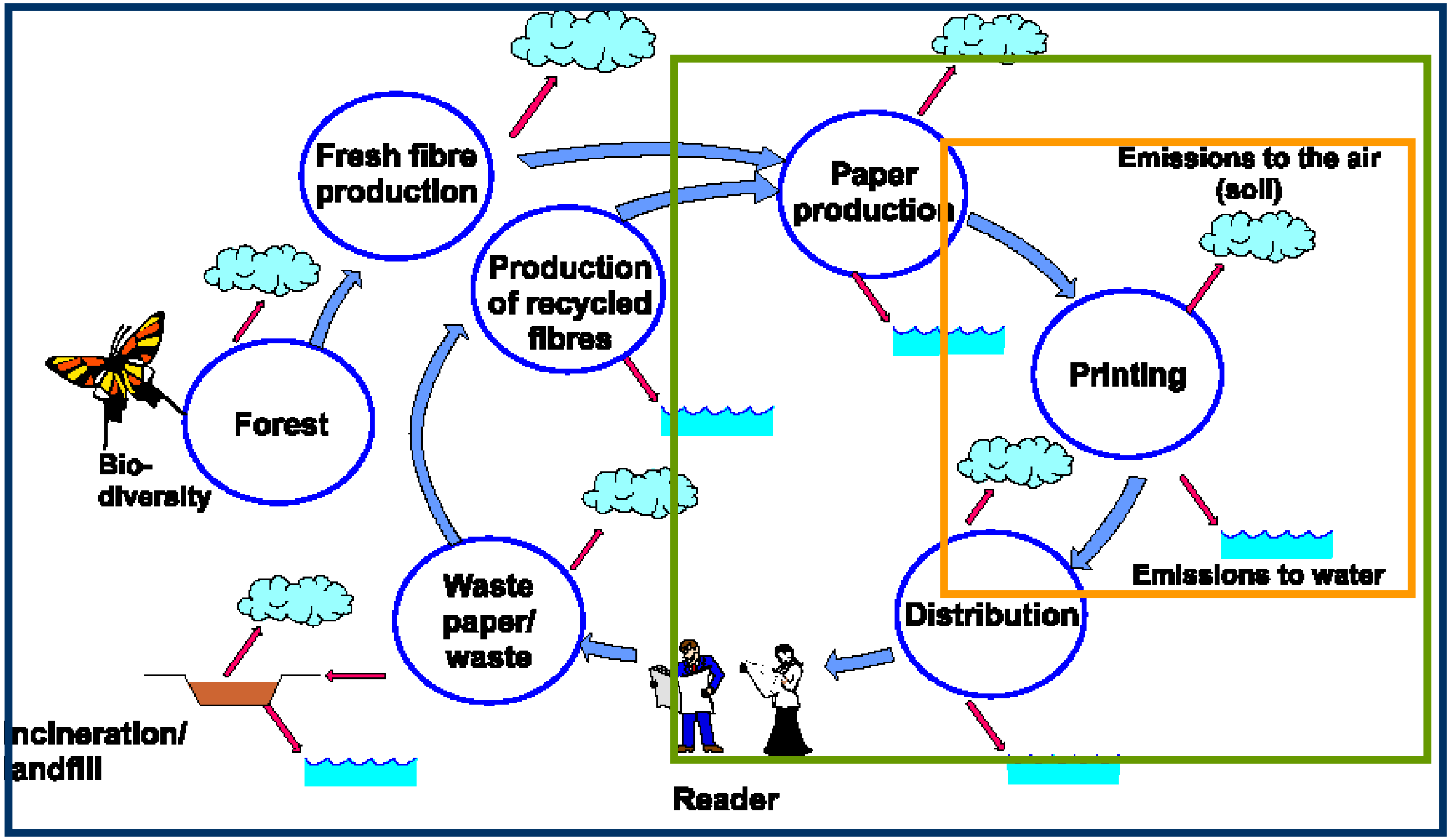
Goal definition & scoping

- Purpose of the LCA
  - Internal
  - External

Goal definition & scoping

- System Boundaries
  - Depends on scope of LCA
  - Depends on type of product and suitability for full LCA

Life-cycle – Identify the boundaries



Life-cycle stages

- Products can be evaluated through each stage of their life-cycle:
    - Extraction or acquisition of raw materials
    - Manufacturing and processing
    - Distribution and transportation
    - Use and reuse
    - Recycling
    - Disposal
- For each stage, identify inputs of materials and energy received; outputs of useful product and waste emissions
- Find optimal points for improvement – eco-efficiency

Goal definition & scoping

- Functional Unit
  - Quantitative measure
  - Crucial for comparative LCA’s

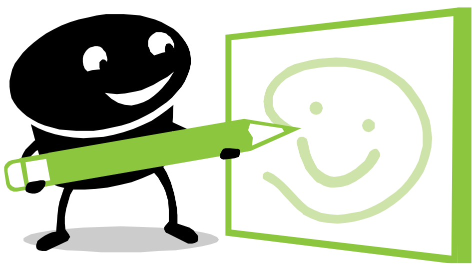
Function & Functional Unit

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”



Function and Functional Unit

- Where to draw the line?
- HUGE impact on results

- Compare one reusable bag to one single-use plastic bag? How many uses?
- What are some reasonable assumptions?

- # of bags required to carry 70 items home each week for one year???

Goal and Scope Definition

- This phase also includes an assessment of the data quality and establishing the specific data quality goals.

- “Goal and Scope Definition” are constantly reviewed and refined during the process of carrying out an LCA as additional data becomes available.

2

Components of LCA

Inventory Analysis:

is a systematic, objective, stepwise procedure for quantifying energy and raw material requirements, atmospheric emissions, waterborne emissions, solid wastes, and other releases for the entire life cycle of a product, package, process or activity. (Curran 1996, Vigon 1993)

Data intensive exercise and require systematic approach

2 Inventory Analysis

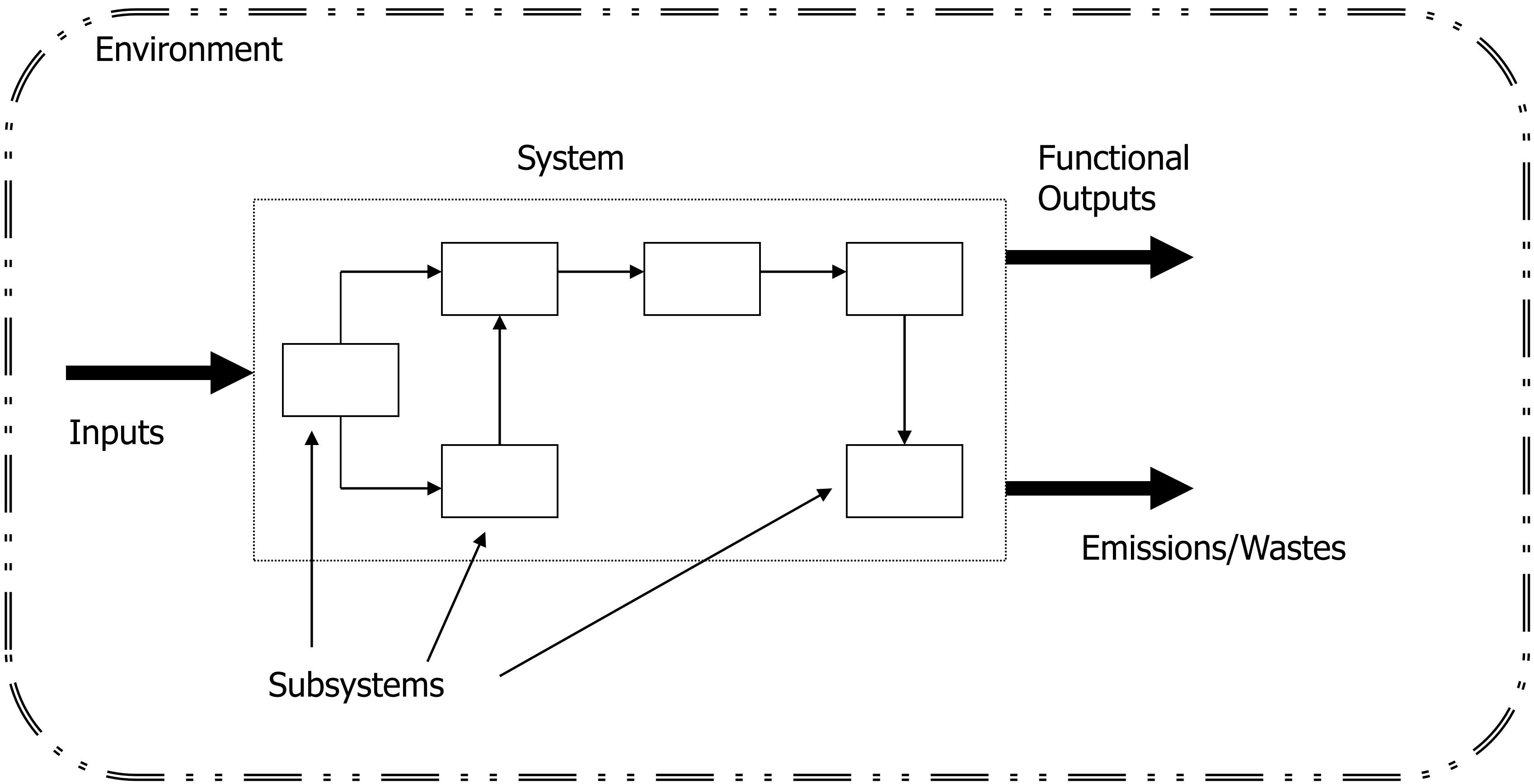
- A system is defined as a collection of materially and energetically connected operations which performs some defined function.

- The system is separated from the environment by a system boundary

Life Cycle Inventory Analysis

- Detailed system characterisation involves its disaggregation into a number of interlinked subsystems.
- Depending on the data available, the subsystems can represent the unit operations or a group of units.

Life Cycle Inventory Analysis



Life Cycle Inventory Analysis

- Environmental burdens are then quantified for each subsystem according to the formula

$$B_j = \sum_{i=1}^{i} bc_{j,i} x_i$$

  - Where $bc_{j,i}$ is burden j from activity i and x_i is a mass or energy flow associated with that activity

Data Collection
Life Cycle Inventory Analysis

- **Time-sensitive**: past 5 years
- **Geographical**: does it match the location from the goal
- **Technology**:
- **Representativeness**: reflects population of interest
- **Consistency**: matches the procedure
- **Reproducibility**: another person could find it

Never Forget . . . .

- **Accuracy:** Quantified values are correct
- **Precision:** The consistent reproducibility of a measurement
- **Completeness:** Covers all the areas outlined in the scope

2 Problems with Inventory Analysis

- The inventory phase usually takes a great deal of **time and effort** and mistakes are easily made.
- There exists published data on impacts of different materials such as plastics, aluminum, steel, paper, etc.
  - However, the data is often **inconsistent** and not directly applicable due to different goals and scope.
  - It is expected that both the quantity and quality of data will improve in the future.
- Results are **generalized improperly**.

3 Components of LCA

Impact Assessment:

- The environmental burdens quantified in "Inventory Analysis" are translated into the related environmental impacts.

This is carried out within the following steps

- Classification
- Characterisation
- Normalisation
- Valuation

3 Impact Assessment

- Classification
  - Involves the aggregation of environmental burdens into a smaller number of environmental impact categories to indicate their potential impacts on human and ecological health and the extent of resource depletion.
  - The aggregation is done on the basis of the potential impacts of the burdens so that one burden can be associated with a number of impacts; eg Volatile Organic Compounds (VOC's) contribute to both global warming and ozone depletion.
  - The approach used most widely for classification of the impacts is known as 'problem oriented', whereby the burdens are aggregated according to their relative contributions to the environmental effects they may have

3 Impact Assessment

- The impacts most commonly considered in LCA are
  - Non-renewable resource depletion
  - Global warming
  - Ozone depletion
  - Acidification
  - Eutrophication
  - Photochemical oxidant formation
  - Human toxicity
  - Aquatic toxicity

Impacts: Regional and Local

3 Impact Assessment

- Characterisation
  - Involves the quantification of the impact of interest relative to a reference substance.
  - In the example we examined we look at the Global Warming Potential of the Products life cycle relative to CO2 emissions. Takes place using the formula

$$E_k = \sum_{j=1}^{j} ec_{k,j} B_j$$

$ec_{k,j}$ represents the relative contribution of burden B_j to impact E_k

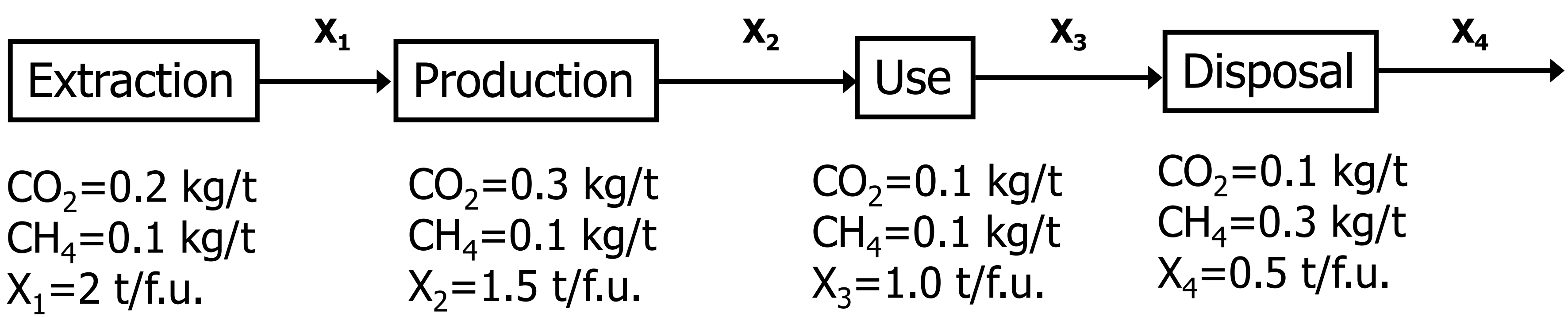
Classification Factors for Selected Burdens

Table A.1 *Classification factors for selected burdens**

Burdens	Resource depletion (world reserves)	Global warming GWP 100 years (equiv. to CO_2)	Ozone depletion ODP (equiv. to CFC-11)	Acidification AP (equiv. to SO_2)	Eutrophication EP (equiv. to PO_4^{3-})	Photochemical smog POCP (equiv. to ethylene)	Human toxicity	Aquatic toxicity (m^3/mg)
Coal reserves	8.72E+13 t							
Oil reserves	1.24E+11 t							
Gas reserves	1.09E+14 m^3							
CO							0.012	
CO_2		1						
NO_x				0.7	0.13		0.78	
SO_2				1			1.2	
HC excluding CH_4						0.416	1.7	
CH_4		21				0.007		
Aldehydes						0.443		
Chlorinated HC		400	0.5				0.98	
CFCs		5000	0.4				0.022	
Other VOCs		11	0.005			0.007		
As							4700	
Hg							120	
F_2							0.48	
HCl				0.88				
HF				1.6			0.48	
NH_3				1.88			0.02	
As							1.4	1.81E+08
Cr							0.57	9.07E+08
Cu							0.02	1.81E+09

Calculating Environmental Burdens & Impacts in LCA - Example

- The system in this example has one functional output and each activity *i* from extraction of raw materials to final disposal generates a certain amount of CO_2 and CH_4.



Calculating Environmental Burdens & Impacts in LCA - Example

- Using the Environmental Burdens equation the total environmental burdens per functional unit related to the emissions of CO_2 and CH_4 are therefore

$B_{CO2} = \sum bc_{CO2} \cdot x_i = (0.2)2+(0.3)1.5+(0.1)1+(0.1)0.5 \rightarrow B_{CO2} = 1.0$ kg/tFU

$B_{CH4} = \sum bc_{CH4} \cdot x_i = (0.1)2+(0.1)1.5+(0.1)1+(0.3)0.5 \rightarrow B_{CH4} = 0.6$ kg/tFU

Calculating Environmental Burdens & Impacts in LCA - Example

The total Environmental Impact = E_{GWP}

$$E_{GWP} = (ec_{CO2})B_{CO2} + (ec_{CH4})B_{CH4}$$

$$= 1(1) + 21(0.6)$$

$$\rightarrow E_{GWP} = 13.6 \text{ kg } CO_2 \text{ equiv / FU}$$

Impact Assessment

- Normalisation
  - The impacts can be normalised with respect to the total emissions or extractions in a certain area over a given period of time.
  - This can help to asses the extent to which an activity contributes to the regional or global environmental impacts.
  - Should be interpreted with care due to lack of reliable data.

Impact Assessment

- Valuation
  - Each impact is assigned a weight which indicates its relative importance. As a result the environmental impacts are aggregated into a single environmental impact function **EI**

$$EI = \sum_{k=1}^{k} w_k E$$

Where w_k is the relative importance of impact E_k

3. Impact Assessment

- Valuation
  - A number of problems at philosophical and practical level in the realisation of this and there is no consensus on the best way to aggregate the environmental impacts into a single EI figure.
  - Some people argue that valuation should not be carried out at all as it obscures information and that considering the impact in a disaggregated form enhances the transparency of the decision making based on LCA results

4. Interpretation/Improvement Assessment

- This phase is aimed at system improvements and innovation and it includes the following steps:
  - Identification of major burdens and impacts
  - Identification of ‘hot spots’ in the life cycle
  - Sensitivity analysis
  - Evaluation of findings and recommendations

4. Interpretation

- Sensitivity Analysis
  - Indicates the level of reliability of the LCA
    - Data availability and reliability
    - Uncertainties
    - Data gaps

Streamlining LCAs

A full LCA can cost from $10,000 to several hundred thousands $ for each product studies (Todd, 1996)

By reducing the LCA at either or both ends from the actual production steps (Raw material acquisition or final disposal or both) may be ignored in the streamlined LCA (Curran 1996)

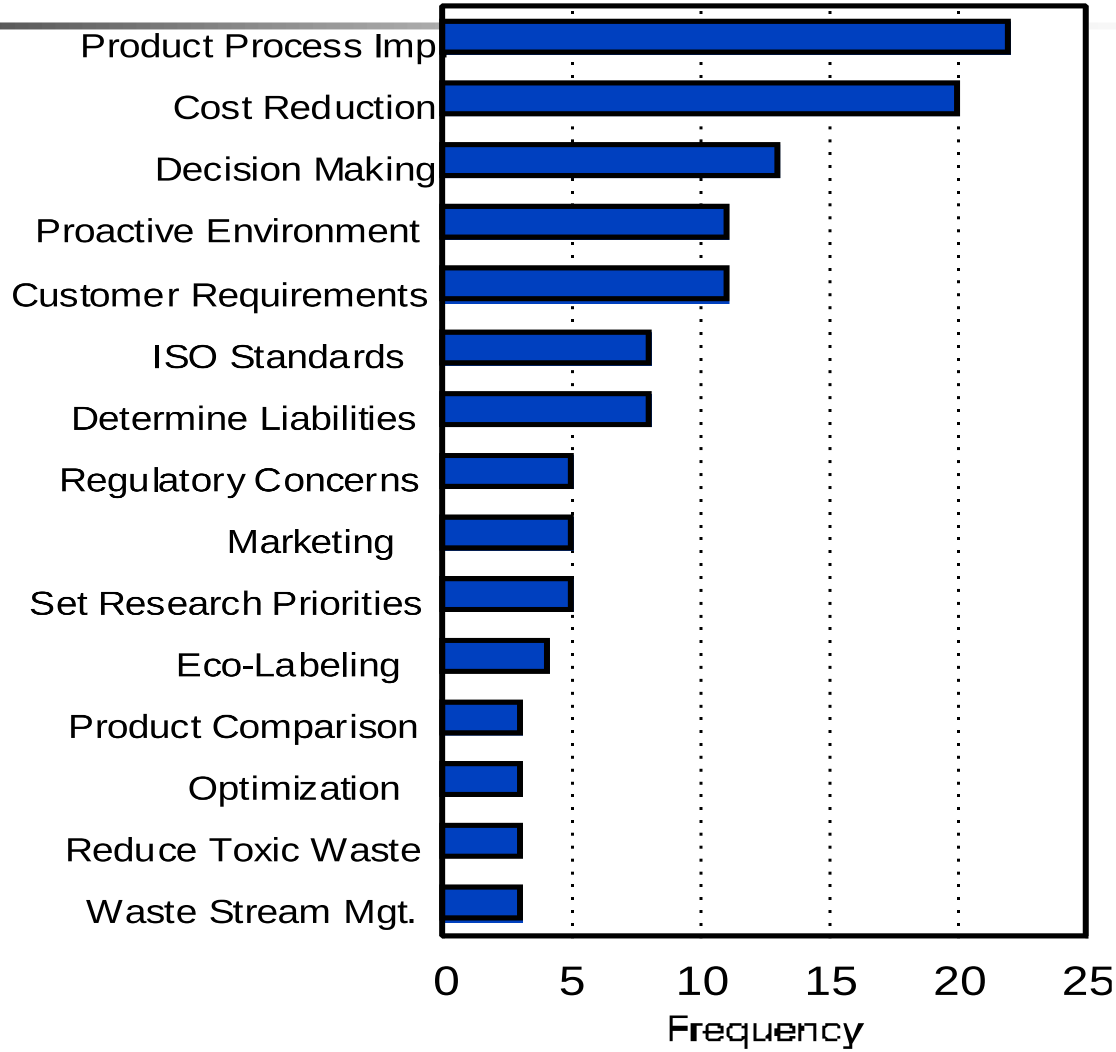
Why Conduct an LCA?

Benefits and Drawbacks

LCA and the Regulatory Process

- LCA is voluntary in most of the countries
- Its use is limited, but expanding
- LCA is mandatory in some European countries
- Global market means LCA will eventually be required for all products

Motivations for Implementing LCA

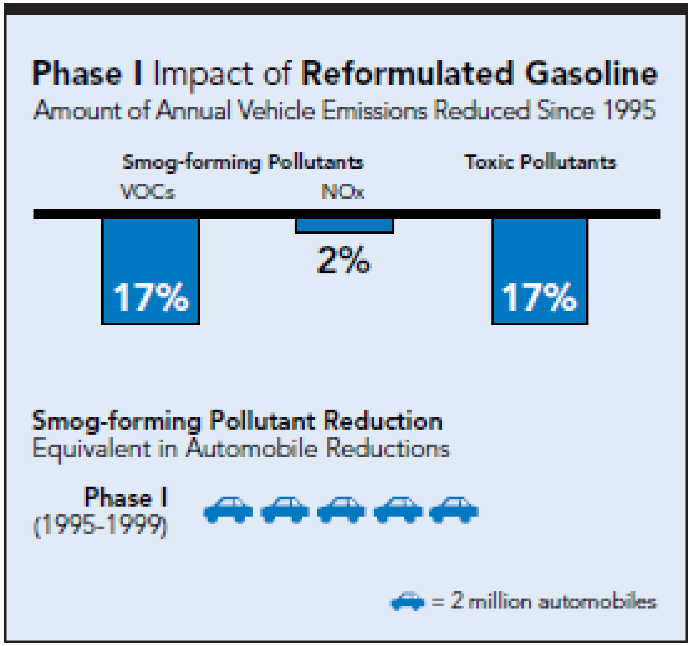


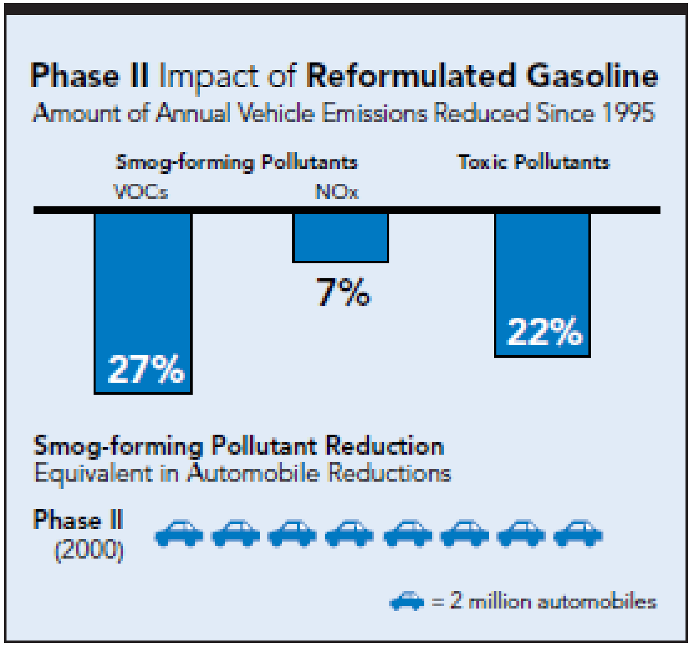
Life-cycle –helps avoid shifting the issues

- Looking at the entire life-cycle helps ensure reducing waste at one point does not simply create more waste at another point in the life-cycle
- **Issues may be shifted** – intentionally or inadvertently – among:
  - Processes or manufacturing sites
  - Geographic locale
  - Different budgets and planning cycles (first cost)
  - Environmental media – air, water, soil (MTBE)
  - Sustainability dimension: economic, social, environmental burdens

Methyl tertiary butyl ether - MTBE

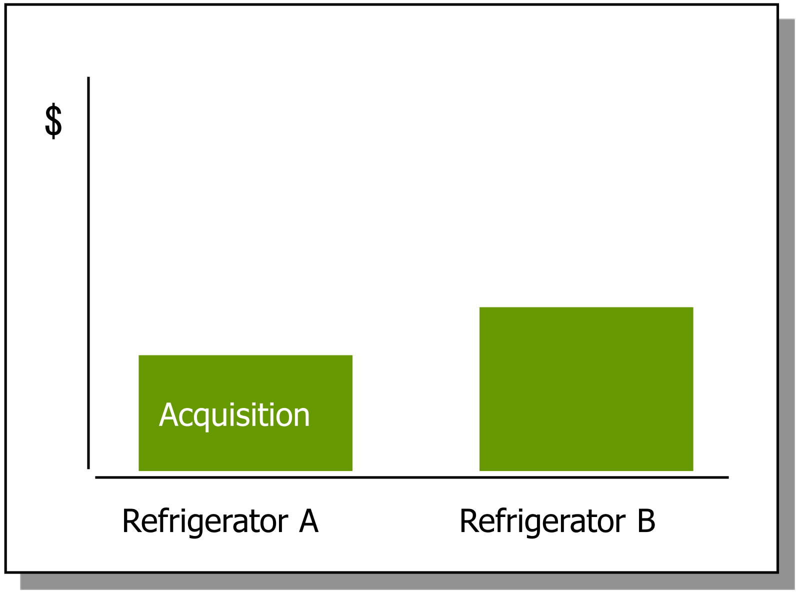
Replaced lead in gasoline. Good!

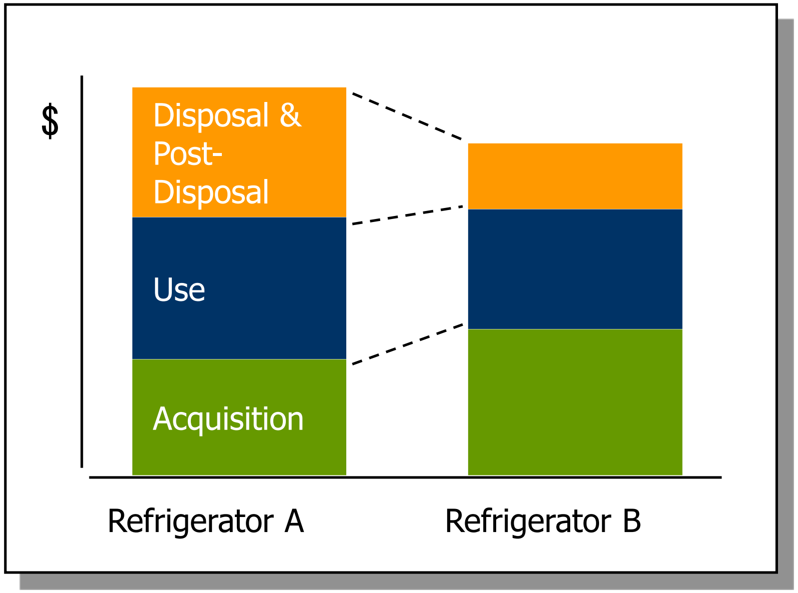




- But, MTBE itself is toxic if not fully combusted
- MTBE measured in the environment (evaporated from gasoline or leaking from storage tanks, lines and fueling stations)
- MTBE in potable water supplies is of most concern (lakes, reservoirs, and groundwater)
- MTBE concentrations in some cases already exceed standard indicators for potable water, including "taste and odor" and "human health".
- Insufficient amount of information on its long-term toxicity, carcinogenicity and reproductive toxicity, to humans, animals and ecosystems

Life-cycle – identify issues and costs





Purchase Price

Refrigerator A appears cheaper

Price + Life-Cycle Costs

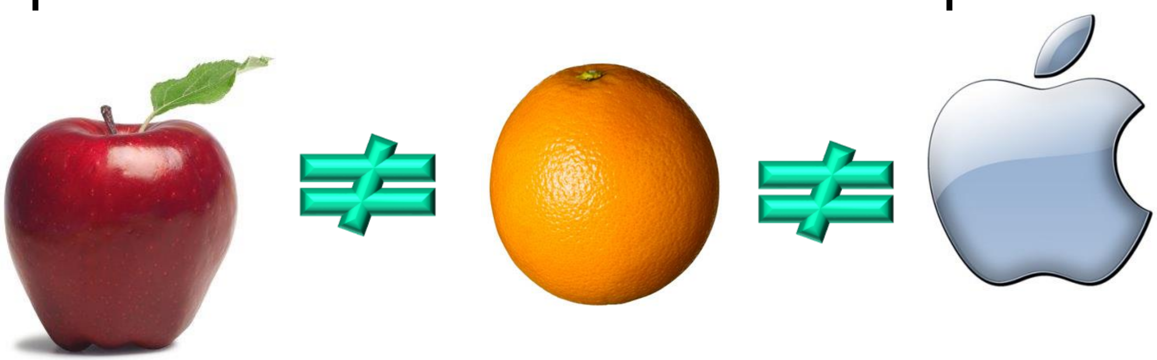
Refrigerator B costs less overall

Benefits Of LCA

- Companies can claim one product is better than another on the basis of LCA
- LCA inventory process helps to narrow in on the area where the biggest reductions in environmental emissions can be made
- Can be used to reduce production costs

Drawbacks of LCA

- Using LCA to compare products is like comparing apples to oranges.
  - For example, which is worse: a product that pollutes the air by consuming energy from coal-fired power plants or one that disrupts ecosystems by consuming energy from massive hydroelectric dam projects? Both types of pollution should be minimized if possible.



Drawbacks (cont.)

- Comparison between heavy energy demand and heavy water use: which imposes greater environmental burden?
- How can the use of non-renewable mineral resources like oil or gas (the ingredients of plastics) be compared with the production of softwoods for paper?
- How should the combined impacts of the landfilling of wastes (air and groundwater pollution, transport impacts etc) be compared with those produced by the burning of wastes for energy production (predominantly emissions to air)?

Drawbacks (cont.)

- LCAs may give different and sometimes contradictory conclusions about similar products.
- Recycling adds more complexity to LCA.

Conclusions – why take a life-cycle approach?

- Systems perspective
- Integrates environment into core business issues
- Efficiency
- Innovation
- Better return on investment
- Engage stakeholders – investors, customers, employees

* www.ciwmb.ca.gov/EPP/LifeCycle/default.htm

Databases and Software's Used in LCA

Sl.	Tool	Developer	URL
1	BEES 3.0	Fire Research Laboratory	http://www.bfrl.nist.gov/oae/software/bees.html
2	Ecoinvent 1.2	Swiss Centre for Life Cycle Inventories	http://www.ecoinvent.ch
3	EDIP PC-Tool	--	http://www.lca-center.dk
4	eiolca.net	--	http://www.eiolca.net
5	EPS 2000 Design System	Assess Ecostrategy Scandinavia AB	http://www.assess.se/
6	GaBi 4	PE Europe GmbH and of	http://www.gabi-software.com/software.html
7	KCL-ECO 4.0	KCL	http://www1.kcl.fi/eco/softw.html
8	MIET 3.0	Centre of Environmental Science	http://www.leidenuniv.nl/cml/ssp/software/miet/index.html
9	SimaPro 6.0	PRé Consultants	http://www.pre.nl/simapro.html
10	TEAM™4.0	Ecobalance	http://www.ecobalance.com/uk_lcatool.php
11	Umberto	ifu Hamburg GmbH	http://www.ifu.com/en/products/umberto
12	US LCI Data	National Renewable Energy Lab	http://www.nrel.gov/lci