CM4310 Chemical Process Safety/Environment

Life Cycle Assessment: Chapter 13

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Presentation Outline

- Why is LCA Important to the Chemical Industry
- An Overview of Life Cycle Assessment
- Goal and Scope Definition
- Life Cycle Inventory (LCI)
- Life Cycle Impact Assessment (LCIA)
- Industrial Perspective: BASF Eco-efficiency

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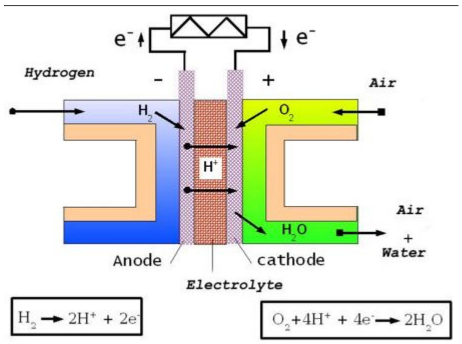
Why is LCA Important?
Sustainable Energy and Fuel Cells

Fuel Cells



Hydrogen is one of the most common atoms on the planet

H_2O is only emission

http://upload.wikimedia.org/wikipedia/commons/thumb/1/14/Fuelcell.en.JPG/450px-Fuelcell.en.JPG

But,…
Where does the H_2 come from? What are impacts of H_2 production?

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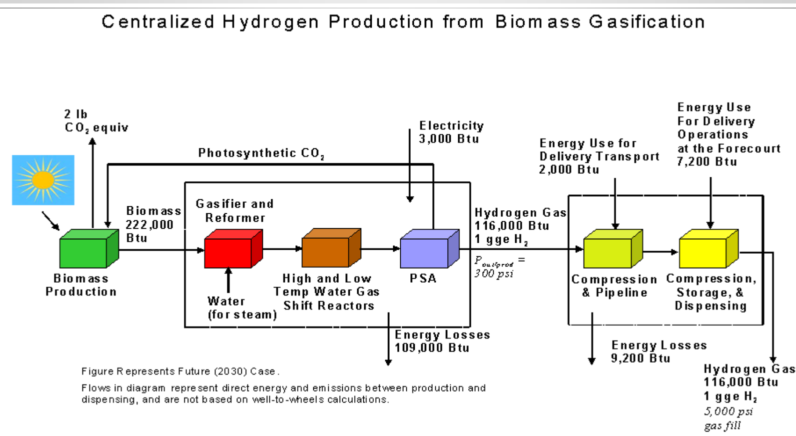
Why is LCA Important?
Hydrogen production.



*www.**hydrogen**.energy.gov/docs/cs_central_biomass_gasification.doc*

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Why is LCA Important? Hydrogen production options

- Solar photovoltaics with water electrolysis.
- Electricity generation by coal or nuclear with water electrolysis
- Gasification of coal and hydrogen recovery
- Gasification of natural gas and hydrogen recovery
- Gasification of biomass and hydrogen recovery
- Microbial production of hydrogen from biomass

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Motivation for Life Cycle Assessment

- Reduce environmental impacts of products over their life cycle.
- Acquire an understanding of an entire product system
- Conserve resources and ecosystems
- Develop and apply clean technologies
- Optimize recycle of materials and waste
- Identify the best pollution abatement or prevention techniques

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Uses of Life Cycle Assessment

- Decision-making in industry and government
  - » Strategic planning, investments, product/process design
- Marketing
  - » Environmental claim, ecolabeling
- Communication with stakeholders
  - » Shareholders, regulatory agencies, policy makers
- Research and Development
  - » Early evaluations of projects, periodic re-evaluations

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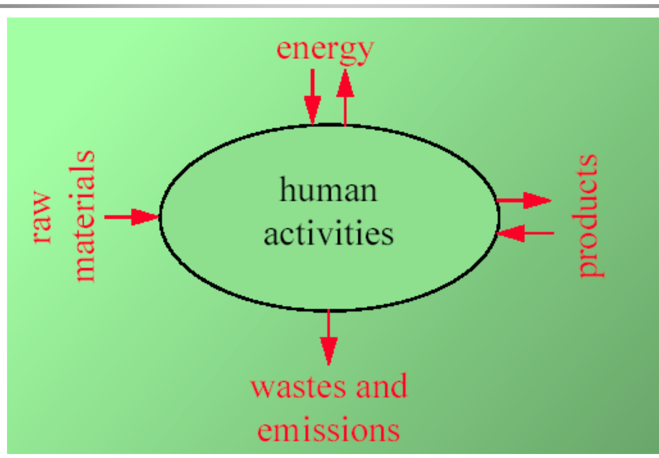
Overview of Life Cycle Assessment



D.T. Allen, University of Texas – Austin
"Life Cycle Assessment: Lesson 1"

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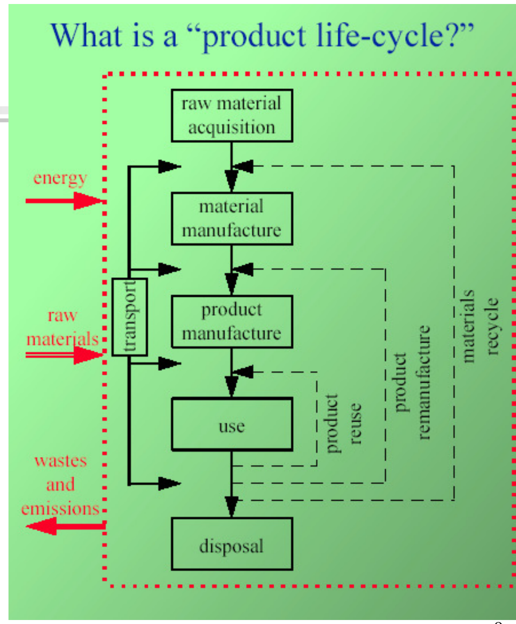
Life Cycle Stages of a Product



D.T. Allen, University of Texas – Austin
"Life Cycle Assessment: Lesson 1"

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International Standards for Life Cycle Assessment

- International Organization for Standardization
  - ISO 14040: Environmental management – Life cycle assessment – *Principles and framework*
  - ISO 14041: *Goal and scope definition and inventory analysis*
  - ISO 14042: *Life cycle impact assessment*
  - ISO 14043: *Life cycle interpretation*

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ISO 14040 Principles and framework

- ISO 14040
  - » Key features of the LCA methodology
    - – *Scope must be from cradle to grave for products*
    - – *LCA studies should be transparent*
    - – *Specific requirements for comparative assertions*
  - » Definition of a *functional unit*
  - » Goal and scope of the study
    - – *Goal: intended application, audience, reasons for the study*
    - – *Scope: product system, types of impacts, data quality*

Functional Unit

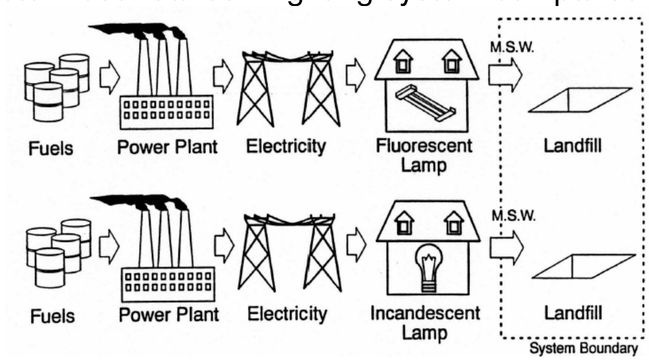
- Functional Unit examples
  - » Paper grocery bag versus plastic (polyethylene) bag
    - – *What is the function? - Carrying groceries*
    - – *How many bags are needed to carry a given amt. of groceries?*
    - – *Equivalence: 2:1 $\pm$ 1 , plastic bags to paper bag.*
  - » Coating systems comparison
    - – *What is the function? – surface protection, appearance*
    - – *What quantity of coating is needed to cover 1000 wooden doors?*

Functional Unit (cont.)

- Functional Unit examples
  - » Mineral water packaging (PET/glass bottles; aluminum cans)
    - – *What is the function? – containment for a beverage product*
    - – *How many bottles/pkgs. are needed for a 1000 liters?*
  - » Incandescent versus fluorescent lamps
    - – *What is the function? – lighting of a space*
    - – *How many lamps and of what wattage are equivalent?*

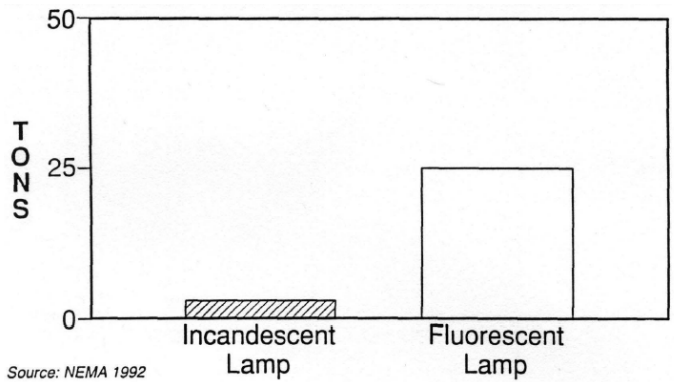
Scope of the study

- System boundaries – lighting system comparison



Allen and Shonnard, Green Engineering: Environmentally Conscious Design of Chemical Processes, Prentice Hall, 2002

System boundaries (Hg emissions)

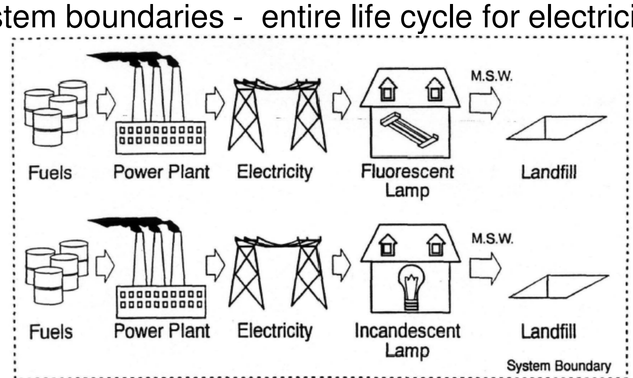


Source: NEMA 1992

D.T. Allen, University of Texas – Austin
"Product Life Cycle Assessment"

Scope of the study

- System boundaries - entire life cycle for electricity



Allen and Shonnard, Green Engineering: Environmentally Conscious Design of Chemical Processes, Prentice Hall, 2002

System boundaries - entire life cycle for electricity

- Incandescent lights release 4 – 10 times more mercury to the environment than fluorescent lamps when the entire life cycle is considered.
- US household lighting requirements consume about 3% of total US electricity sales to all sectors (total sales is 12 quadrillion BTU/yr, page 219 of Annual Energy Review 2002, Energy Information Agency, US Department of Energy). What is savings potential?

www.eia.doe.gov/emeu/lighting/chapt2.html

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System boundaries - entire life cycle for electricity & bulbs

- Sketch out life cycle stages for this system
- Under each stage, list the major processes to include in the inventory for both types of bulb
- Discuss issues in defining the functional unit for this LCA comparison.
- What bulb characteristics will need to be measured to begin inventory data collection?

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Summary of LCA Introduction

- Motivation for LCA: Reduce environmental impacts of products over their life cycle.
- LCA is used for decision-making, communication, marketing, and strategic planning
- ISO 14040-14043 cover all elements of LCA, from planning/execution to methodologies.
- Setting of goals and scope in LCA studies are among the most important elements of an LCA

Life Cycle Inventory (LCI)

- ISO 14041
- Categories of inventory data
- Allocation method
- Data quality requirements

Categories of inventory data

- Energy resources (process heating and electricity)
  - » *Oil, natural gas, coal, nuclear, hydro, wind, solar, biomass*
- Other raw materials
  - » *Fe, NaCl, water, air, $CaCO_3$, Ni, Zn, etc.*
- Emissions
  - » *to air, water, land*
- Other categories
  - » *Land area use (often used in Europe and Japan)*

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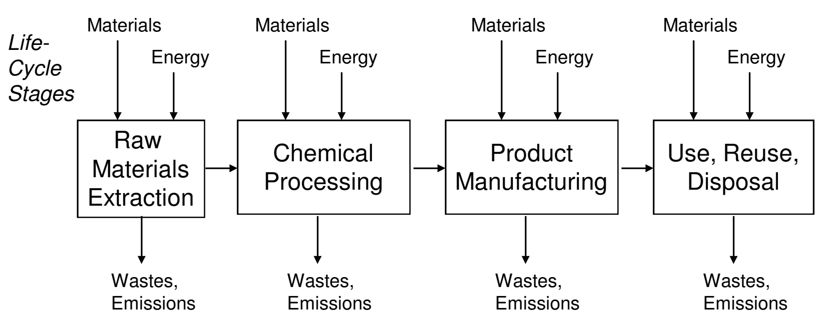
Inventory at each stage



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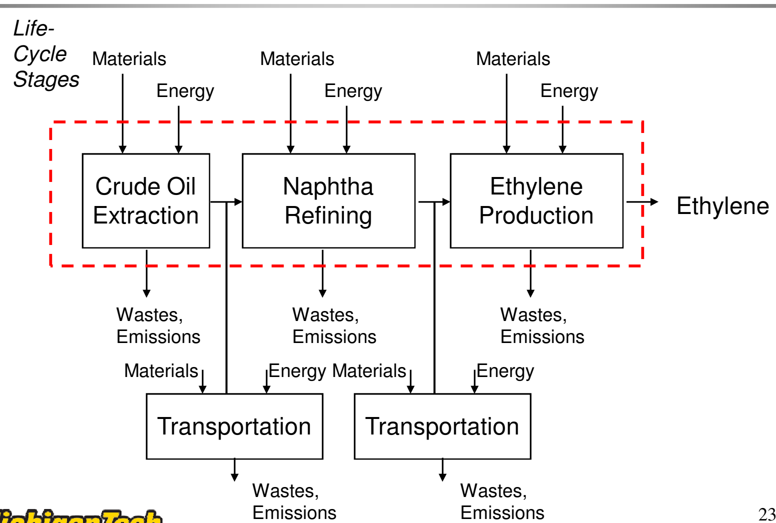
Inventory for ethylene production



Inventory categories (ethylene example)

Allen and Shonnard, Green Engineering: Environmentally Conscious Design of Chemical Processes, Prentice Hall, 2002

Table 13.2-1 Life-Cycle Inventory Data for the Production of 1 kg of Ethylene (Boustead, 1993).

Category	Input or Output	Unit Average
Energy content fuels, MJ	Coal	0.94
	Oil	1.8
	Gas	6.1
	Hydroelectric	0.12
	Nuclear	0.32
	Other	<0.01
	Total	9.2
Feedstock, MJ	Coal	<0.01
	Oil	31
	Gas	29
	Total	60
Total Fuel + Feedstock		69

Boustead, I., Eco-profiles of the European Plastics Industry, Report 1-4, European Center for Plastics in the Environment, Brussels, May 1993.

Inventory categories (ethylene example), cont.

Allen and Shonnard, Green Engineering: Environmentally Conscious Design of Chemical Processes, Prentice Hall, 2002

Raw Materials, mg	Iron ore	200
	Limestone	100
	Water	1,900,000
	Bauxite	300
	Sodium chloride	5,400
	Clay	20
	Ferromanganese	<1
Air emissions, mg	Dust	1,000
	Carbon monoxide	600
	Carbon dioxide	530,000
	Sulfur oxides	4,000
	Nitrogen oxides	6,000
	Hydrogen sulfide	10
	Hydrogen chloride	20
	Hydrocarbons	7,000
	Other organics	1
	Metals	1

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Inventory categories (ethylene example), cont.

Allen and Shonnard, Green Engineering: Environmentally Conscious Design of Chemical Processes, Prentice Hall, 2002

Water emissions, mg	Chemical oxygen demand	200
	Biological oxygen demand	40
	Acid, as H+	60
	Metals	300
	Chloride ions	50
	Dissolved organics	20
	Suspended solids	200
	Oil	200
	Phenol	1
	Dissolved solids	500
	Other nitrogen	10
Solid waste, mg	Industrial waste	1,400
	Mineral waste	8,000
	Slags and ash	3,000
	Nontoxic chemicals	400
	Toxic chemicals	1

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Allocation of environmental burdens

Some fraction (a) of the environmental burdens input to the process by C and emitted from the process in stream D are allocated to product A. The remaining fraction (b) are allocated to product B.

The allocation is usually based on mass stoichiometry

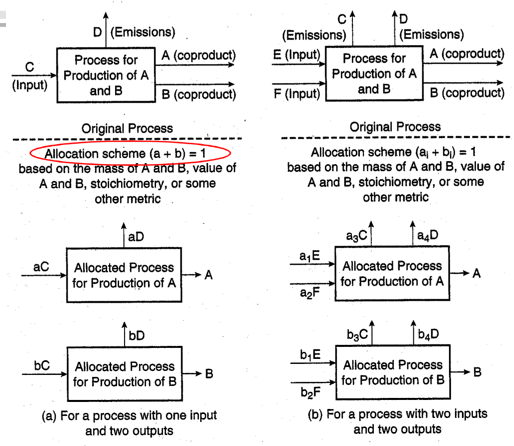

Figure 13.2-3 Allocating material use, energy use, and emissions among multiple products that are manufactured in the same processes can be difficult.

Allen and Shonnard, Green Engineering: Environmentally Conscious Design of Chemical Processes, Prentice Hall, 2002

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Data quality requirements

- Time-related coverage of data:
  - » *How current is data? Averaged over what period?*
- Geographic coverage of data collection:
  - » *Local, regional, national, continental, global?*
- Technology coverage of data:
  - » *Average of process mix?, best available technology?*

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Sources of inventory data

Boustead Model 5.0
Boustead Consulting Ltd.
Black Cottage, West Grinstead
HORSHAM, West Sussex, RH13 8GH, UK
http://www.boustead-consulting.co.uk/

SimaPro 7.0 LCA software
PRé Consultants
Plotterweg 12 · 3821 BB
Amersfoort, The Netherlands
http://www.pre.nl/

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Sources of inventory data (cont.)

Franklin Associates, Ltd.
4121 W. 83rd Street, Suite 108
Prairie Village, KS 66208
(913) 649-2225 Ext. 221
http://www.fal.com/

LCAccess
National Risk Management Research Laboratory
U.S. Environmental Protection Agency
http://www.epa.gov/ORD/NRMRL/lcaccess/

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Emission estimation from process units

- Emissions to Air
  - » Emission factors from US EPA
    - Reactors, separation devices, fugitive sources, utilities
    - Air ClearingHouse for Inventories and Emission Factors
      - Air CHIEF CD http://www.epa.gov/ttn/chief/index.html
  - » Process simulation software
    - **HYSYS, ASPEN**
      - Gas streams exiting process (absorption columns, ..)
- Emissions to Air/Water/Land
  - » Wastewater treatment, EPI Suite software
    - Fate of pollutants in wastewater treatment

Appendix F in:
Allen and Shonnard, Green Engineering: Environmentally Conscious Design of Chemical Processes, Prentice Hall, 2002

Inventory data by survey

- From production units
  - » Energy consumption of all types
  - » All raw material inputs ratio'd to product output
  - » Emissions to air (measured values preferred)
  - » Wastewater flows and concentrations
  - » Solid waste (conventional, hazardous, toxic)

Uncertainty of inventory data

- Inventory databases / software tools
  - » National coverage is routine, regional is not.
  - » Facility - facility variability is high
  - » Energy and raw materials is higher quality
  - » Emissions (overall) data are of lower quality
- Emission factors and estimation (EPA)
  - » Fuel combustion-related emissions are of higher quality (CO_2, CO, NOx, SO_2)
  - » Factors for process units are order of magnitude estimates

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Summary of life cycle inventory

- Possibly the most challenging part of LCA.
- ISO 14041 provides guidelines
- Categories: energy, raw materials, …
- Commercial software tools are available, but the most accurate inventories may be generated internally for manufacturers.
- Time-related, geographic, and technology coverage of inventory data – reduce uncertainty

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Life Cycle Impact Assessment (LCIA)

- ISO 14042
- Mandatory requirements for LCIA
  - » *Identify* impact categories,
  - » *classify* inventory elements into impact categories,
  - » *characterize* impacts for each inventory element
- Optional features of LCIA
  - » *normalization*
  - » *valuation*

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Identification of Impact Categories

Global warming

Stratospheric ozone depletion

Smog formation (O_3)

Acidification

Human health impacts

Ecosytem health

Eutrophication

Biodiversity

Resource depletion

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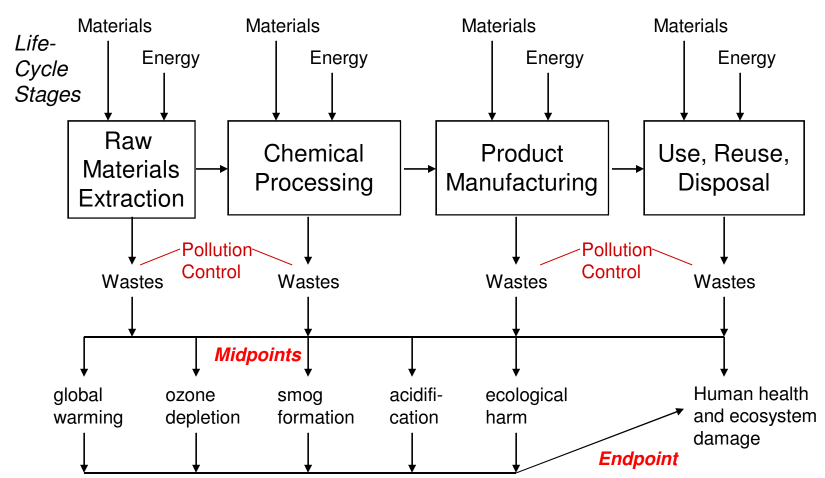
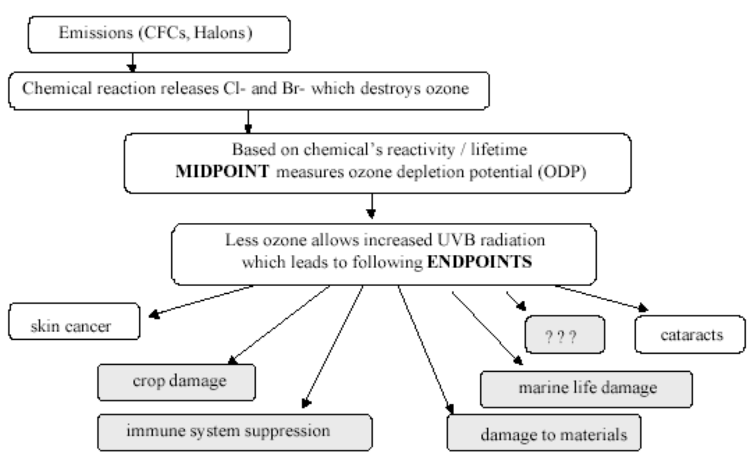
Scope of Environmental Impacts

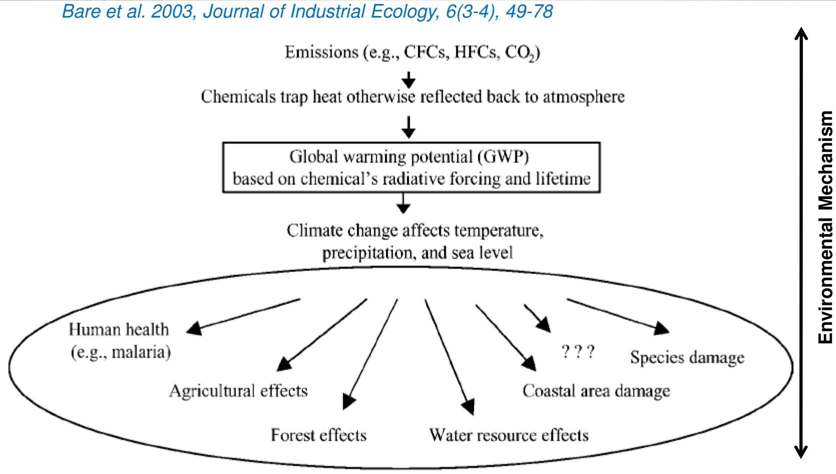


Midpoint versus Endpoint



Category Indicators:
Midpoints and Endpoints –
Global Warming

Bare et al. 2003, Journal of Industrial Ecology, 6(3-4), 49-78



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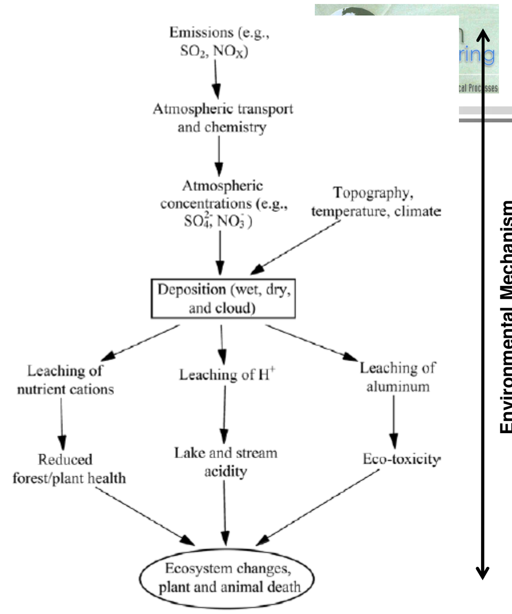
Category Indicators:
Midpoints and Endpoints –
Acidification

Bare et al. 2003, Journal of Industrial Ecology, 6(3-4), 49-78



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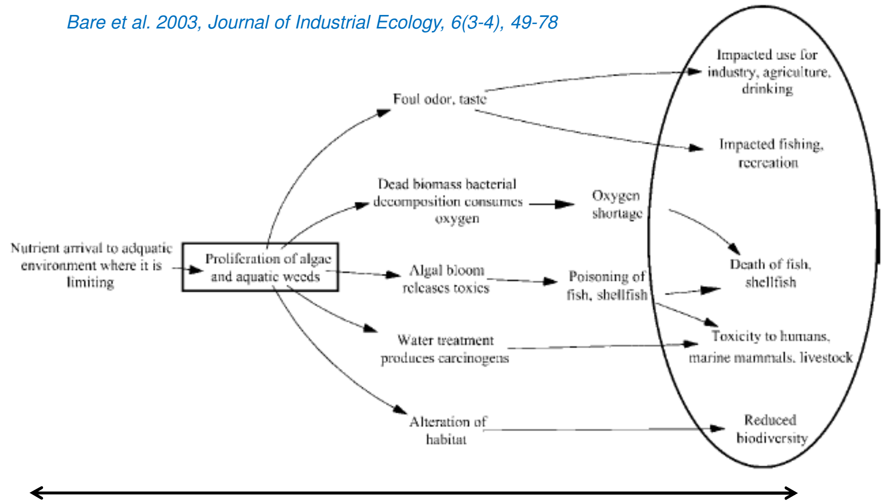
Category Indicators:
Midpoints and Endpoints - Eutrophication

Bare et al. 2003, Journal of Industrial Ecology, 6(3-4), 49-78



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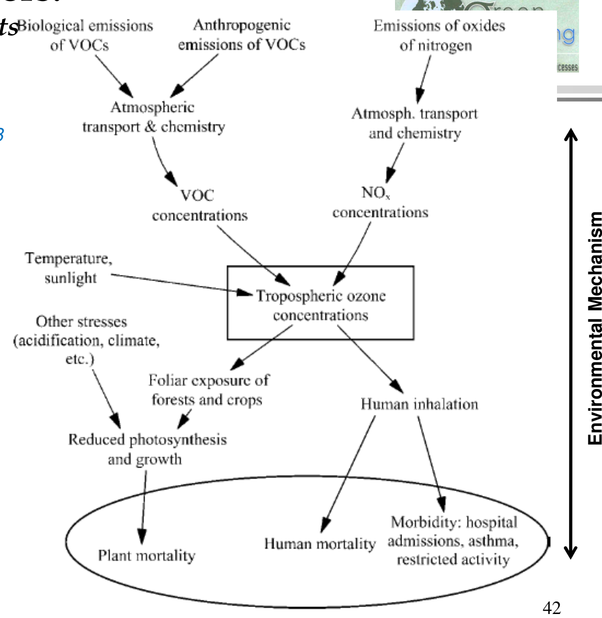
Category Indicators:
Midpoints and Endpoints
Tropospheric Ozone

Bare et al. 2003, Journal of Industrial Ecology, 6(3-4), 49-78



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Midpoint Indicators
Advantages /Disadvantages

- ISO 14042 allows indicators to be somewhere between inventory data and endpoint impacts
- Midpoint indicators are closer to the inventory data than endpoints
  - » *Environmental processes are less complicated to model*
  - » *Less uncertainty in describing the midpoint impacts*
- Midpoint indicators are less precise
  - » *Do not describe actual damage to human health / ecosystems*
  - » *Require greater knowledge of damage processes by user*
  - » *More difficult to interpret by decision makers*

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Midpoint Methods

- TRACI-Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts
  - » *Characterization factors included*
  - » *No Normalization or Weighting of categories*
- Eco-Indicator 95
  - » *Characterization factors included*
  - » *Normalization or Weighting of categories*
  - » *Weighting based on a "Distance to Target" approach*
  - » *Uncertainty whether Distance to Target weightings accurately represent sustainability*
- BASF Eco-efficiency Analysis Method

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Endpoint Indicators
Advantages /Disadvantages

- Endpoint indicators are further removed from the inventory data in terms of environmental processes
  - » *Environmental processes are more complicated to model*
  - » *More model uncertainty in describing the resulting impacts*
- Endpoint indicators are more precise
  - » *Describe actual damage to human health / ecosystems*
  - » *Requires less knowledge of damage processes by user*
  - » *Easier to interpret by decision makers*
- Eco-Indicator 99 from SimaPro7.0

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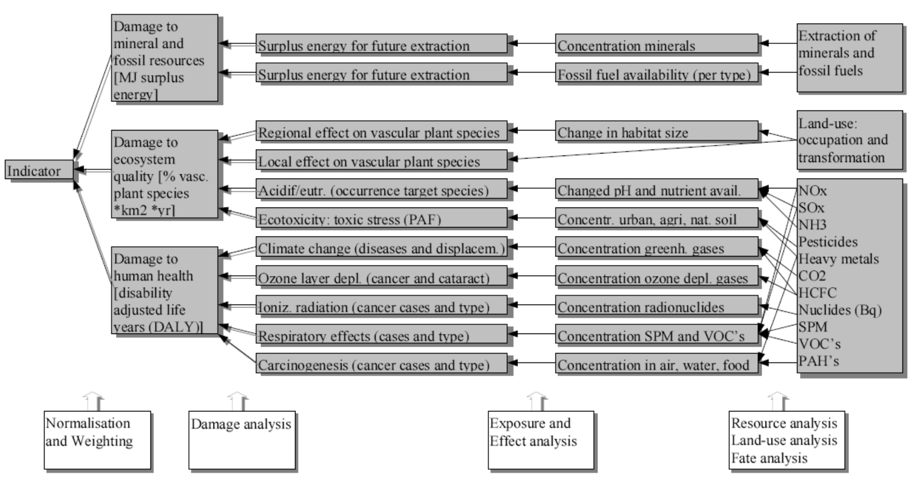
Eco-Indicator 99 Method:
An Endpoint Impact Assessment Method



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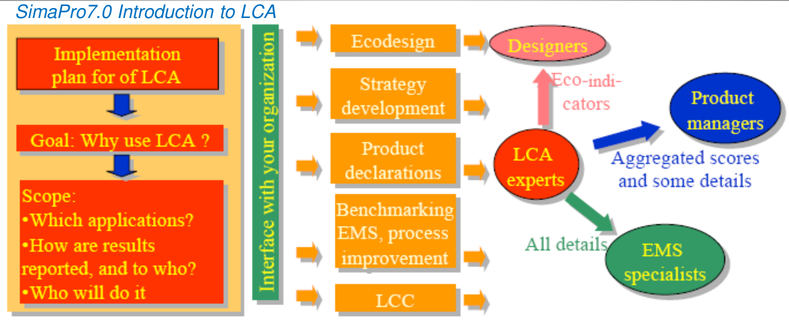
Life Cycle Impact Assessment (LCIA)

Deciding on an Impact Assessment Method

SimaPro7.0 Introduction to LCA



- LCIA: to gain an understanding of the potential environmental impacts of a product system.
- Goal and Scope of the LCA help decide the impact assessment method and categories

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Normalization

- How important are the life cycle impacts of a product or process compared to a regional or national benchmark?
  - » U.S. inventory of greenhouse gas emissions from the Department of Energy, US EPA, etc.
  - » U.S. inventory of all ozone depletion substances
  - » U.S. inventory of all cancer causing agents
  - » U.S. inventory of all non cancer causing health effects.

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Valuation approaches

Table 13.3-5 Strategies for Valuing Life-cycle Impacts (Christiansen, 1997).

Life-cycle impact assessment approach	Description
Critical volumes	Emissions are weighted based on legal limits and are aggregated within each environmental medium (air, water, soil).
Environmental Priority System (Steen and Ryding, 1992)	Characterization and valuation steps combined using a single weighting factor for each inventory element (see example below). Valuation based on willingness-to-pay surveys.
Ecological scarcities	Characterization and valuation steps combined using a single weighting factor for each inventory element. Valuation based on flows of emissions and resources relative to the ability of the environment to assimilate the flows or the extent of resources available.
Distance to target method	Valuation based on target values for emission flows set in the Dutch national environmental plan.

Surveys of decision-makers

Allen and Shonnard, Green Engineering: Environmentally Conscious Design of Chemical Processes, Prentice Hall, 2002

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Summary of life cycle impact assessment

- ISO 14042 provides guidelines
- *Identify* categories of environmental impacts, *classify* pollutants into categories, *characterize* potency of pollutants for impact categories.
- *Relative risk* calculation using emission estimation, environmental fate modeling, and impact potency.
- Commercial software tools are available (the same tools as shown in the inventory section).

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Summary of life cycle assessment

- Motivation for LCA: Reduce environmental impacts of products over their life cycle.
- LCA is used for decision-making, communication, marketing, and strategic planning
- ISO 14040-14043 cover all elements of LCA, from planning/execution to methodologies.
- Software tools are available to aid in LCA studies – SimaPro 7.0 is the most popular tool.