Life Cycle Assessment - LCA

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Agenda

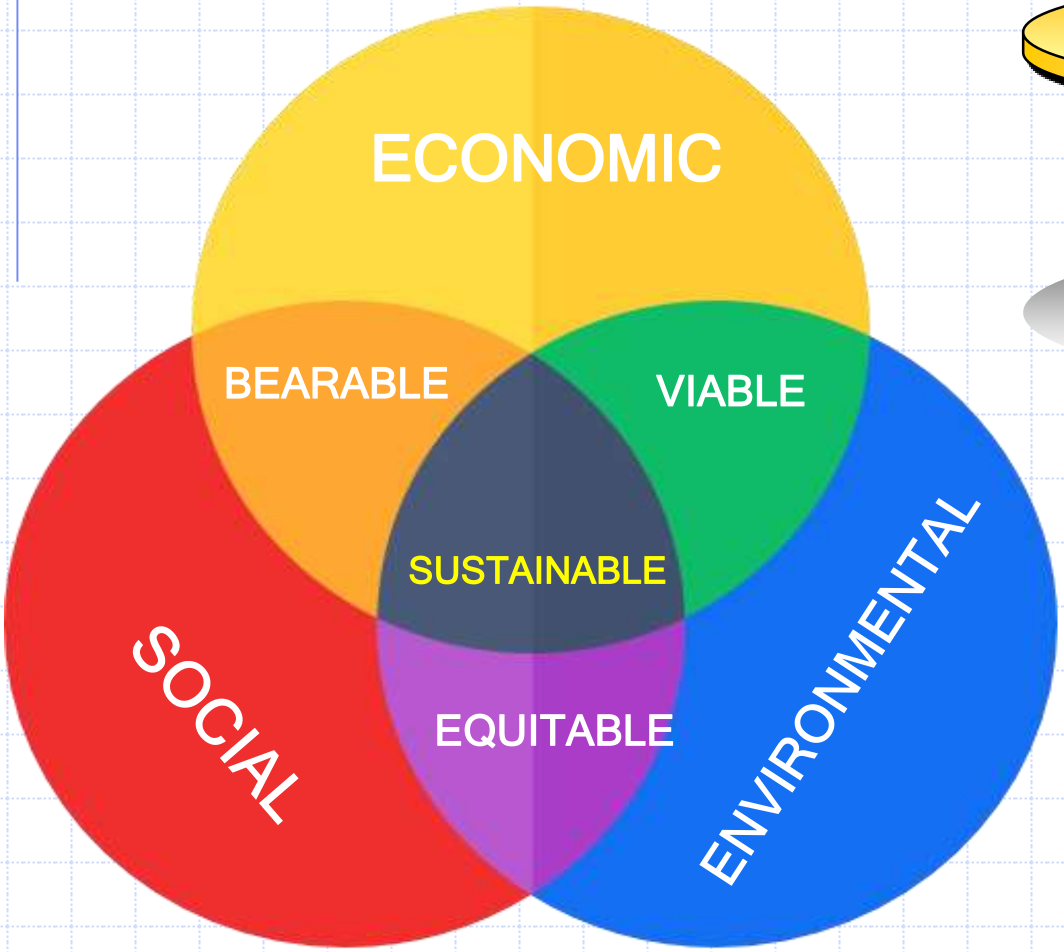
- Life cycle thinking
- Quantitative methods and life cycle cost analysis
- The ISO LCA standard
- Life cycle inventory
  - Data needs and data quality
  - Data sources
  - Handling multifunction systems (disaggregation and allocation)
  - Uncertainty
  - Input-output LCA
- Impact assessment
- Conclusions

Why LCA?

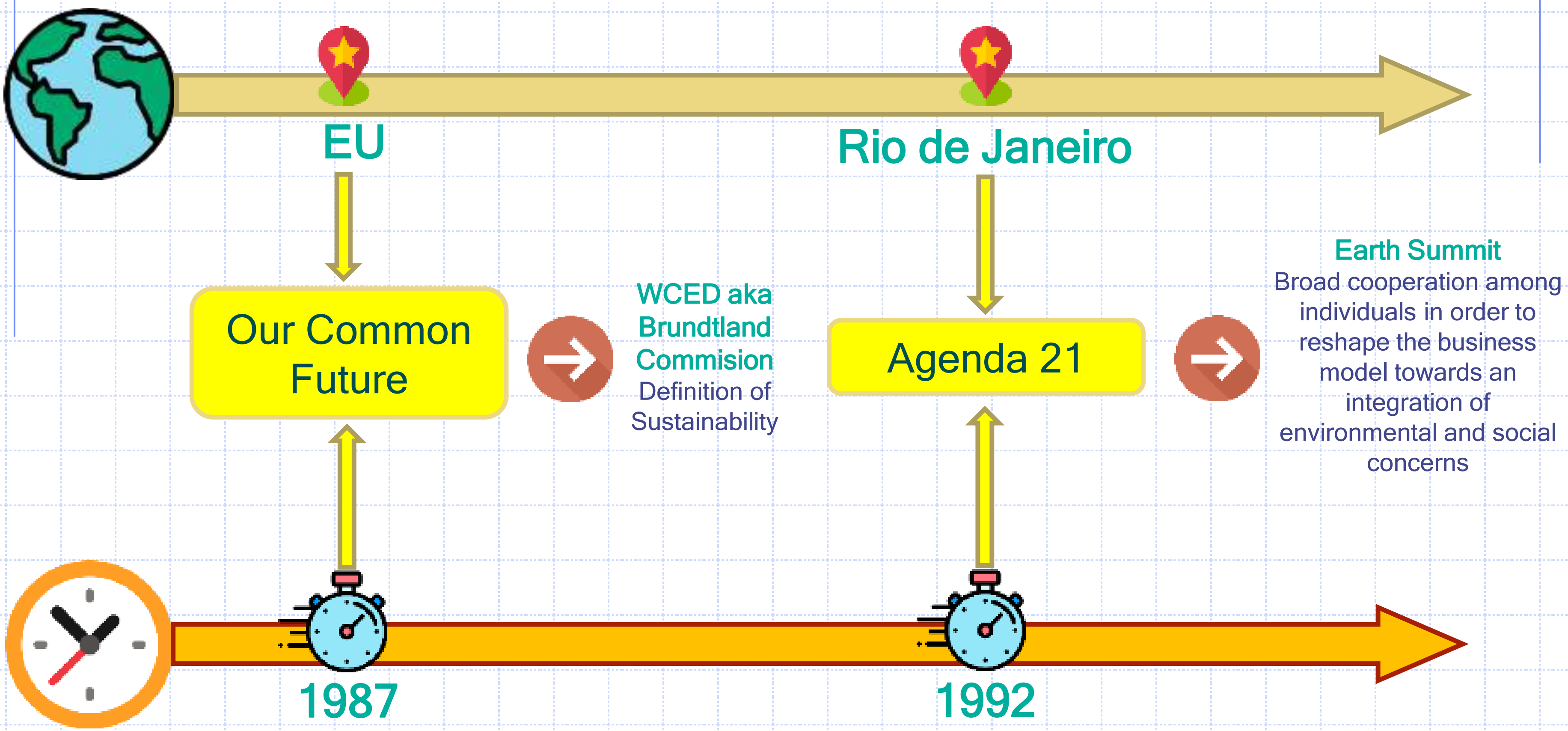
- "**Business as usual**" can be defined as meeting needs of present without considering future needs or current social costs
- What is the impact of "business as usual"?
  - Ripple effects
  - Intuition not a sufficient framework for analysis!
- LCA = systematic method for comparing **systemic impacts** of products and policies
- **Product life cycle views**: examples
  - A piece of fruit
  - A tuxedo
  - A car
  - A computer
- **Engineering** and environment evolution …
  - End of pipes treatments
  - Remediation
  - Pollution prevention Cleaner production
  - Sustainability

Why LCA?

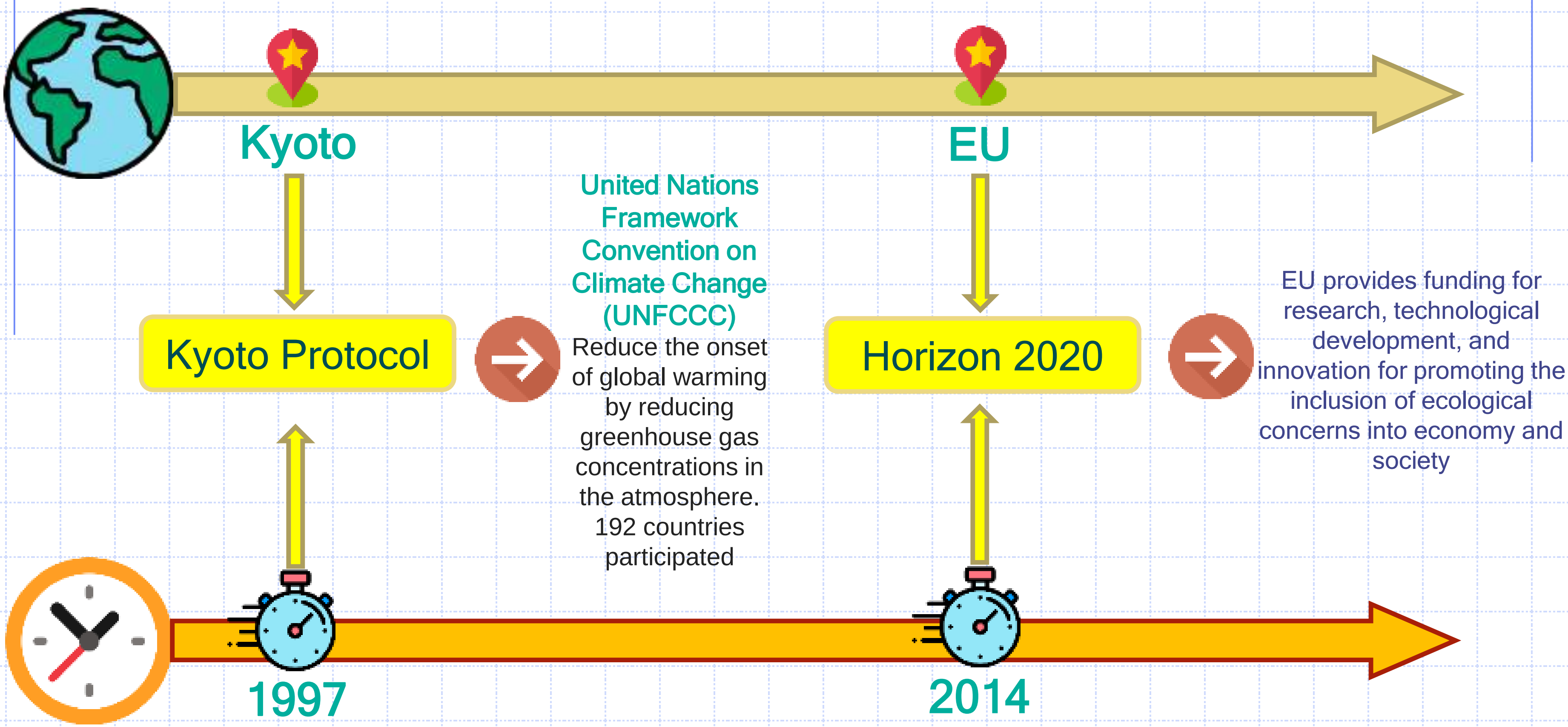
- Sustainability is "**meeting needs of present without compromising our ability to meet future needs**"



Sustainability Roadmap



Sustainability Roadmap



Sustainability Roadmap

Paris

Paris Agreement

2015

- Global average temperature < 2°C above preindustrial levels and temperature increase < 1.5°C
- Increasing the ability to adapt to the adverse impacts of climate change
- Making finance flows consistent with low greenhouse gas emissions

EU

Agenda for Sustainable Development

2015

United Nations General Assembly formally adopted 17 Sustainable Development Goals (SDGs), i.e. fighting poverty, hunger, discriminations and illiteracy, promoting clean energy, climate and natural life safeguard, good-health, sanitation, and recycling

Sustainability Methodologies

Design for Environment (DfE)
starting from the product design stage, it takes into consideration the potential refurbishing and/or recycle of the final product or some of its components, embedding their long term environmental and human impacts. Components are designed to exhibit interchangeability for reusable ones or biodegradability for consumables ones.

Life Cycle Assessment (LCA)
it comprehends the potential environmental impacts and the resources exploited throughout the entire product's life-cycle from cradle, i.e. extraction of raw materials, to grave, i.e. waste disposal.

Total Quality Environmental Management(TQEM)
it is a high level framework adopted by companies to improve their environmental performance through a top down approach
from management support through increasing employees' and stakeholders' awareness on environmental protection.

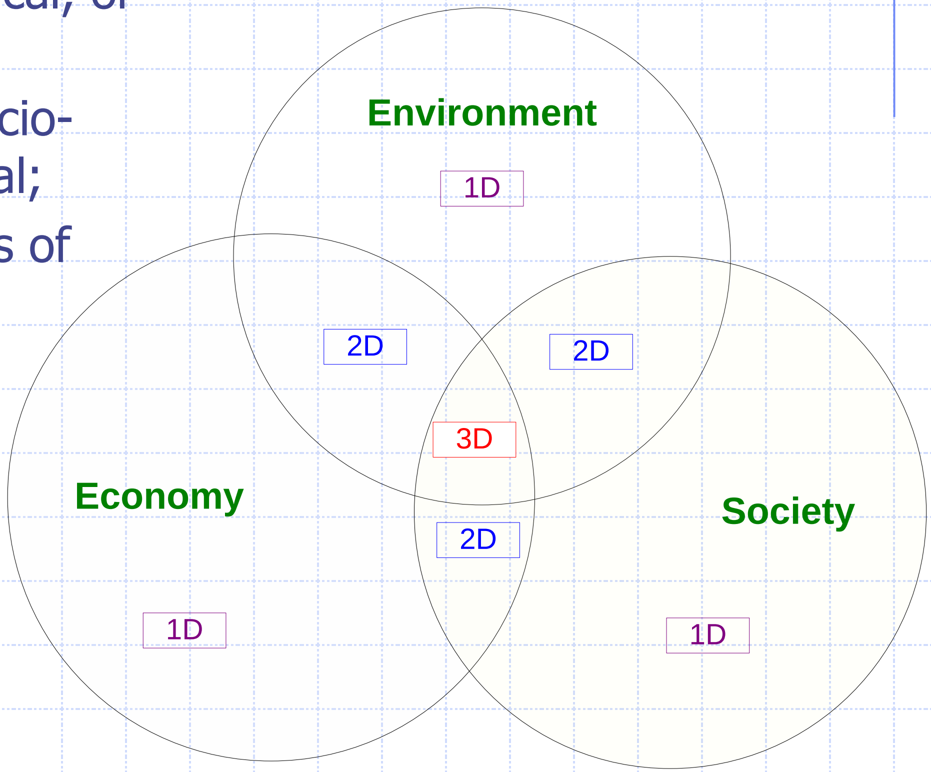
Sustainable Supply Chain Management(SSCM)
means integrating environmental, social and economical thinking into supply-chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers as well as end-of-life management of the product after its useful life.

PSP and WAR algorithm
PSP is a combination of 3D indexes, including all the 3 aspects of sustainability, and WAR algorithm focuses on sustainability of chemical processes. Effects on environmental indexes are considered.

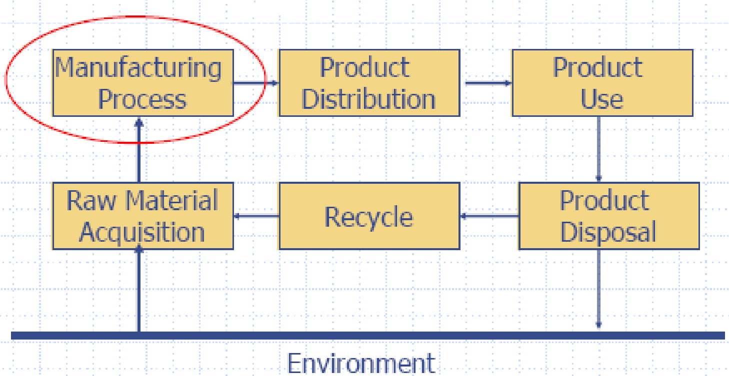
ISO 14000 family standards
provide practical tools for companies and organizations of all kinds looking to manage their environmental responsibilities.
The updated version of ISO 14001 is ISO 14001:2015 and it is based on the Plan-Do-Control-Act (PDCA) cycle to constantly improve the environmental performance of the manufacturing process.

Sustainability evaluation (of a process) - PSP

- The question of Indicators
  - 1D indicators: economical, ecological, or social;
  - 2D indicators: socio-ecological, socio-economical, or economic-ecological;
  - 3D indicators: all three dimensions of sustainability
- Indicators in this study:
  - Four 3D
  - Four 1D (environment)



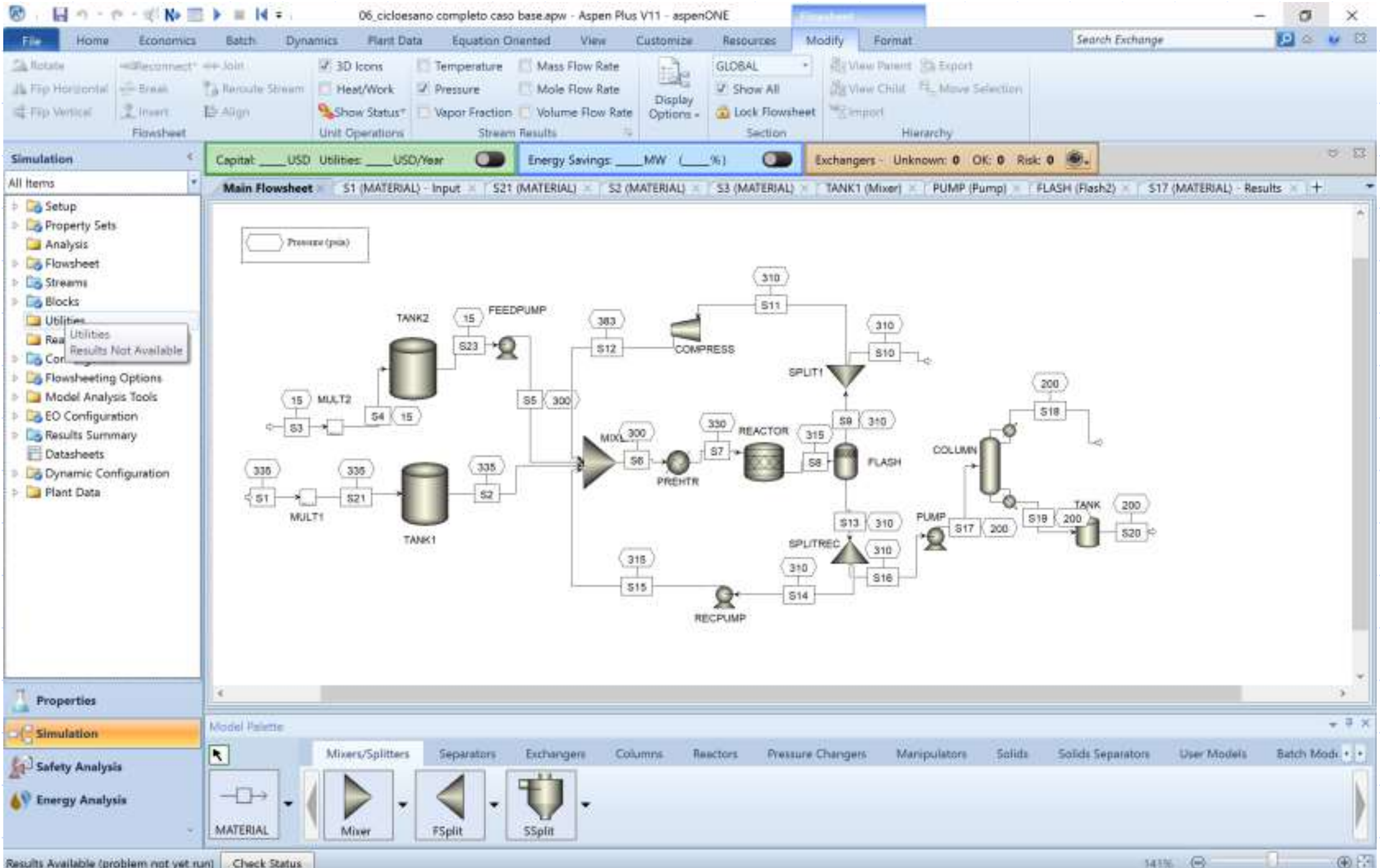
From Martins, 2006



Fermeglia M., Longo G., Toma L., AIChE J, 2009

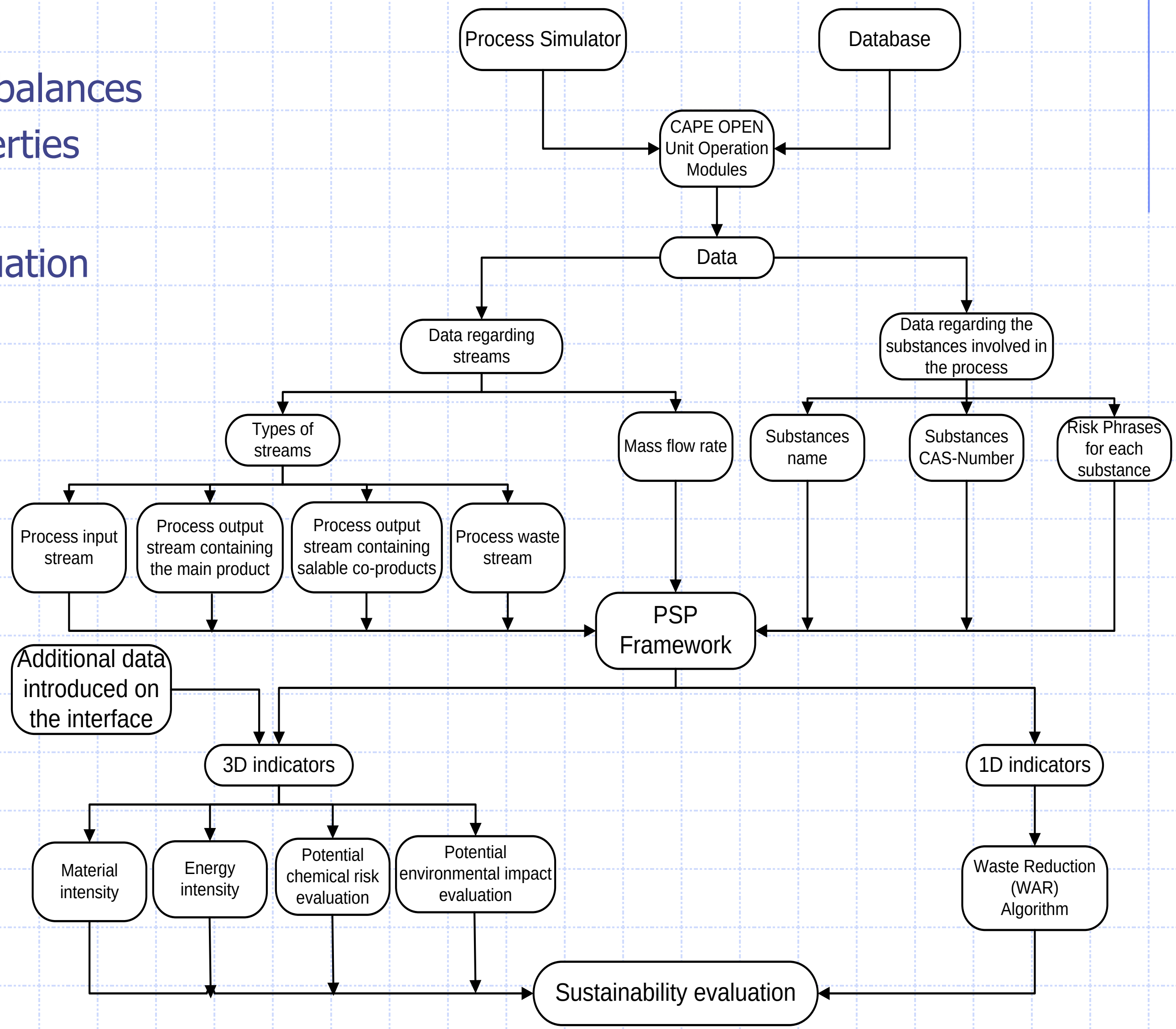
A process simulator

- Solves material and energy balances with computer codes



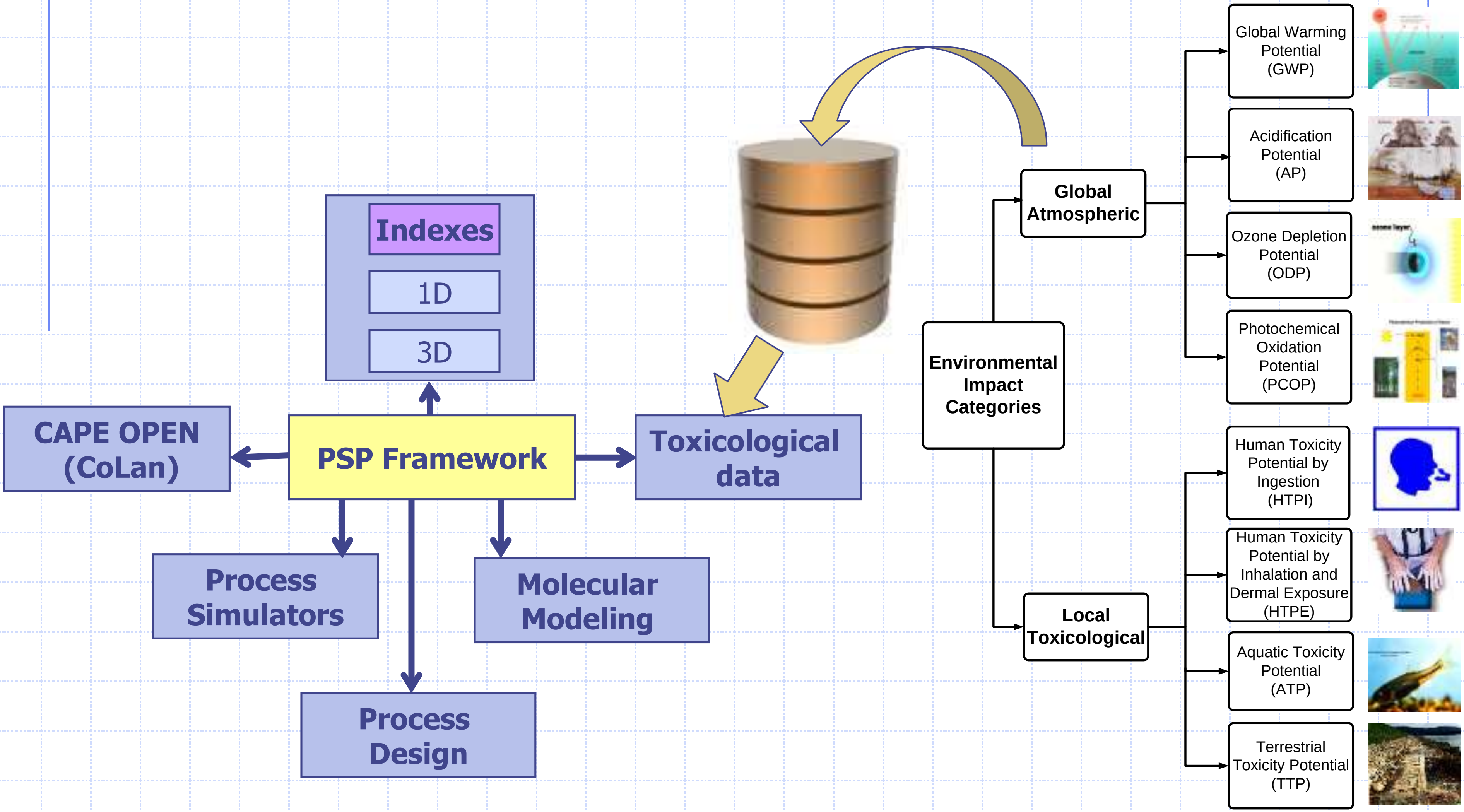
PSP framework

- Input data
  - Material & Energy balances
  - Toxicological properties
- Output
  - Sustainability evaluation

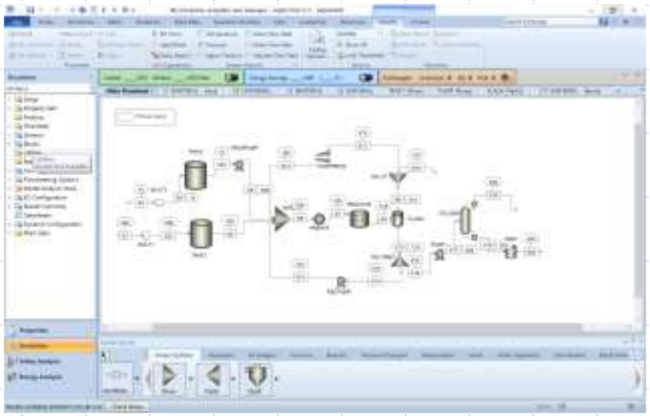


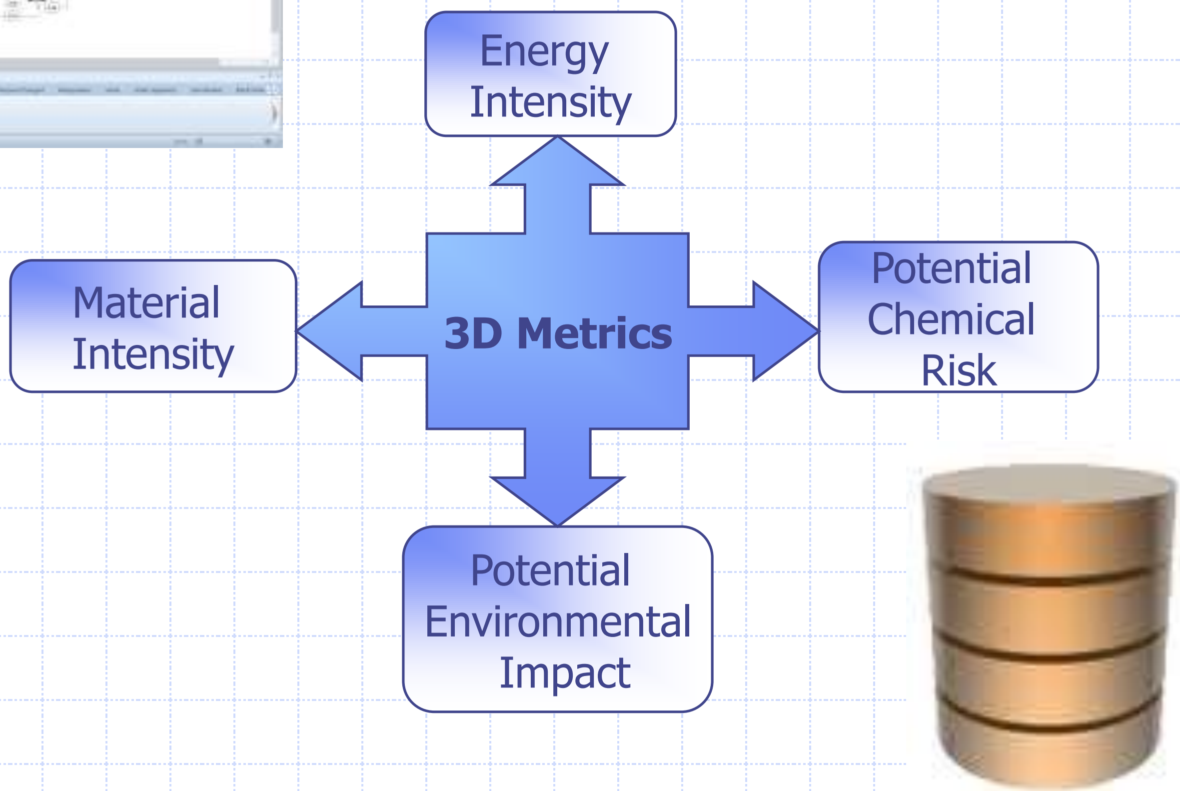
Fermeglia M., Longo G., Toma L., AIChE J, 2009

PSP framework & Environmental Indexes



3D Indicators





Material Intensity (MI) & Energy Intensity (EI)

- amount of nonrenewable resources required to obtain a unit mass of products

- energy demands of the process per unit mass of products
- focused on the use of nonrenewable energy (natural gas, fuel oil, steam, electricity)

$$MI = \frac{mass\ of\ raw\ materials - mass\ of\ products}{output}$$

$$EI = \frac{net\ energy\ consumed\ in\ primary\ fuel\ equivalents}{output}$$

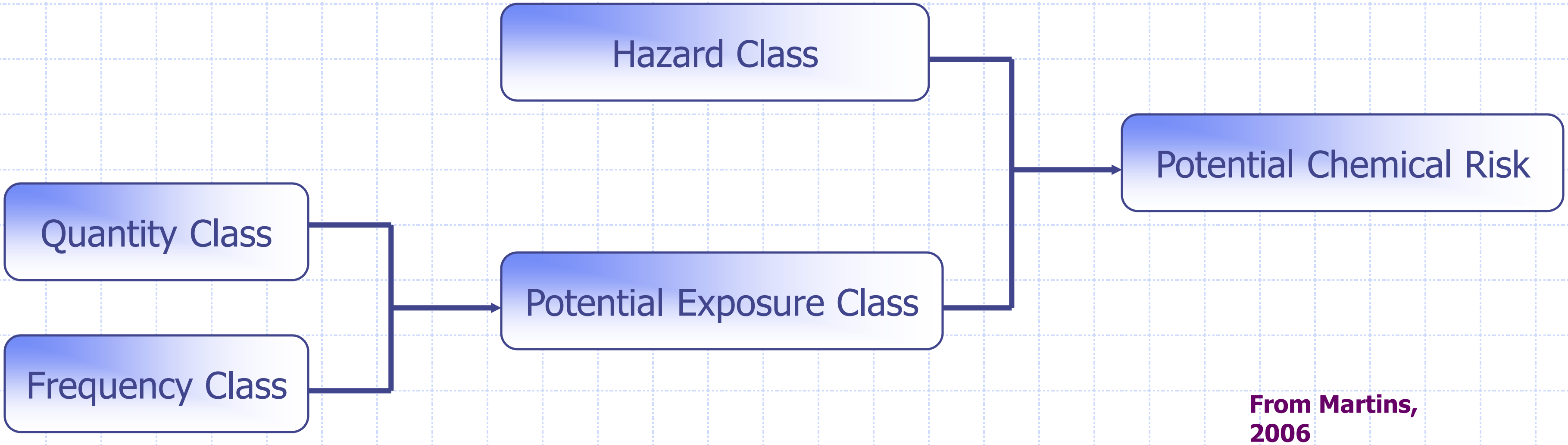
$$output = \frac{mass\ of\ product + mass\ of\ salable\ coproducts}{mass\ of\ product}$$

$$output = \frac{mass\ of\ product + mass\ of\ salable\ coproducts}{mass\ of\ products}$$

From Martins, 2006
From Tanzil, 2004

Potential Chemical Risk (PCR)

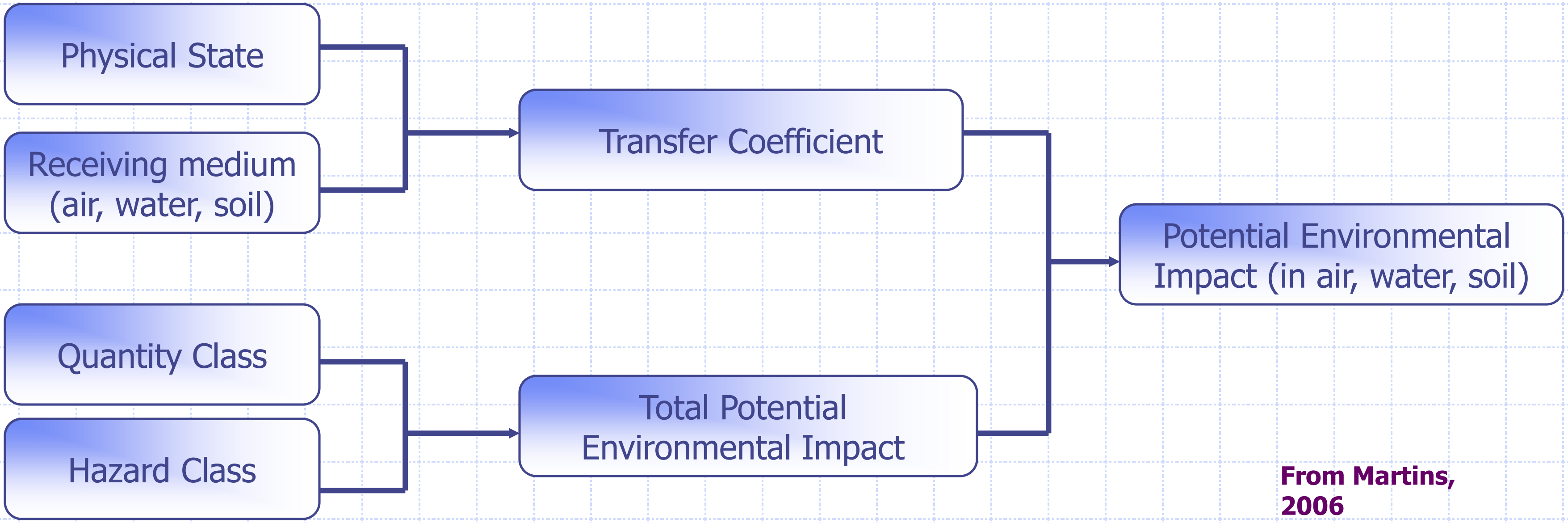
- Process safety and potential risk to human health
  - Due to manipulation, storage and use of hazardous chemicals
  - per unit mass of products



From Martins, 2006

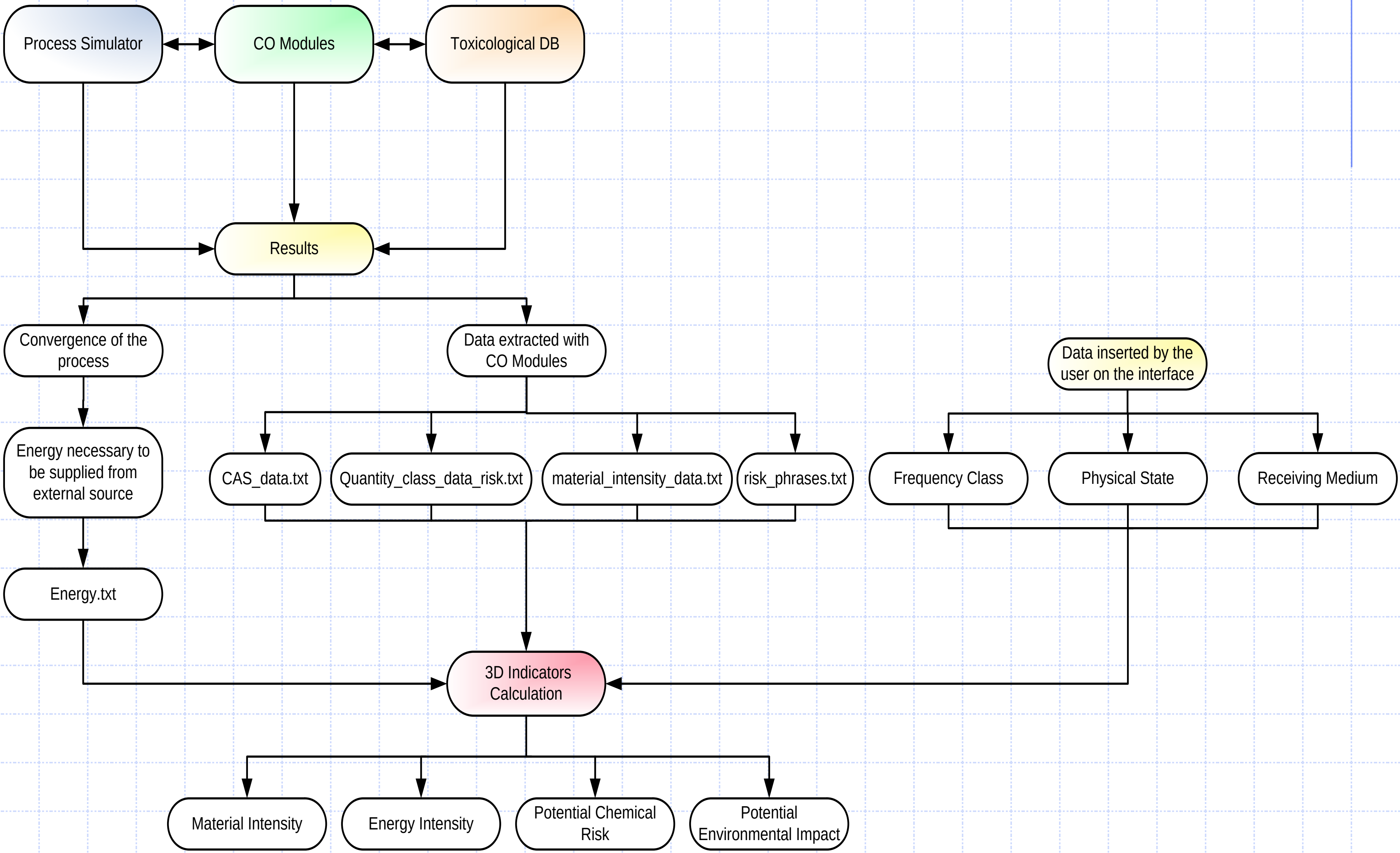
Potential Environmental Impact (PEI)

- Potential impact due to the emissions and the discharge of the hazardous chemicals to the environment
  - per unit mass of products



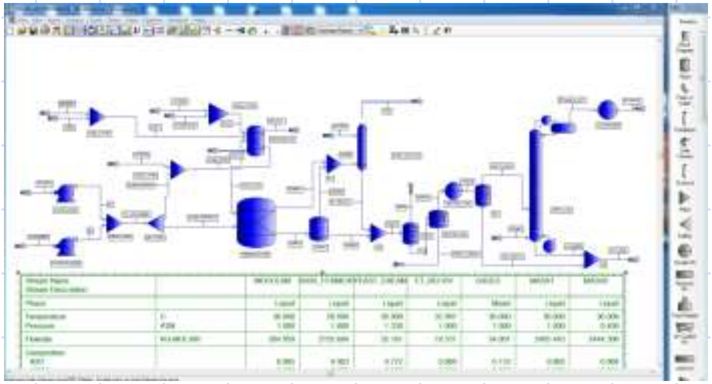
From Martins, 2006

General Schema of 3D Implementation



1D Indicators

- Waste Reduction Algorithm (WAR)



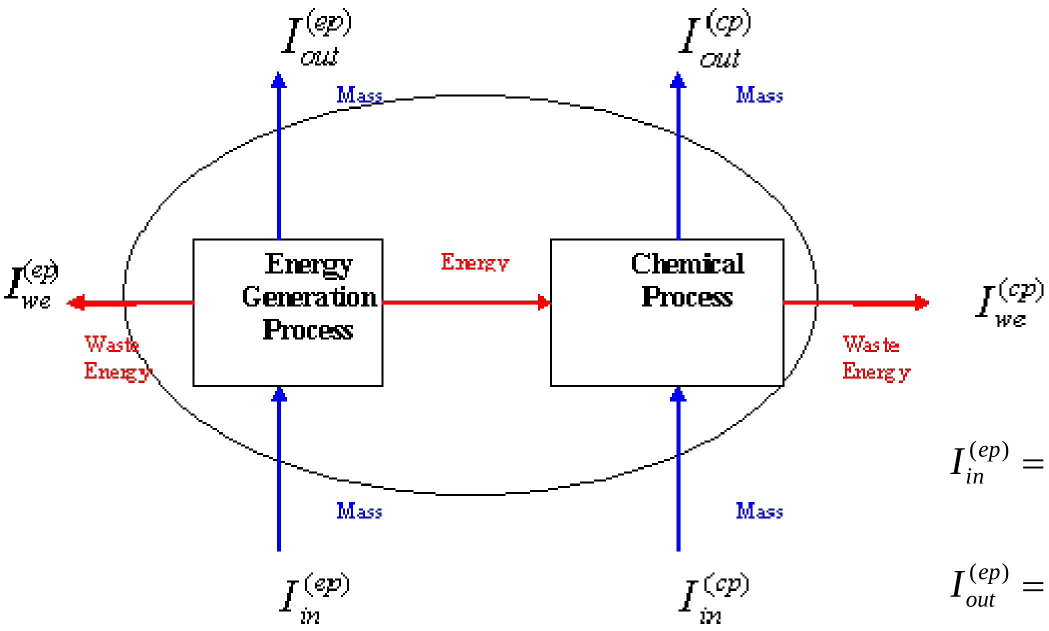
1D Indicator

- Total impact output per mass of products $\hat{I}^{(t)}_{out}$
- Total rate of impact output $I^{(t)}_{out}$
- Total rate of impact generation $I^{(t)}_{gen}$
- Total impact generated per mass of products $\hat{I}^{(t)}_{gen}$

From D.M.Young and H.Cabezas, 1999

The balance of Potential Environmental Indexes (I)

$$\frac{\partial I_{syst}}{\partial t} = I_{in}^{(cp)} + I_{in}^{(ep)} - I_{out}^{(cp)} - I_{out}^{(ep)} - I_{we}^{(cp)} - I_{we}^{(ep)} + I_{gen}^{syst}$$



$$I_{in}^{(cp)} = \sum_j^{cp} I_j^{(in)} = \sum_j^{cp} \dot{M}_j^{(in)} \sum_k x_{kj} \cdot \Psi_k + \ldots$$

$$I_{out}^{(cp)} = \sum_j^{cp} I_j^{(out)} = \sum_j^{cp} \dot{M}_j^{(out)} \sum_k x_{kj} \cdot \Psi_k + \ldots$$

$$I_{we}^{(cp)} = \sum_i^{cp} \dot{E}_j^{(cp)} \cdot \Psi_{we} \approx 0$$

$$I_{in}^{(ep)} = \sum_j^{ep} I_j^{(in)} = \sum_j^{ep} \dot{M}_j^{(in)} \sum_k x_{kj} \cdot \Psi_k + \ldots \approx 0$$

$$I_{out}^{(ep)} = \sum_j^{cp} I_j^{(out)} = \sum_j^{ep-g} \dot{M}_j^{(out)} \sum_k x_{kj} \cdot \Psi_k + \sum_j^{ep-s} \dot{M}_j^{(out)} \sum_k x_{kj} \psi_k + \ldots$$

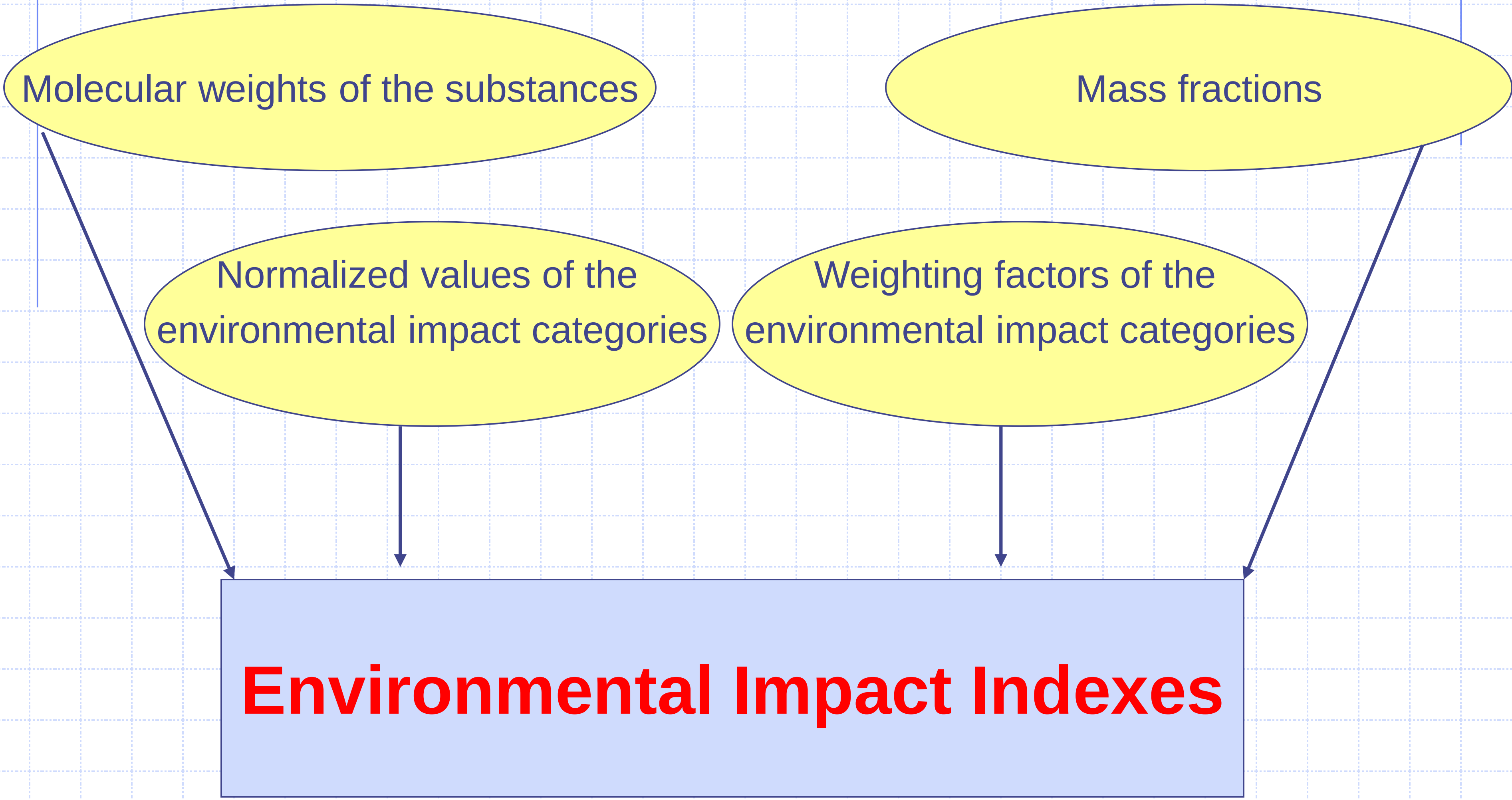
$$\approx \sum_j^{ep-g} \dot{M}_j^{(out)} \sum_k x_{kj} \cdot \Psi_k + \ldots$$

$$I_{we}^{(ep)} = \sum_i^{ep} \dot{E}_j^{(ep)} \cdot \Psi_{we} \approx 0$$

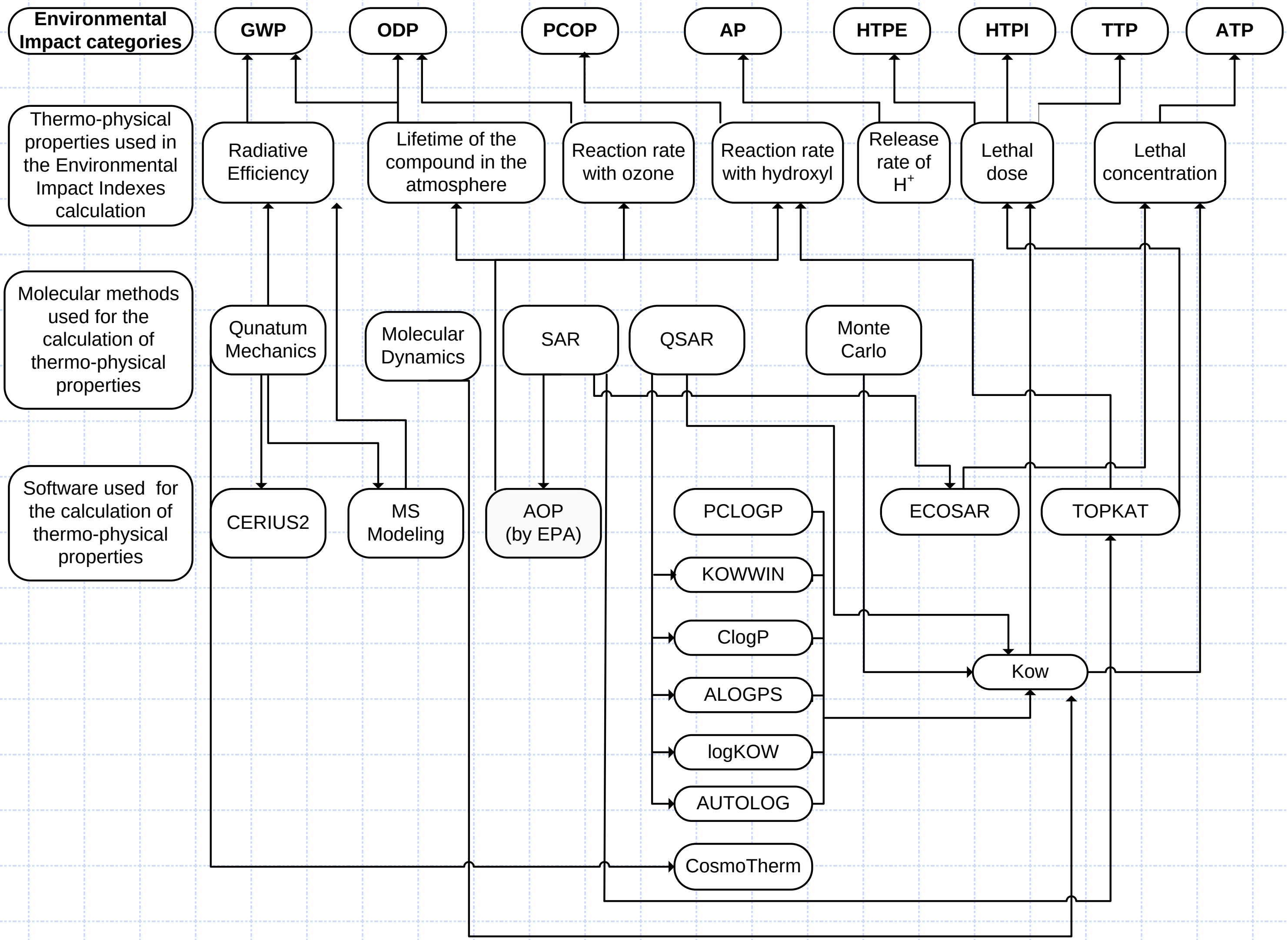
In = input
Out = output
We = waste energy
Gen = generation

From D.M.Young and H.Cabezas, 1999

Necessary elements to calculate the terms of the equation



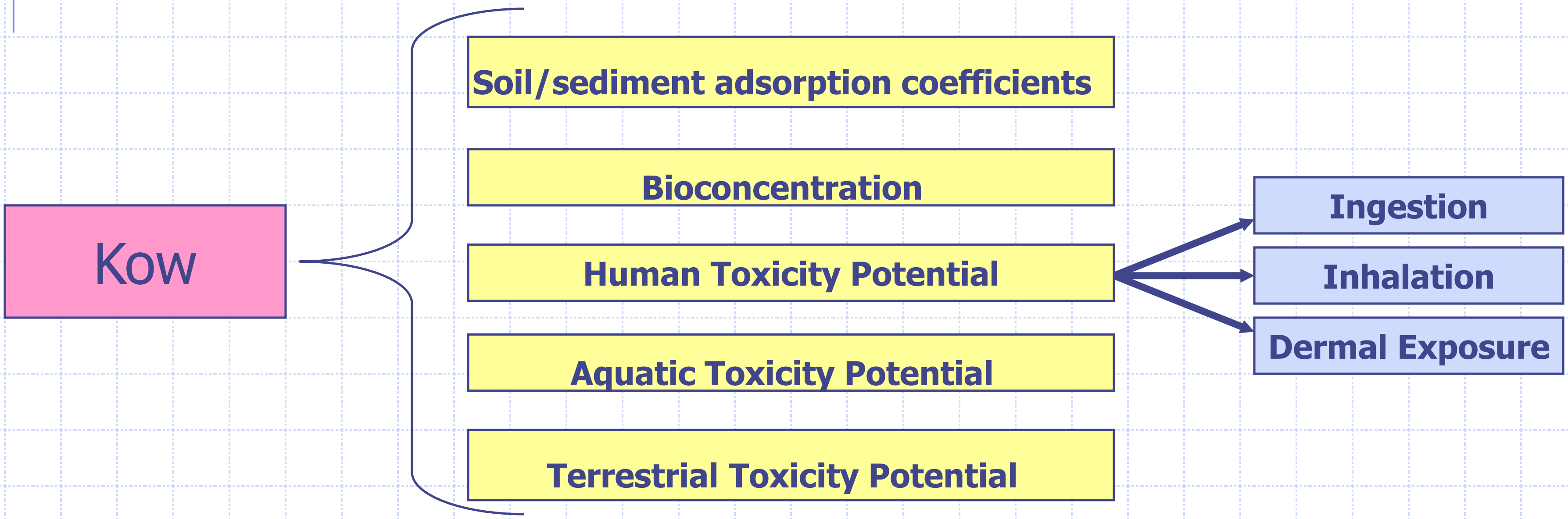
Molecular modeling



Octanol-water partition coefficient

$$Kow = \frac{concentration\ in\ octanol\ phase}{concentration\ in\ aqueous\ phase}$$

- Kow is used to calculate different properties



Fermeglia M., Longo G., Toma L., Env.Progress (2008)

Kow-Results

Substance	logKow (exp)	logKow calculated		logKow RAD	
		QSAR	CSM COSMO	QSAR	CSM COSMO
Methanol	-0.77	-0.63	-0.73	0.1818	0.0529
Naphthalene	3.3	3.17	3.09	0.0393	0.0625
Phenol	1.46	1.51	1.42	-0.0342	0.0192
Chloroform	1.97	1.52	2.1	0.2284	-0.066
Toluene	2.73	2.54	2.65	0.0696	0.0275
Anisole	2.11	2.07	2.23	0.0189	-0.0555
Methyl Ethyl Chloride	1.25	1.34	1.26	-0.072	0.0073
Benzene	2.13	1.99	2.1	0.0657	0.0121
Methane	1.09	0.78	1.02	0.2844	0.0677
Ethane	1.81	1.32	1.63	0.2707	0.0984
Propane	2.36	1.81	2.18	0.2330	0.0077
Benzoic Acid	1.87	1.87	2.24	0	-0.1967

- The relative absolute deviation (RAD) between the experimental and the predicted method (QSAR e COSMO) has been calculated
- The error has lower values for when Kow is calculated using
  QM - COSMO

$$RAD = \frac{\log Kow_{experimental} - \log Kow_{calculated}}{\log Kow_{experimental}}$$

Processes developed and analyzed with PSP Framework

Process from the scientific literature

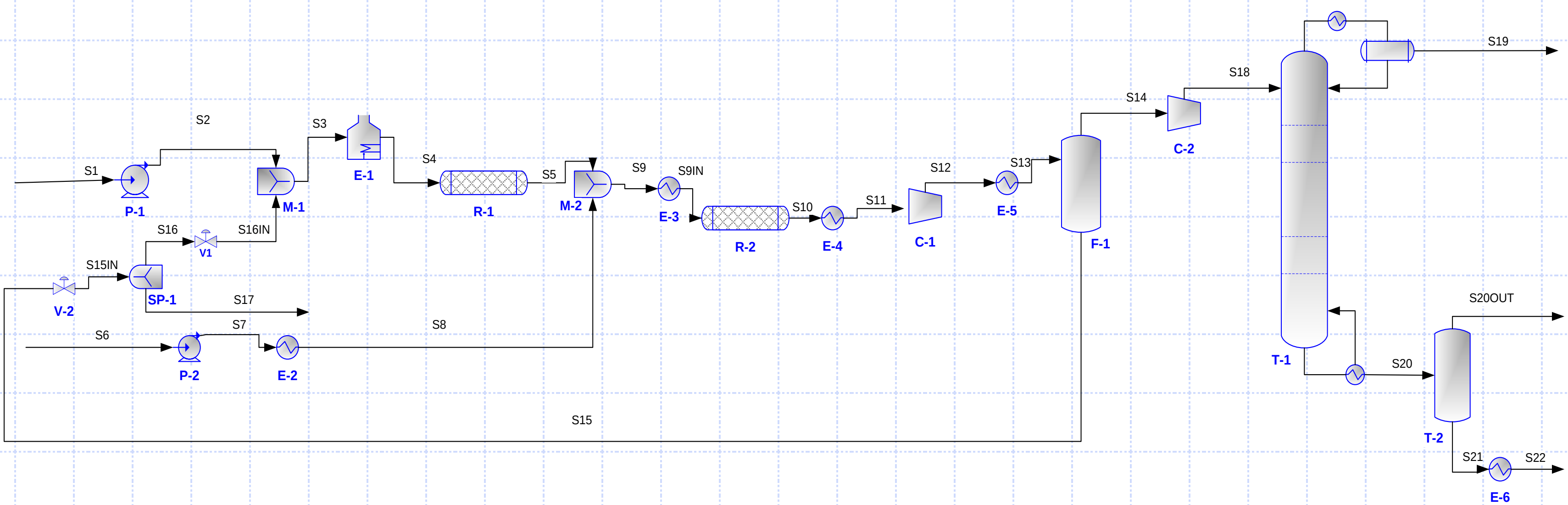
- Acrylic Acid production process
- Sweetening natural gas by DGA absorption
- Formaldehyde production process
- Phthalic Anhydride production process
- Maleic Anhydride Production process
- Dimethylether production process
- Dimethylformamide production process
- R134a production process

Chemical Plants situated in the developing countries

- Fuel Ethanol production from sugar cane molasses (Cuba)
- Multiple Effect of Sugar Cane Juice (Mexico)
- Electroplating wastewater discharge process (Russia)

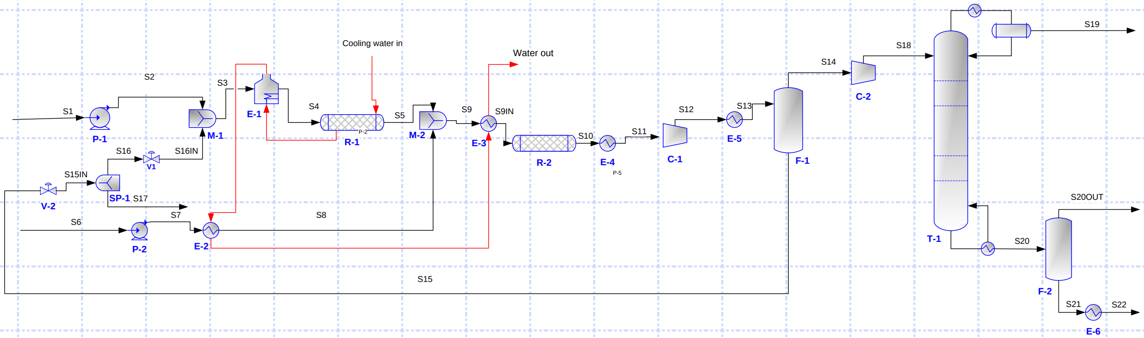
R-134a Production Process

- Case1 (base case)

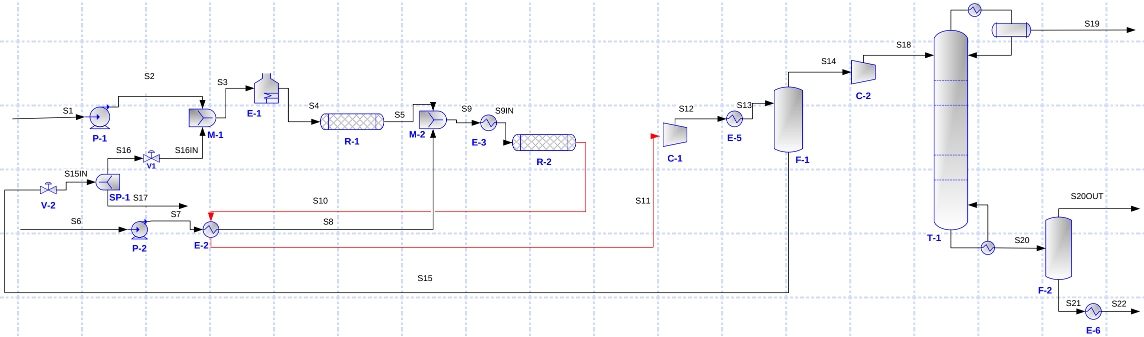


Case studies

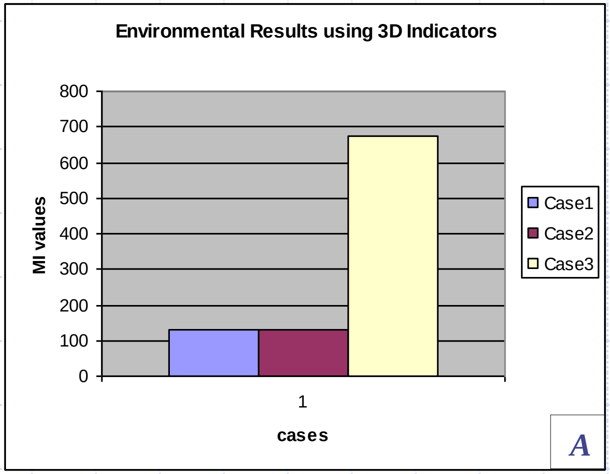
- Case1 (previous slide)
- Case2

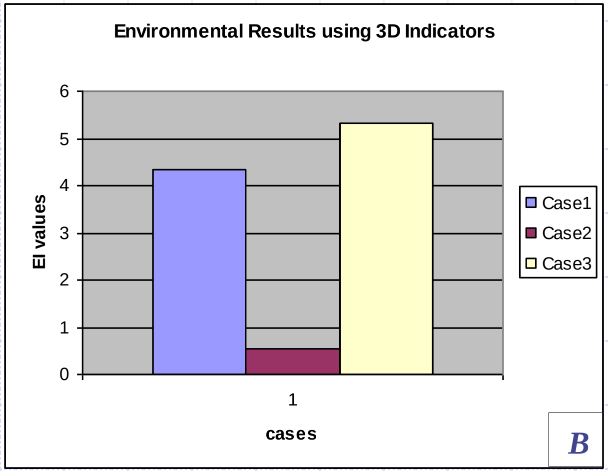


- Case3



3D Results





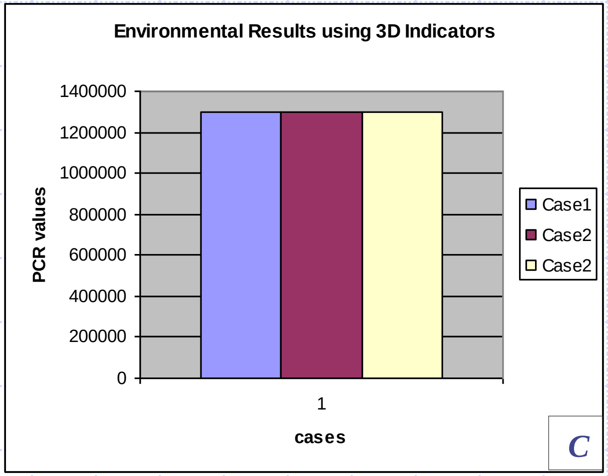
3D indicators for R-134a production

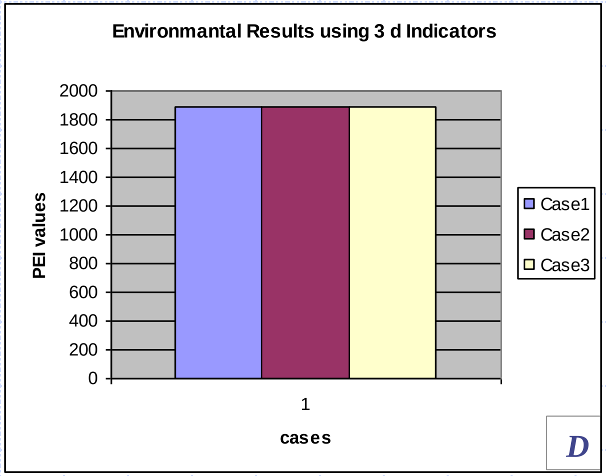
A) MI

B) EI

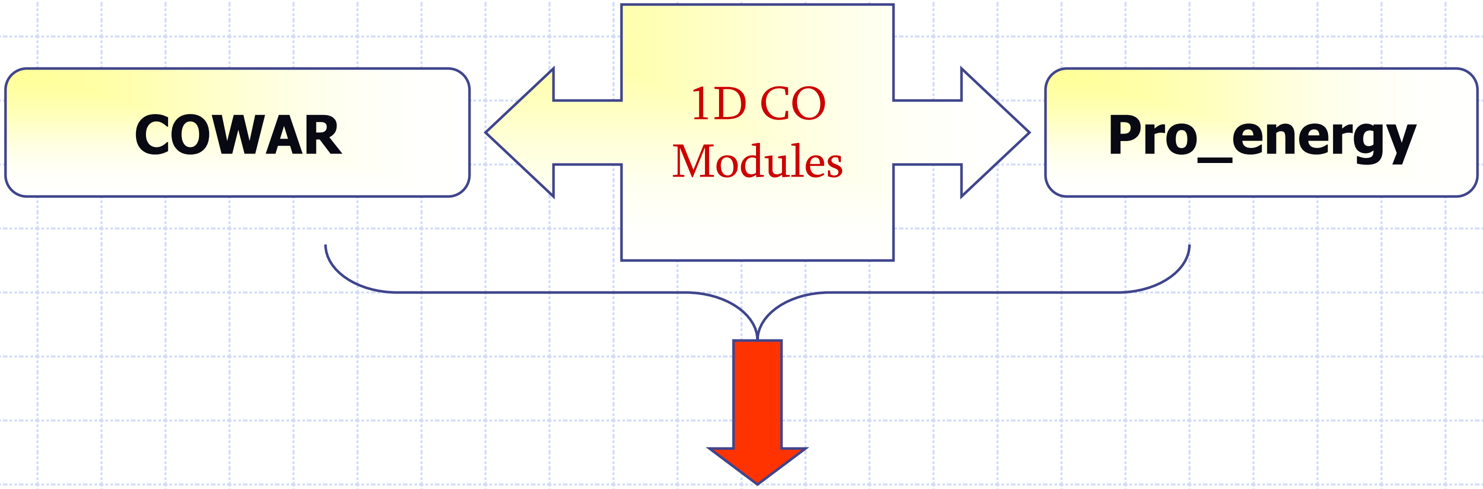
C) PCR

D) PEI



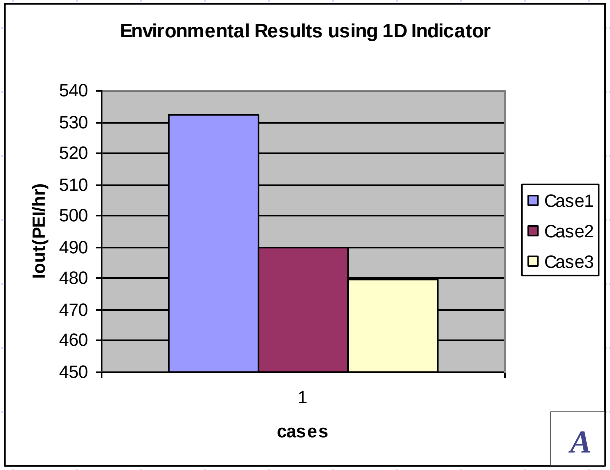


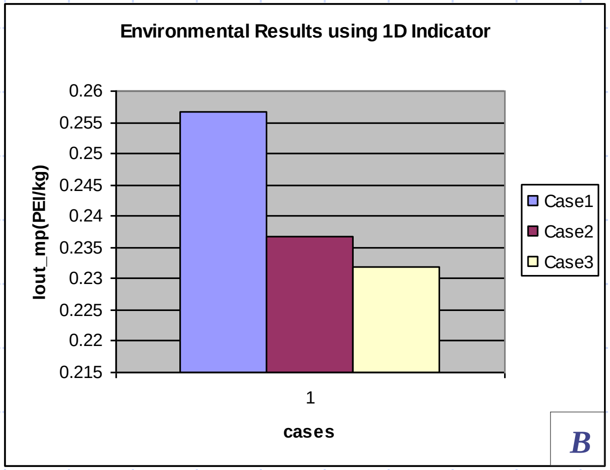
1D Specifications Table

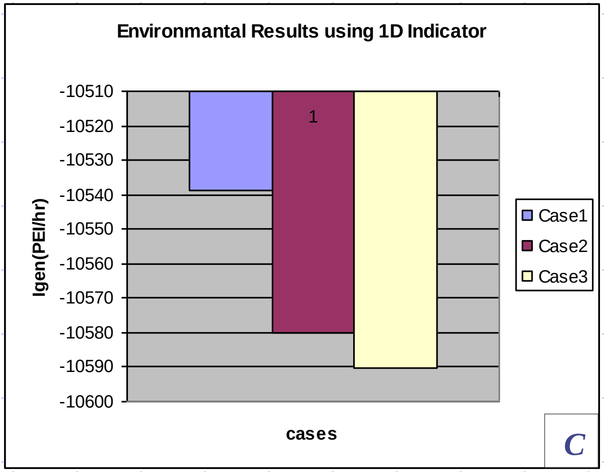


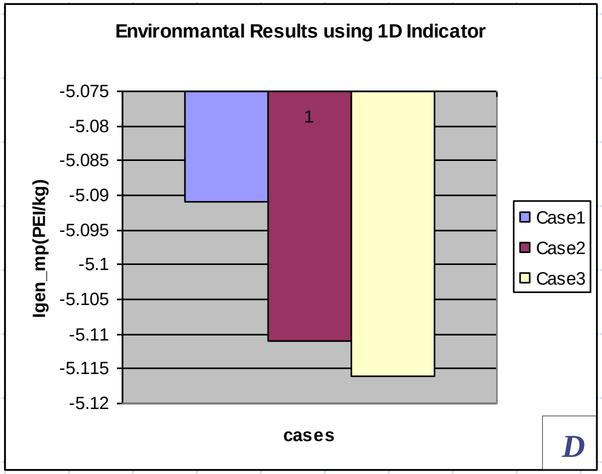
CO MODULE NAME	CO MODULES PARAMETERS			CONNECTED STREAM
	PROCESS_TYPE	CAPE_POSITION	CAPE_ID	
CO1	0	0	1	S1
CO2	0	0	2	S6
CO3	0	1	3	S17
CO4	0	2	4	S19
CO5	0	2	5	R134A
CO6	0	1	6	S21
CO7	1	1	7	S32

1D Results









1D indicators for R-134a production

A) Iout

B) Iout_mp

C) Igen

D) Igen_mp

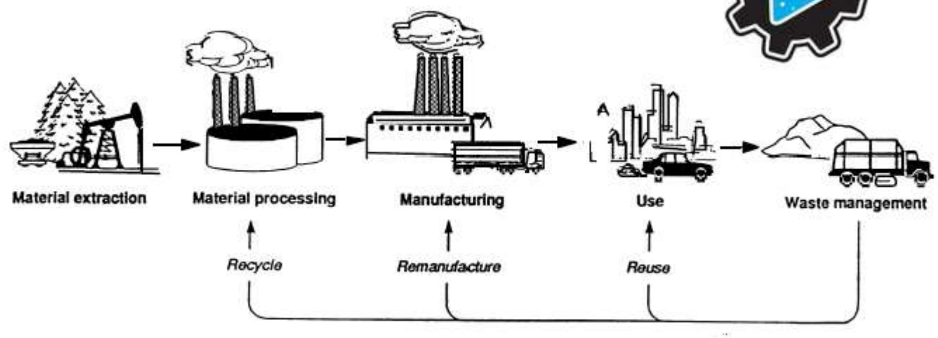
Systems thinking - Life cycle thinking

- Standard industrial model: **linear sequence** of extraction, production, distribution (Hawkins)
  - Focus on **creation of value**
  - Not concerned **with the natural systems** which allow for "extraction" or must absorb emissions and end-of-life products
- Consideration of the broader system is a **key component of sustainability** theory
- Acknowledging the **complex connectivity** of our societies, economies and the natural environment
  - **Understanding** system behaviors and responses (positive and negative)
  - **Modifying** complex systems to achieve a more sustainable balance
  - **Life cycle thinking**, applied to products and processes, is a specific example of systems thinking

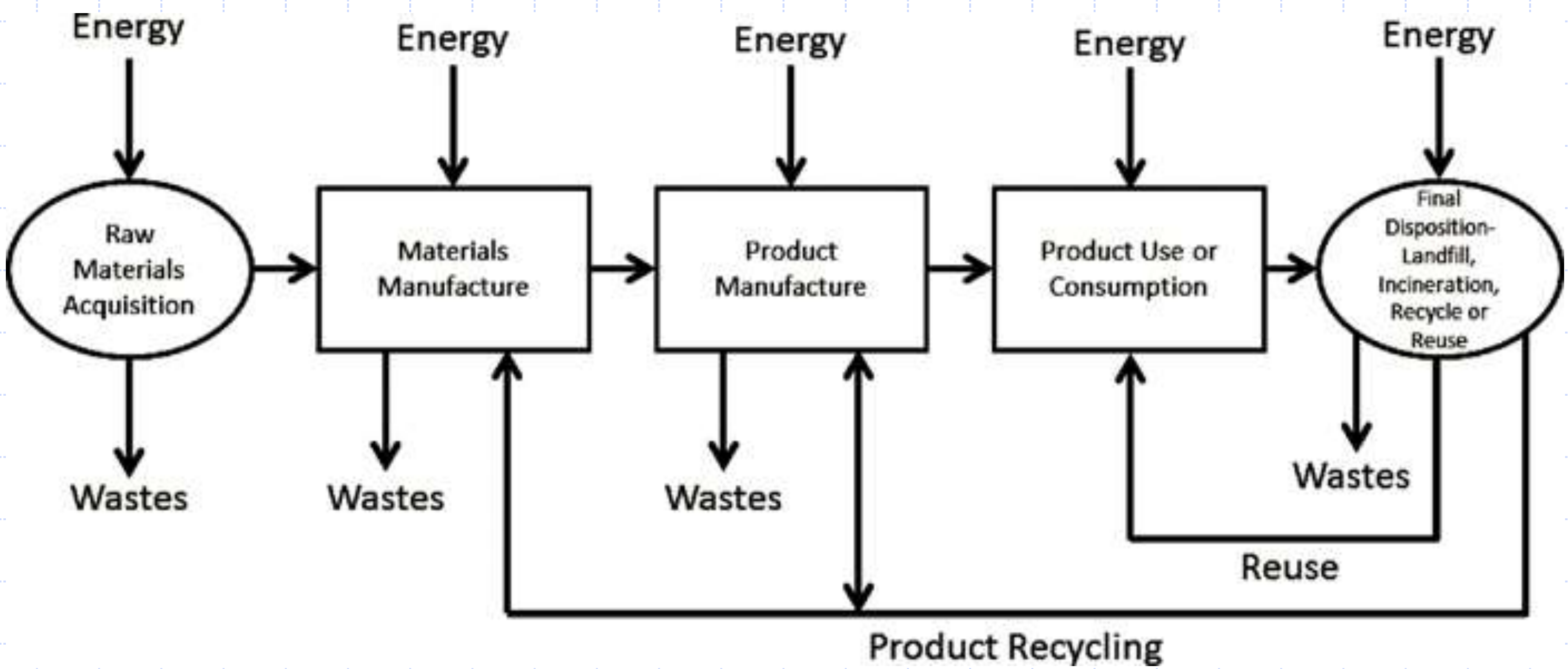
Natural Capitalism, Hawkins, Lovins and Lovins, 1999

LCA

- Reconsider '**common linear path**'
- Introduce '**disposition pathways**'
  - Reuse
  - Remanufacturing
  - recycling



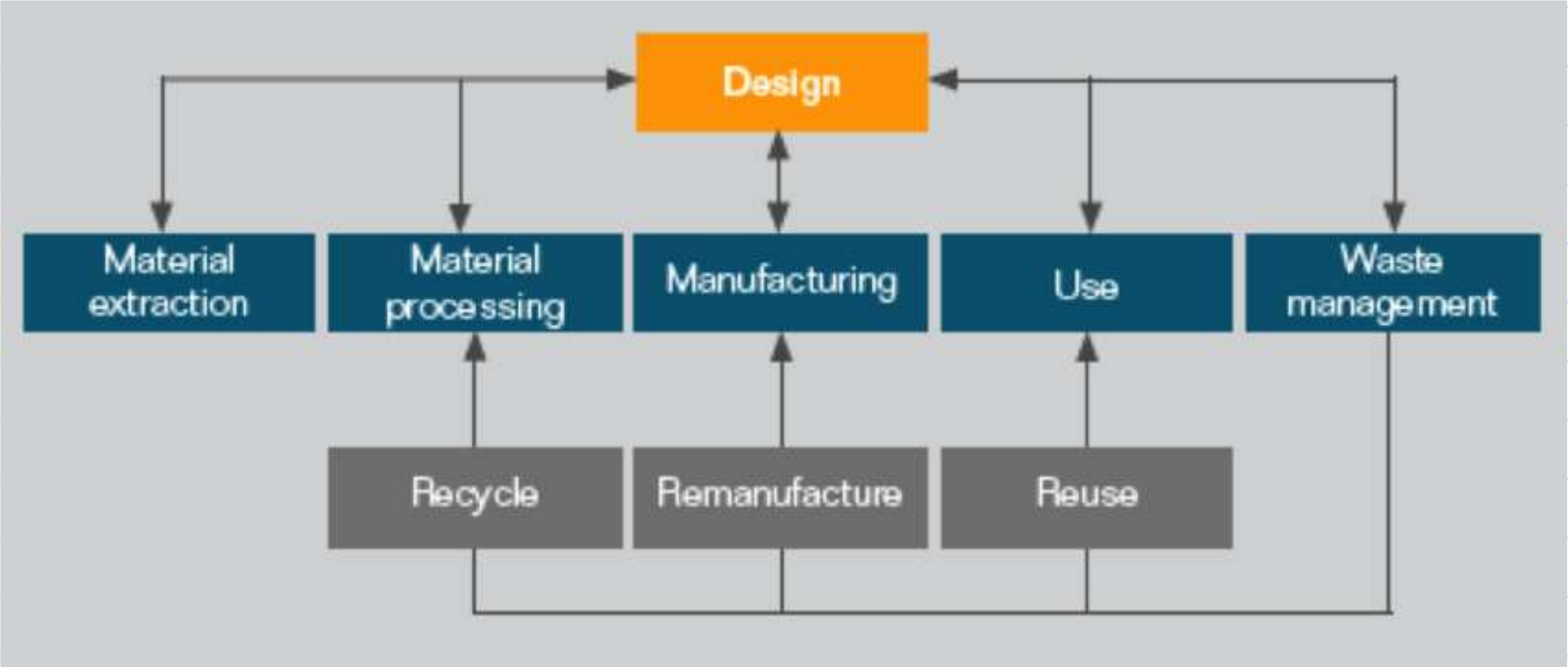
Stages of life cycle (OTA, 1992)



Source: http://read.nxtbook.com/wiley/plasticsengineering/may2014/processengineeringforrecycled.html

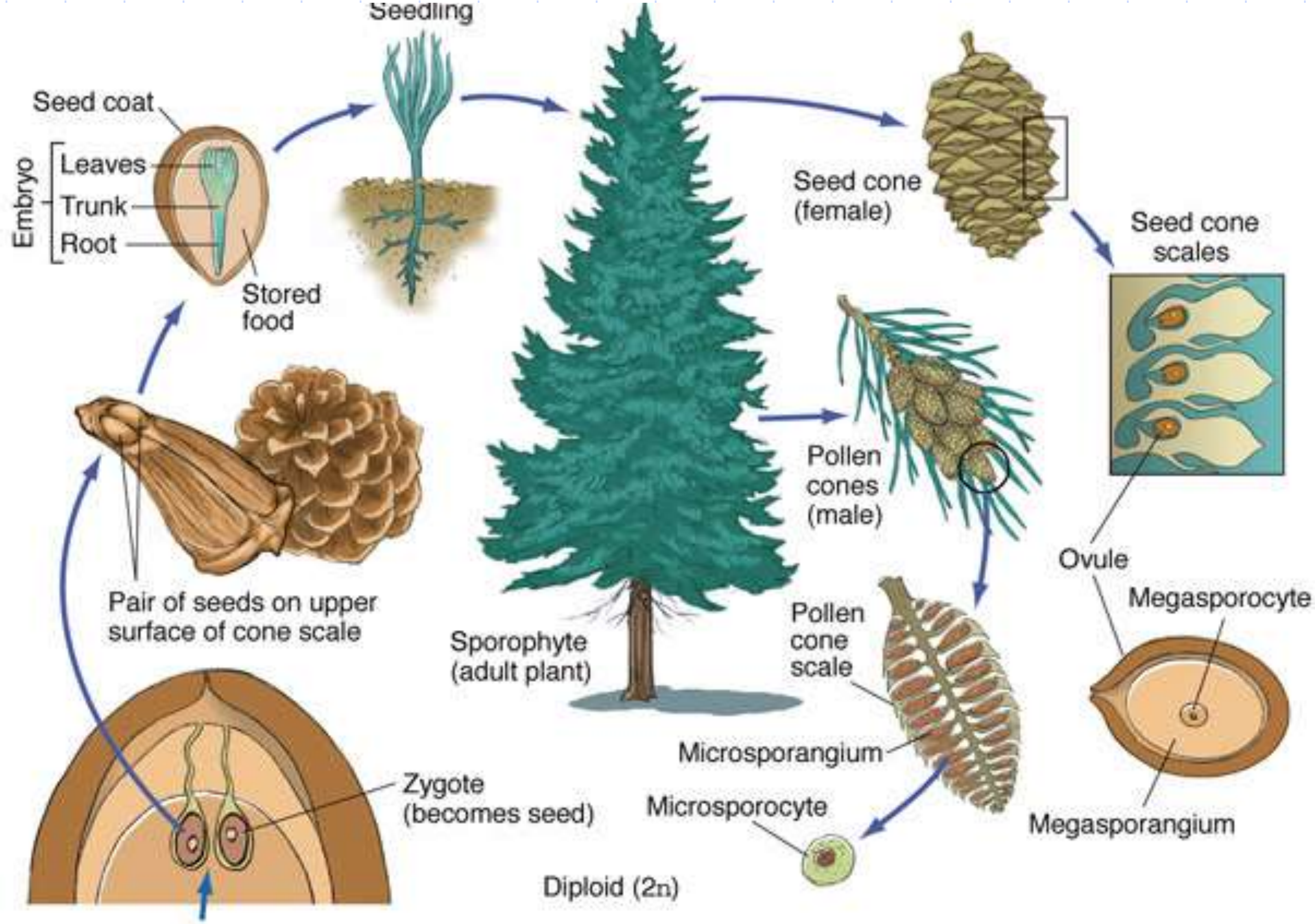
The role of design in LCA

- A **life cycle of a product** (a.k.a. "cradle to grave") begins with raw materials production and extends to manufacture, use, transport, and waste management

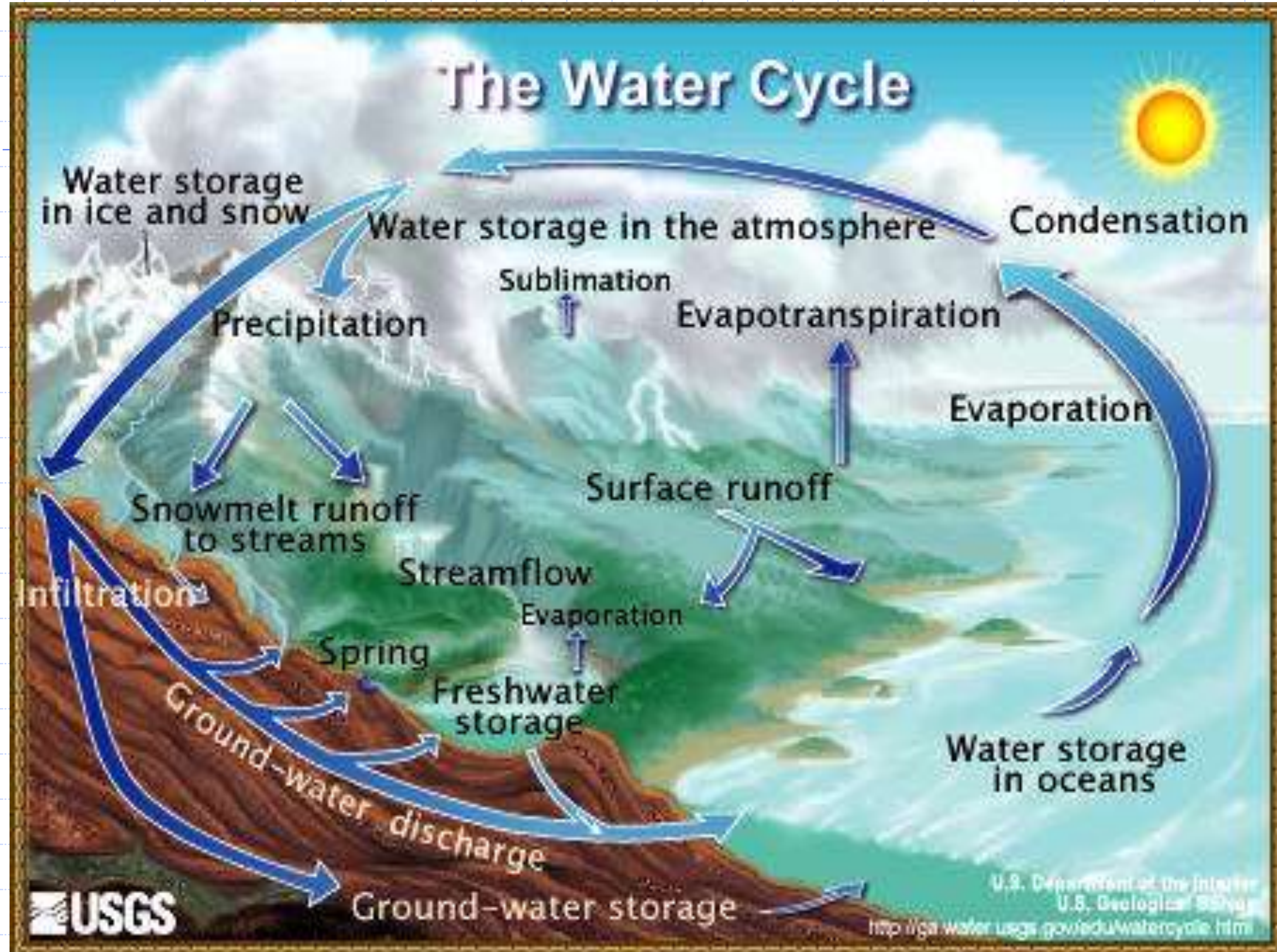


Point of departure: a life cycle

Normally in biology terms

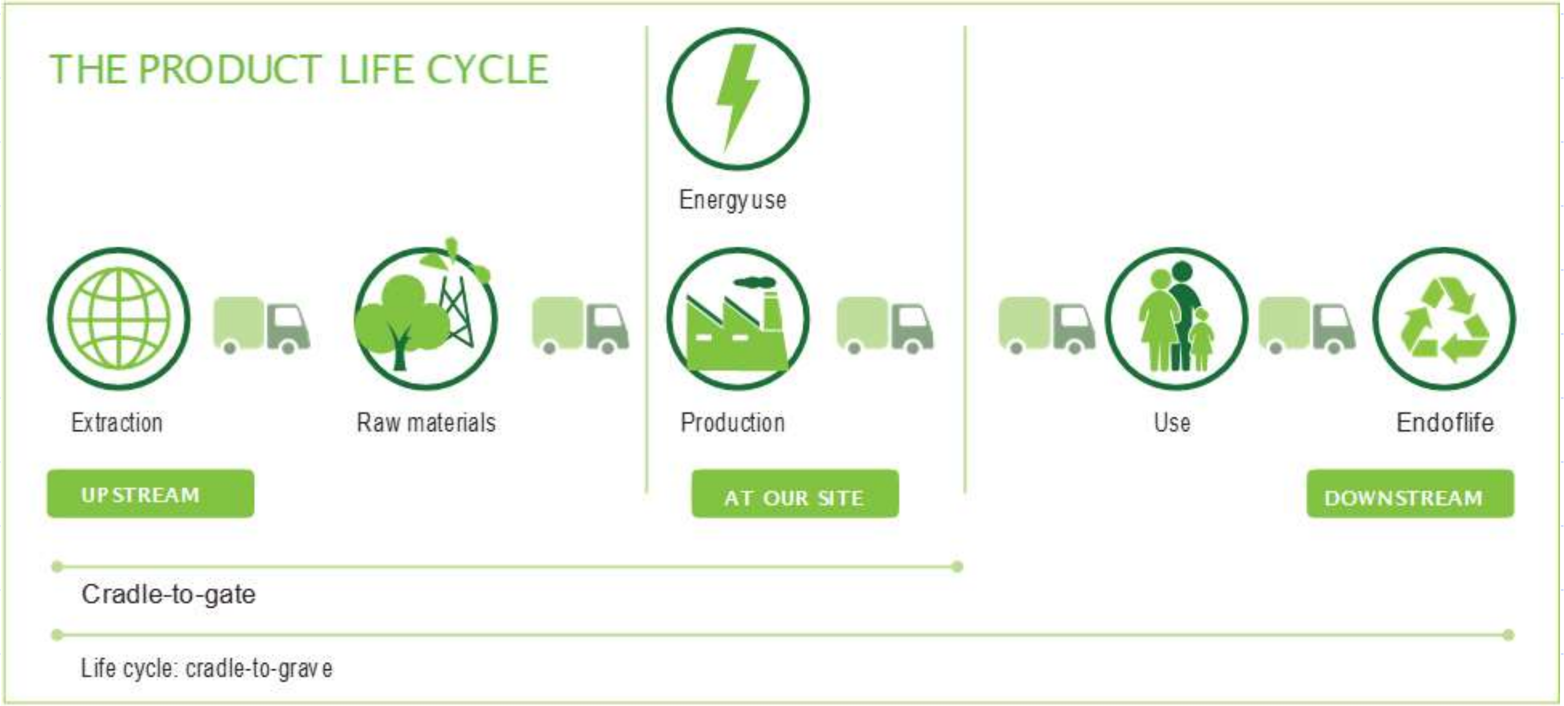


Source: http://www.biographixmedia.com/biology/pine-tree-life-cycle.jpg


The Water Cycle
Water storage in ice and snow
Water storage in the atmosphere
Condensation
Sublimation
Precipitation
Evapotranspiration
Evaporation
Surface runoff
Snowmelt runoff to streams
Streamflow
Infiltration
Evaporation
Spring
Freshwater storage
Ground-water discharge
Water storage in oceans
Ground-water storage
USGS
U.S. Department of the Interior
U.S. Geological Survey
http://ga.water.usgs.gov/edu/watercycle.html

Cradle to ….

- Cradle to grave
  - **The entire life cycle of a product**: follow the product to the grave
- Cradle to gate
  - LCA term, consideration **limited to the point of product distribution** (a boundary condition)
- Also gate to gate
  - Life cycle inside the production **facility boundaries**.



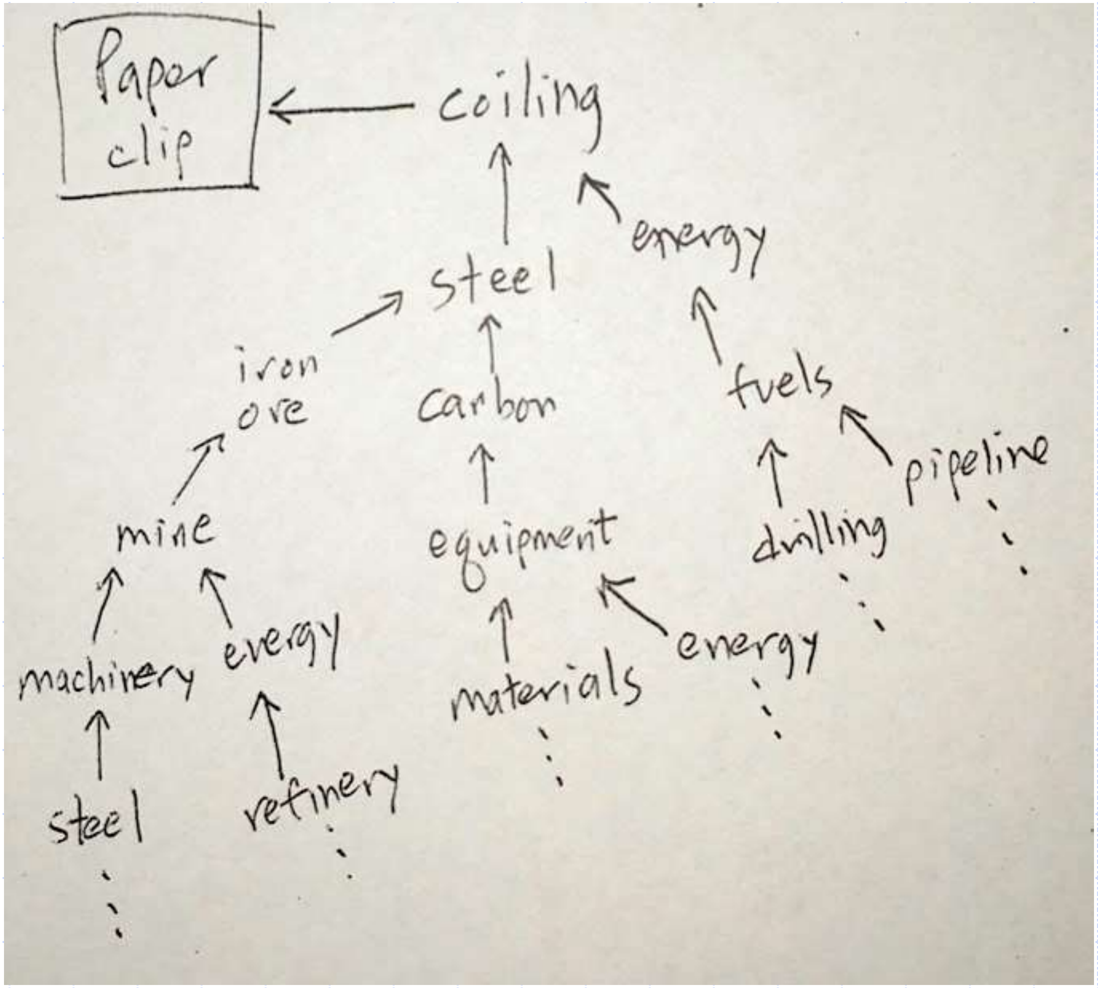
Cradle to ….

Cradle to cradle

- Term coined by Walter Stahel to describe a **circular economy** that internalizes all costs
- 2002 book: *Cradle to Cradle: Remaking the Way We Make Things*, by architect William McDonough and chemist Michael Braungart
- They presented an integration of design and science that provides enduring benefits for society from safe materials, water and energy in **circular economies** and **eliminates the concept of waste**.
- In LCA, refers to the **incorporation of recycling impacts**

LCA Complexity – an example

- What materials/resources do I need to consider for an analysis?
- … a paper clip!!!



If only… (decisions made without Life Cycle thinking)

- In early 1990s, California had a policy goal of reducing emissions of air pollution by encouraging adoption of **zero emission vehicles** (ZEVs) into 2% of fleet by 1998 (10% in 2003).
  - These vehicles were battery-powered (lead acid)
  - These vehicles had no tailpipes
- **A study in Science** by Lave et al (1995) suggested this policy would not achieve its intended goals
- What were (some of) the problems?
  - Cars fully powered by batteries
    - Batteries of this type need to be recharged
    - Recharging happens with electricity
    - Electricity production has air emissions!
  - Batteries were lead-acid
    - Heavy batteries for battery-only power
    - Large amounts of lead needed (with significant manufacture/recycling emissions of lead)
    - More lead released than without ZEVs!
- LCA could have pointed this out

Lave, L., C. Hendrickson, and F. McMichael, “Environmental Implications of Electric Vehicles,” Science, pp. 993-995, May 19, 1995.

Life Cycle Assessment

- What is (and what is not) LCA
  - LCA is a way of structuring/organizing the relevant parts of the life cycle
  - It is a tool to track performance
  - LCA is not a cure-all for our environmental problems
  - LCA is not an “exact” science with provable axioms/theories
  - LCA is part of the sustainability tool box
- History of LCA
  - Initial LCA work was focused on energy
  - 1969 - first multi-criteria study for Coca-Cola
    - Glass versus plastic for container
    - Choice between internal / external container production
    - End of life options (recycling or one-way)
    - Result: plastic bottle was best, contrary to expectations
    - Study never published
    - Questions of validity then occurred (a running theme!)
    - Led to calls by scientific community for a standardization process
  - Early 1990: “paper or plastic?”
  - LCA formal and structured definitions: 1997: first version of ISO LCA
  - Most recent ISO LCA standard is 2006

Agenda

- Life cycle thinking
- Quantitative methods and life cycle cost analysis
- The ISO LCA standard
- Life cycle inventory
  - Data needs and data quality
  - Data sources
  - Handling multifunction systems (disaggregation and allocation)
  - Uncertainty
  - Input-output LCA
- Impact assessment
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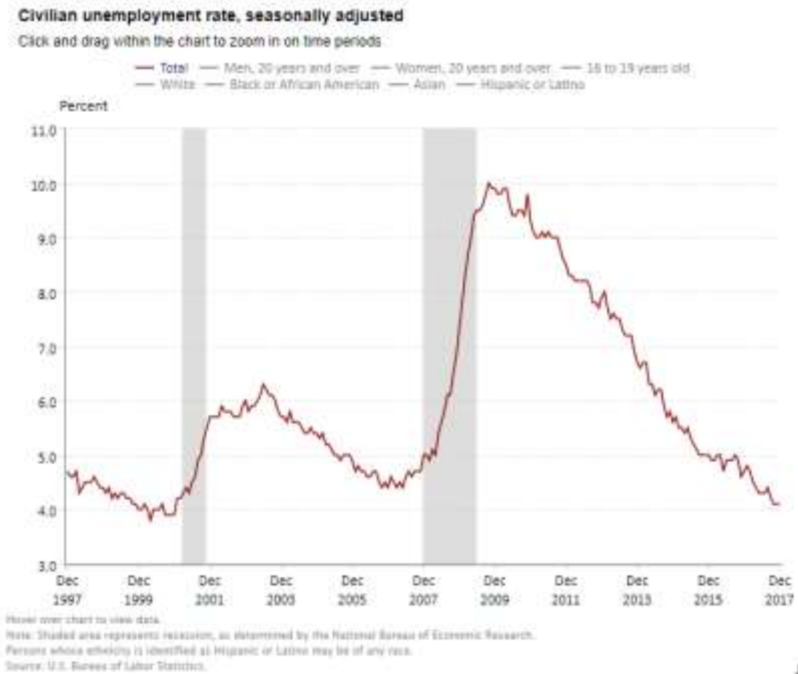
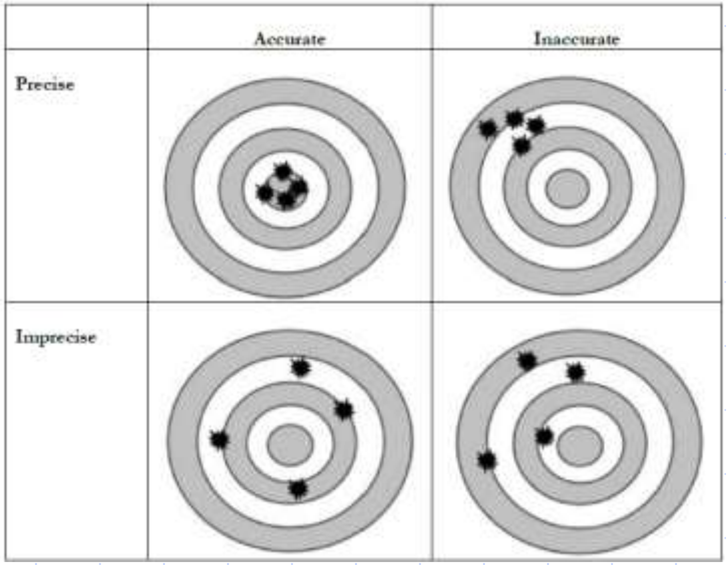
Primary Sources

- Be quantitative!
  - … sometimes a qualitative skill may be needed
- A reference, article, etc., that is the original source of data or results
  - Example: US Dept. of Labor/Bureau of Labor Statistics collects data on unemployment through monthly household surveys
  - December 2017 – 4.1%
  - https://www.bls.gov/bls/unemployment.htm
- When working with data sources, pay attention to:
  - Accuracy vs. precision
  - Uncertainty and variability
  - Ranges
  - Management of significant digits
  - Units and unit conversions
  - Energy conversion and efficiency
  - Estimation vs. calculation





Secondary Sources

- A reference that repeats the data/results found in a primary source
  - Example: An article in The New York Times discussing previus month's unemployment (4.1%) which came from the Dept. of Labor

The New York Times

POLITICS

Unemployment Rates Hit Record Lows in 3 US States Last Month

By THE ASSOCIATED PRESS JAN. 23, 2018, 1:18 P.M. E.S.T.

WASHINGTON — The unemployment rate fell to record lows in three U.S. states last month, as steady hiring soaked up more of those out of work.

The Labor Department said Tuesday that the jobless rate fell to the lowest levels since records began in 1976 in Hawaii, Mississippi and California. The rate in Hawaii was 2 percent, while Mississippi's dropped to 4.6 percent and California's declined to 4.3 percent.

Nationwide, employers added 148,000 jobs last month and the U.S. unemployment rate stayed at 4.1 percent. Employers added 2.1 million jobs last year, the fewest in seven years. Hiring typically slows as the unemployment rate falls and there are fewer people to hire.

https://www.nytimes.com/aponline/2018/01/23/us/politics/ap-us-state-unemployment.html

Released: Dec 2006
Next CBECS will be conducted in 2007

Table C14. Electricity Consumption and Expenditure Intensities for Non-Mall Buildings, 2003

	Electricity Consumption						Electricity Expenditures		
				Distribution of Building-Level Intensities (kWh/square foot)					
	per Building (thousand kWh)	per Square Foot (kWh)	per Worker (thousand kWh)	25th Per-centile	Median	75th Per-centile	per Building (thousand dollars)	per Square Foot (dollars)	per kWh (dollars)
All Buildings*	202	14.1	12.2	3.6	8.2	17.1	15.7	1.09	0.078

US Dept. of Energy, 2003 Commercial Buildings Energy Consumption Survey (CBECS), Table C14. "Electricity Consumption and Expenditure Intensities for Non-Mall Buildings, 2003", 2006.

Release date: May 2016

Table C14. Electricity consumption and expenditure intensities, 2012

	Electricity consumption						Electricity expenditures		
				Distribution of building-level intensities (kWh/square foot)					
	per building (thousand kWh)	per square foot (kWh)	per worker (thousand kWh)	25th per-centile	Median	75th per-centile	per building (thousand dollars)	per square foot (dollars)	per kwh (dollars)
All buildings	237	14.6	14.1	3.8	8.7	17.2	23.3	1.44	0.098

https://www.eia.gov/consumption/commercial/data/2012/c&e/pdf/c14.pdf

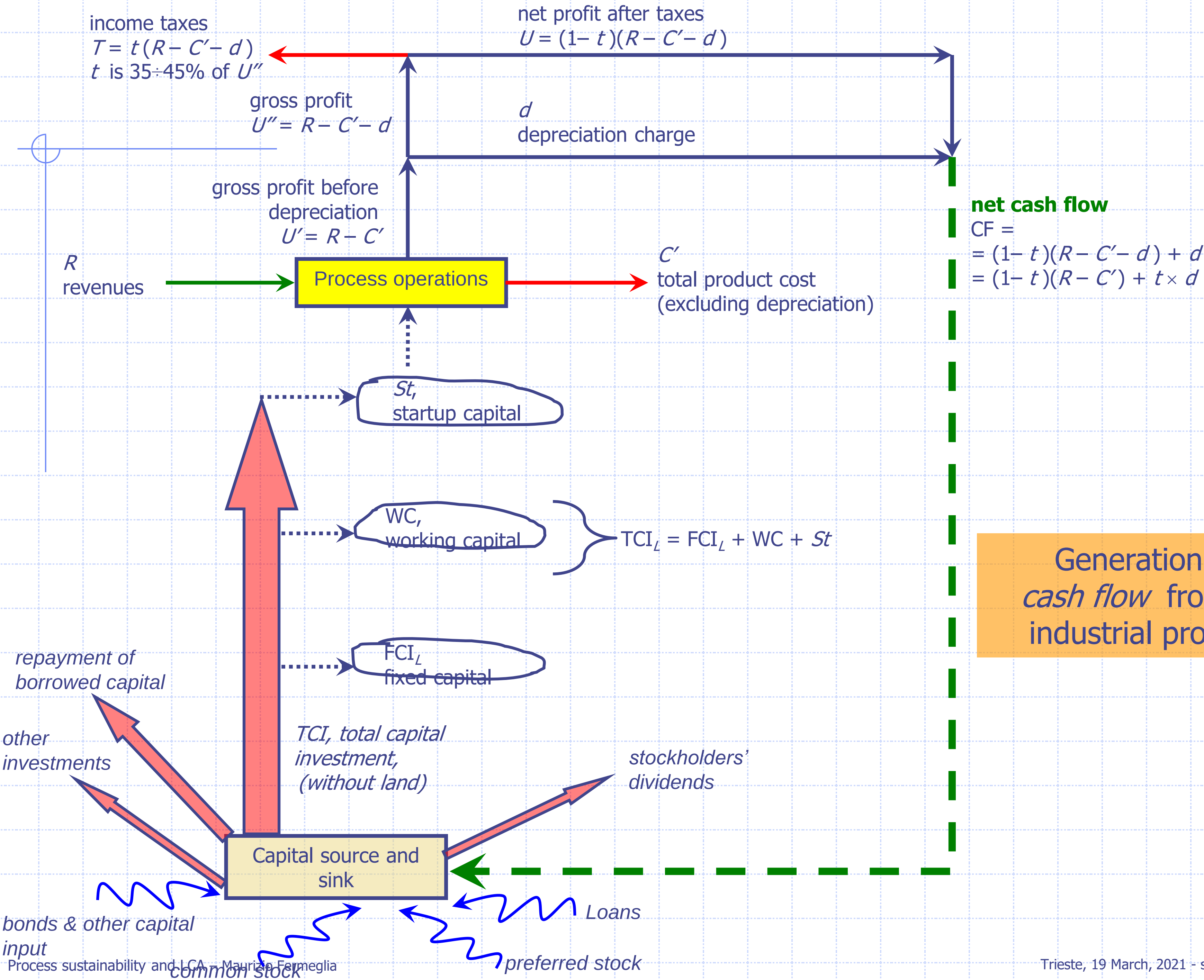
Attributes of ‘good assumptions’

- Main attributes
  - Clarify and simplify
  - Correct, credible and feasible
  - Not a shortcut
  - Unbiased
- Validate your estimate
- Build quantitative models
- General guideline on how to quantitatively answer question. Provide:
  - A description of the method used to complete the task
  - The result or output of the task
  - A critical assessment, validation, or thought related to the result

Point of Departure: Life Cycle Cost Analysis (LCCA)

- Developed to **track costs** over life cycle of infrastructure projects
  - Lets decision makers think about “first cost” and maintenance, etc.
  - Useful also for personal decisions
- Concepts from **engineering economics** or investment analysis,
  - In depth coverage elsewhere
  - Related to this is the **total cost of ownership**
- LCCA as a **basis for LCA**
  - LCCA often used as a **planning tool** early in a project
  - LCCA is the **economic analysis** of various phases of a project’s useful life
    - Construction (including materials)
    - Occupation or use by the public (operating costs, maintenance, rehabilitation)
    - Disposition (demolition)
  - Very similar to the frameworks for environmental life cycle models

Generation of *cash flow* from an industrial process



Breakdown of total product cost

Total product cost (TPC)

manufacturing cost
(operating or production costs)

direct production costs
(variable production costs)

- raw materials
- utilities
  - ➢electricity
  - ➢fuel
  - ➢refrigeration
  - ➢steam
  - ➢waste treatment & disposal
  - ➢process water
  - ➢cooling water
- maintenance & repairs
- operating supplies & laboratory charges
- operating labor
- direct supervision & clerical labor
- patents & royalties

60% TPC

fixed charges

- depreciation
- local taxes
- insurance
- rent
- interest

10÷20% TPC

plant overhead

- general plant upkeep & overhead
- payroll overhead
  - ➢social security
  - ➢retirement plans
- packaging
- medical services
- safety & property protection
- restaurants & recreation facilities
- storage facilities

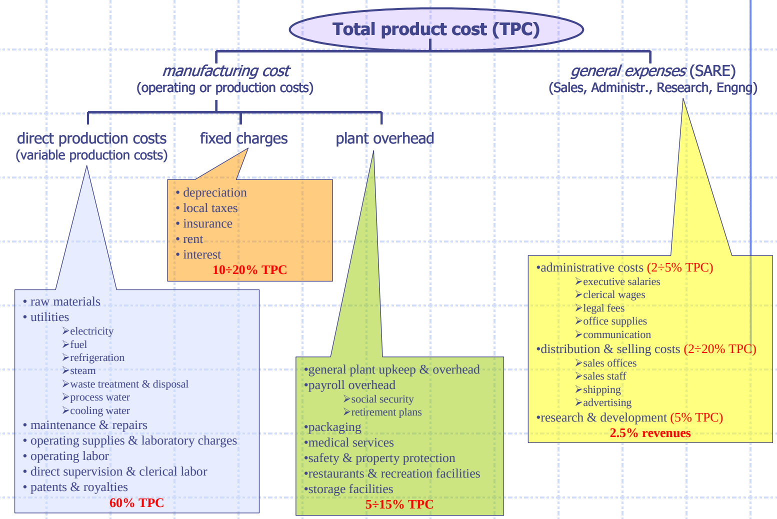
5÷15% TPC

general expenses (SARE)
(Sales, Administr., Research, Engng)

- administrative costs (2÷5% TPC)
  - ➢executive salaries
  - ➢clerical wages
  - ➢legal fees
  - ➢office supplies
  - ➢communication
- distribution & selling costs (2÷20% TPC)
  - ➢sales offices
  - ➢sales staff
  - ➢shipping
  - ➢advertising
- research & development (5% TPC)

2.5% revenues

A model for the estimation of total product cost (TPC)



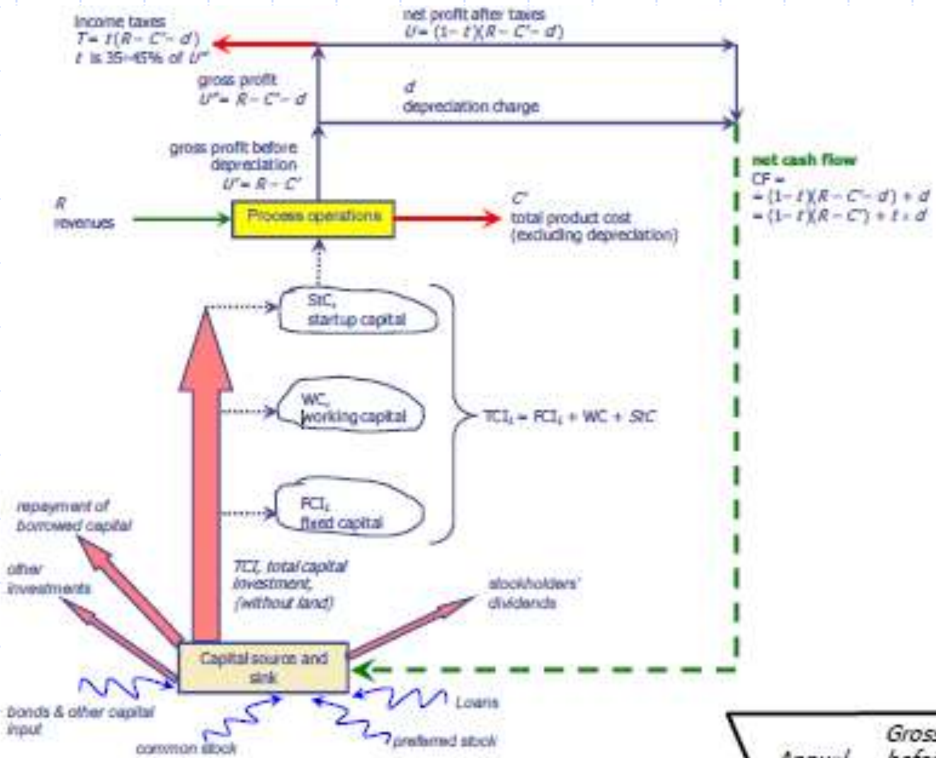
- A few (sound) hypotheses (Douglas, 1988)
  - SARE ≅ 2.5% of revenues
  - maintenance ≅ 4% FCI each year
  - cost of operating labor: ≅ 10^5 \$/(operator×year)
  - no borrowed capital; no expenses for land
  - no depreciation allowance (so far)

$$\begin{pmatrix}\text{total product}\\ \text{cost, TPC; \$/yr}\end{pmatrix}_{\substack{excluding\\ depreciation}} \cong 1.03\begin{pmatrix}\text{raw materials costs}\\ +\ \text{utilities costs}\end{pmatrix} + 0.186\begin{pmatrix}\text{onsite direct}\\ \text{costs, ISBL}\end{pmatrix} + 2.13\times 10^{5}\left(\text{no. of operators}\right) + 0.025\left(\text{revenues}\right)$$

All numeric coefficients have proper unit dimension

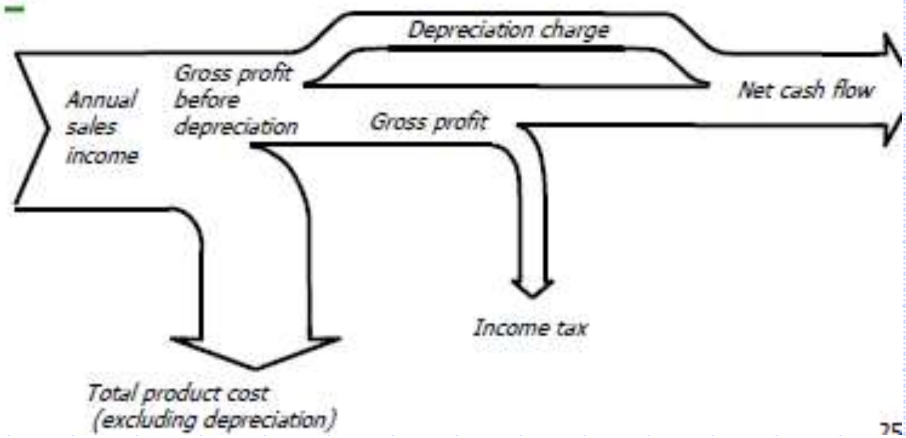
- To be able to provide and estimate of the total product cost, we need to determine:
  - amount of raw materials needed
  - utilities consumption
  - installed costs for all the pieces of equipment
  - total number of operators needed to run the plant
  - revenues from product sales

Profitability analysis



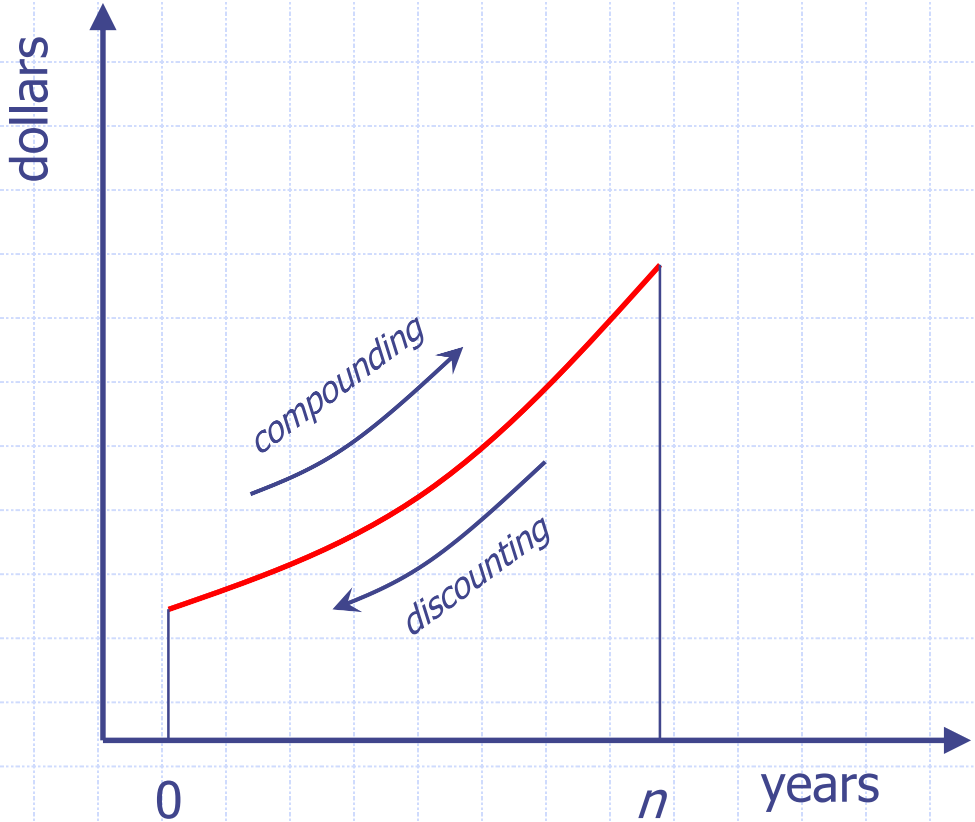
Depreciation returns to investors through a special ***isolated channel***, separated from the ***profit*** conduit

- *it is tax-free*
- *it is the procedure used by investors recover the initial investment*



Discounting and compounding

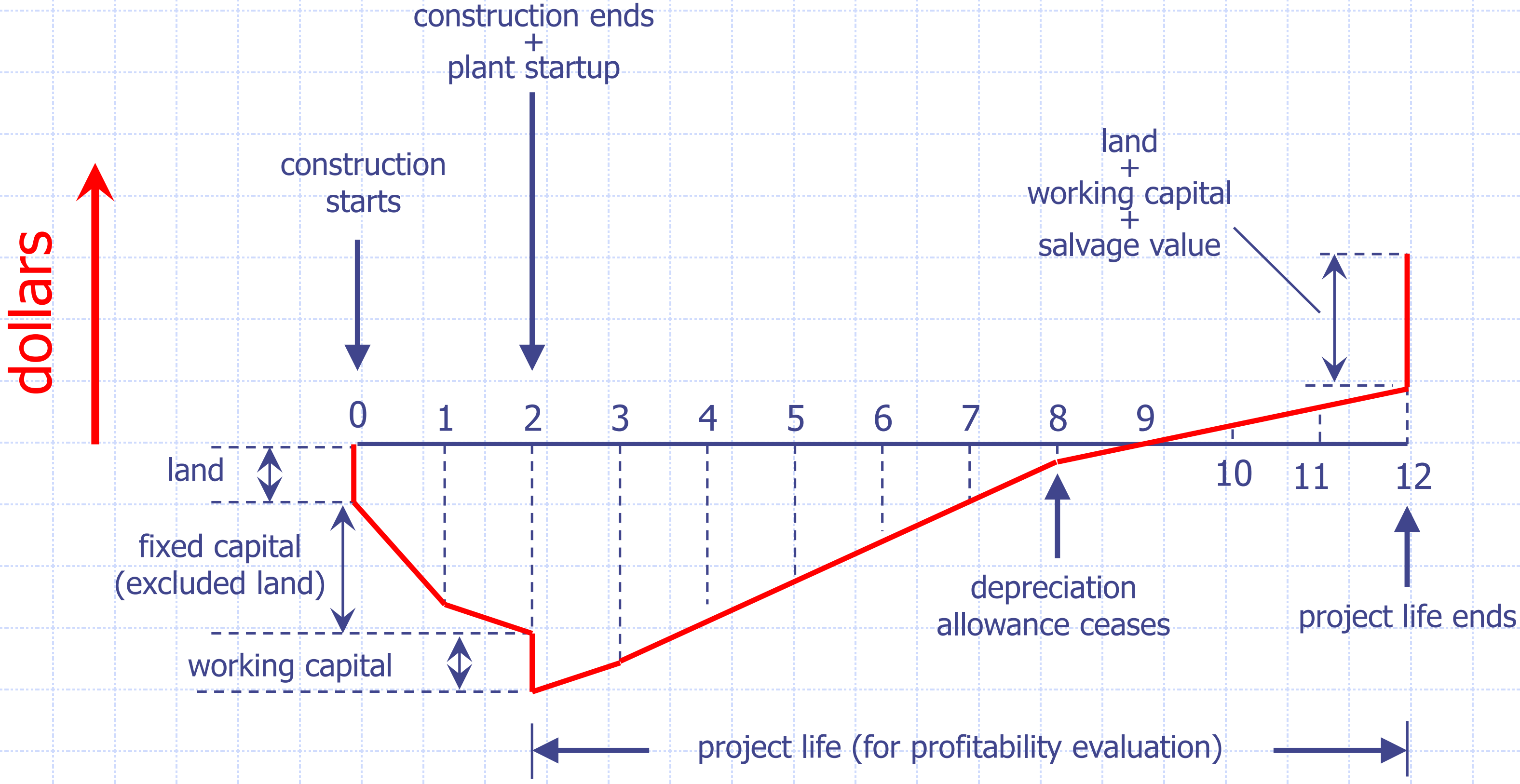
- Cash flows appear at (the end of) different years during the life of a plant
  - they can be negative (investments; expenses) or positive (revenues)
- To compare these cash flows, they must be put on the same basis, i.e. they must be referred to the same year in time (forward or backward)



- The concept of **interest** is used to move forth and back in time
  - compounding
  - discounting
- **Interest represents the earnings on money loaned (and invested)**
  - also the cost of borrowed money is called interest
- The **interest rate** is the amount of money earned on 1 $ in 1 year
  - this is the investor point of view

Cumulative discounted cash flow diagrams

- Building a new plant ususally requires 6 months to 3 years (e.g. 2 years, in the diagram below)
  - most of the capital is invested in the first year
  - at the end of the 2nd year the plant is started up
  - working capital is required to float the few months of operation (startup costs not accounted for)
  - the project life is 10 years (in the example below)



Objectives of LCCA

- Identify costs that happen during the life of the "project"
  - First cost (construction, manufacturing)
  - Future costs (monthly, annual, intermittent, final)
- Determine a "total cost" with a common monetary basis
  - "Discount" all future costs to the present for comparison (e.g., present value)
  - Sum all costs on "net present value" (NPV) basis
- Compare alternatives
  - Best NPV?
  - Identify high cost components for re-design

Example - Light Bulbs

- Should we choose incandescent, fluorescent or LED?
- “First” costs: bulbs costs \$1.25, \$1.50, \$2.49, respectively
- “Operating” costs
  - How long are they on? Hours → kWh → \$
- “Replacement” costs
  - How long do they last? 1,000 vs. 15,000 hrs
  - How much do they “cost to buy & change”
    - e.g., campus laborers cost \$48.67/hr
    - CMU/FMS no longer stocks incandescent bulbs

Lightbulb analysis… a start

Assumptions			
Operating hours	8,760	24 hours/365 days/year	
Cost of electricity	0.075	$/kWh	
Changeout cost (1 hour of labor)	$ 48.67	1 laborer	(2016)

Lightbulb analysis… a start

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Operating hours	8,760	24 hours/365 days/year	
Cost of electricity	0.075	$/kWh	
Changeout cost (1 hour of labor)	$ 48.67	1 laborer	(2016)

Lightbulbs (60W equiv)	Incandescent	Fluorescent	LED
Bulbs/pack	16	6	2
$/pack	$ 19.98	8.98	4.98
$/bulb	$ 1.25	$ 1.50	$ 2.49
Lumens	555	900	800
Rated life (hours)	1,000	10,000	15,000
Watts	60	13	9
Bulbs/year (rounded up)	9	0.876	0.584

Lightbulb analysis… a start

Assumptions				
Operating hours	8,760	24 hours/365 days/year		
Cost of electricity	0.075	$/kWh		
Changeout cost (1 hour of labor)	$ 48.67	1 laborer	(2016)	
Lightbulbs (60W equiv)				
	Incandescent	**Fluorescent**	**LED**	**2016 LED**
Bulbs/pack	16	6	2	6
$/pack	$ 19.98	8.98	4.98	12.98
$/bulb	$ 1.25	$ 1.50	$ 2.49	$ 2.16
Lumens	555	900	800	750
Rated life (hours)	1,000	10,000	15,000	5000
Watts	60	13	9	9
Bulbs/year (rounded up)	9	0.876	0.584	1.752
Annual bulb replacement cost	$ 11.24	$ 1.31	$ 1.45	
Annual operating cost	$ 39.42	$ 8.54	$ 5.91	
Subtotal:	$ 50.66	$ 9.85	$ 7.37	
Annual changeout labor	$ 438.03	$ 42.63	$ 28.42	
Total annual cost	$ 488.69	$ 52.49	$ 35.79	

Lightbulb analysis, more

- So far, considered initial cost to purchase, install, and one year of operation
- What about the cost of the next years?
  - Lifespan of a project, planning horizon?
- We can account for the cost over the life cycle of a product using "discounting" to calculate the "present value" of those costs
  - We care more about current costs than future costs
  - Discount rates are applied to future costs

- Simple cost analysis considers only first costs, or of only first year costs,
  - Partial understanding
- Full life cycle accounting (aka "discounted cost assessment") provides sounder basis for decisionmaking
- Discounting allows for consideration of preferred present value of money
  - Costs are compared using a common basis

Discounting future values to the present

- Costs in the future are less important than costs in the present
- The present value of a future cost is represented by

$$P = \frac{F}{(1+r)^n}$$

- where
  - P = present value
  - F = future value
  - r = discount rate
  - n = the year the cost is incurred

- Back to our example:
  - Initial costs are counted in Year 0
  - Costs assumed to be incurred at the end of the year
- Year 5 example:
  - $1
  - r=5%
  - n=5
  - Discount factor = [1/(1+0.05)5]= 0.784
  - PV of $1 in Year 5 is $0.78
- NPV is the sum of all costs, calculated on a present value basis

Adding NPV to the light bulbs

	Year						
	0	1	2	3	4	5	NPV
Incandescent	$ 488.69	$ 474.46	$ 460.64	$ 447.22	$434.19	$ 421.55	$ 2,726.74
Fluorescent	$ 52.49	$ 50.96	$ 49.47	$ 48.03	$ 46.63	$ 45.28	$ 292.86
LED	$ 35.79	$ 34.75	$ 33.74	$ 32.75	$ 31.80	$ 30.87	$ 199.70
	Discount rate:						
	3%						

- Note that this analysis uses single point assumptions
  - Provides no understanding of uncertainty or sensitivity to assumptions
- Results last year showed fluorescent bulbs were preferable
- LED lifespan is improving!

Life Cycle Costs of a Passenger Car

- What are life cycle costs for a car?
- Edmunds.com – "True cost to own" calculator
  - http://www.edmunds.com/tco.html

Ownership Costs: 5 Year Breakdown

15213 Update Results for Pittsburgh, PA

Two 4dr Hatchback

(1.8L 4-cyl. Hybrid CVT Automatic)

True Cost To Own*

$25,517

*Based on a 5-year estimate with 15,000 miles driven per year.

Total Cash Price

$15,907

Roll over chart to view prices.

5 Year Details

	Year 1	Year 2	Year 3	Year 4	Year 5	5 Yr Total
Depreciation	$3,170	$1,491	$1,312	$1,163	$1,043	$8,179
Taxes & Fees	$997	$36	$36	$36	$36	$1,141
Financing	$716	$572	$422	$263	$94	$2,067
Fuel	$792	$816	$840	$865	$891	$4,204
Insurance	$712	$733	$755	$778	$801	$3,779
Maintenance	$306	$1,288	$1,061	$737	$1,048	$4,440
Repairs	$203	$296	$343	$400	$465	$1,707
True Cost to Own ®	**$6,896**	**$5,232**	**$4,769**	**$4,242**	**$4,378**	**$25,517**