Process sustainability and Life Cycle Assessment

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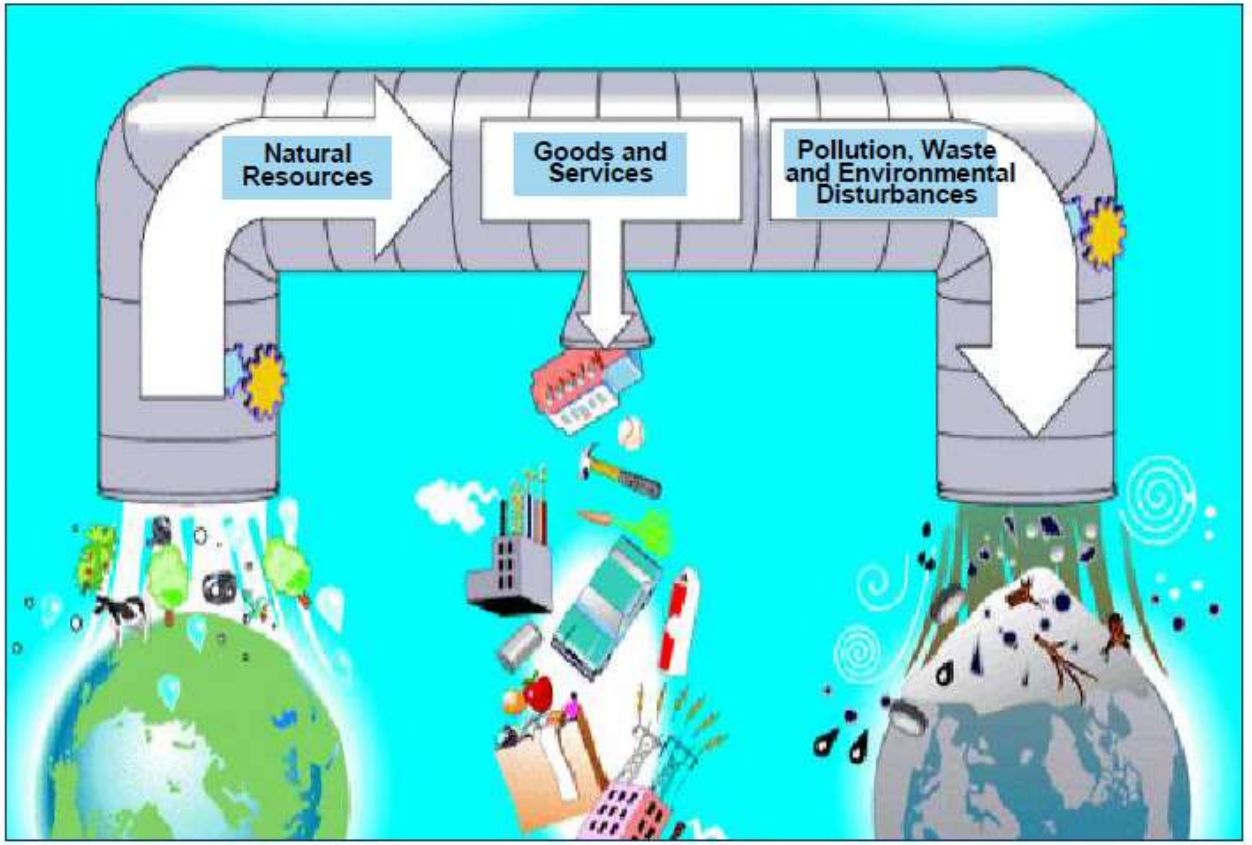
Motivation: are our products and processes sustainable?

Only 25 wt% of what goes into the pipe comes out as goods and services – scope for significant improvements



Adapted from Drioli, 2005

Without significant improvements, our products-processes are not sustainable

Sustainable Development

- Objectives
  - Reducing (eliminating) poverty through industrialization
  - Industrialization requires high amounts of energy & water

- Social progress must recognise the basic needs of everyone
- Effective protection of the environment
- Prudent use of natural resources
- Maintenance of high and stable levels of economic growth and employment

Sustainable Development of Industrial Processes

Reduce the use of energy and water

Improve Utility System Performance

Reduce Environmental Impact

The process must be economically sustainable!

Sustainable Development by **Process Integration**

Fundamental Requirements of any Industrial (and Social) Activities

- achieving Safety S
- ensuring human Health H
- protecting the Environment E
  - with respect to both processes and products
  - is this enough to achieve sustainability?

- A further relevant factor: population
  - Total world population predicted to be around 10 billion by year 2050
  - The larger growth expected in less developed countries
  - Widening gap between rich and poor
  - Equity (the fair distribution of wealth, knowledge and power) must become the dominant variable

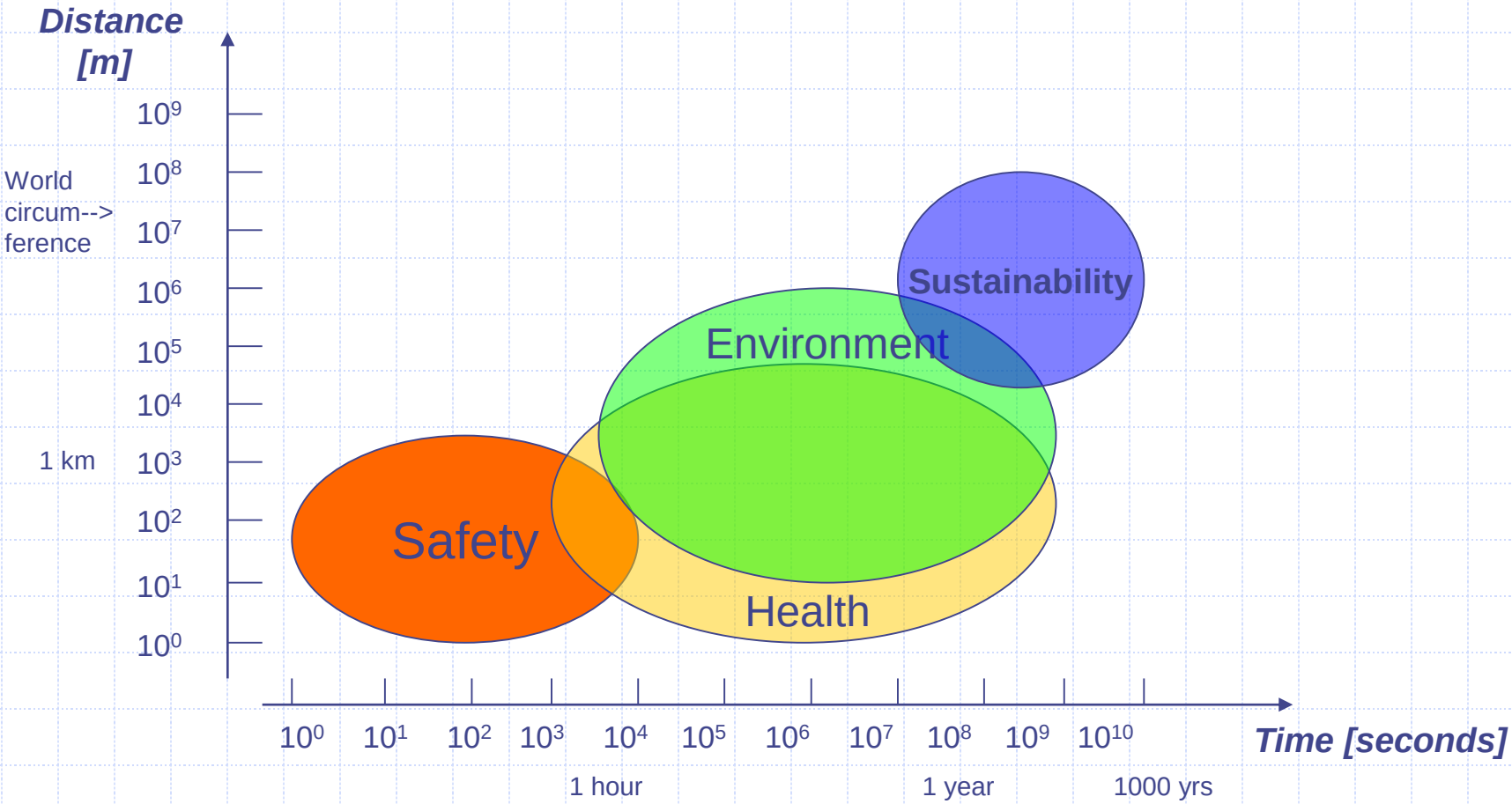
Sustainability

- Fundamental issues
  - All people want to share prosperity
  - All people have the right to do it
  - The 'developed' countries represent a minority (12%), but give a major contribution (80%) to the depletion of natural resources
  - World population is growing, average lifetime is increasing
  - Pollution has become a daily issue also for human health (not only for the environment) in many parts of the world
  - Energy and materials are being consumed at a rate which could not be applicable to the total world population
  - We will come to fight about the same (limited) resources
- This situation cannot last any longer: it is not sustainable

Some Definitions of Sustainability

- "*Sustainable development is the means of improving the quality of human life while living with the carrying capacity of the supporting ecosystems*" (UNEP)"
- "*Humanity has **the ability** to make development sustainable, **to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs***" (The Bruntland Report, 1987)
- What about sustainability of **industrial chemical productions**?
  "*Sustainability in Chemical Engineering is a continuous effort to improve*
  - environmental protection
  - raw material exploitation
  - energy use efficiency
  - water use efficiency
  - safety and health protection
  - in all kinds of material conversion processes and material production" (EFCE definition)
- The goal of Sustainability: SHE respecting environmental constraint
  - It means running the world ecosystem in sustainable steady-state conditions with respect to materials, energy and population

Inter-relation with Time and Space Scale



from S.M. Lemkowitz and H.J. Pasman, Delft Univ., 1999

The Problem of Chemical Productions

- Chemicals are produced in well defined locations
  - In chemical and biochemical plants hazardous materials are often processed
- First question: how to manage hazardous productions
- ***Are chemical/biochemical plants sustainable?***

- Chemicals are essential for well-being of mankind
  - Chemicals are produced in well defined locations, but they are used everywhere (by industries and people)
- Second question: how to handle hazardous chemicals in both manufacturing and human activities
- ***Are chemical products sustainable?***

How to Assess (Un)sustainability of Chemical/Biochemical Productions?

Sustainability Annual Impact on the Environment
=
(Environmental Impact per Unit of Resource
x
(Resource Use per Unit of Product)
x
(Product Demand per person per Year)
x
(Number of People)

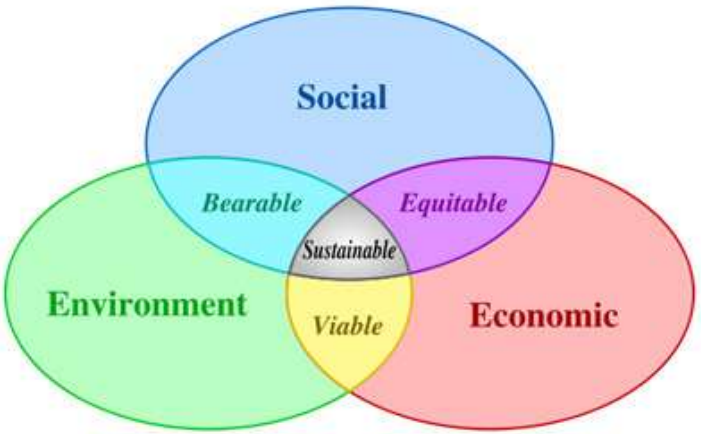
How to proceed?

- Relevant factors to reduce impact:
  - Average product demand per person: rapidly increasing
  - Number of people: increasing up to 10 billions
  - Environmental Impact: some improvements done in last 50 years
  - Resource use: little being done at present
- *How can the last two factors be evaluated?*
  - by process simulation, optimisation and control
  - by environmental modelling
- *How can their values be decreased?*
  - by inventing new processes and products
- *How can these new alternatives be developed at the industrial level?*
  - by Process Simulation and Life Cycle Assessment

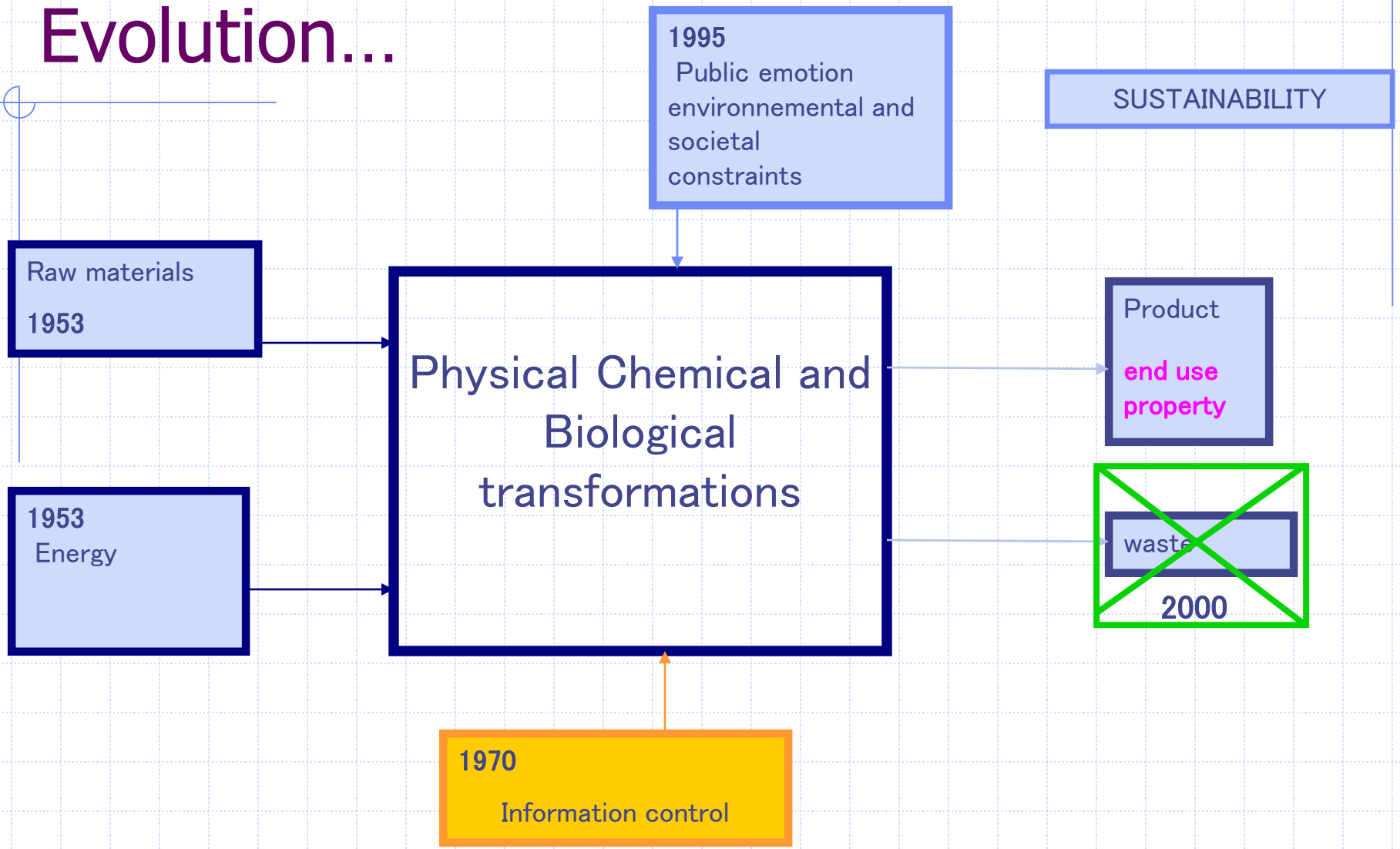
Sustainable Chemical Technologies

- Sustainable Chemical Technologies should enable Environmentally Sound Processes and Products
  - under safer conditions (neither risks nor toxic compounds)
  - with minimum resource consumption (dematerialization)
  - with minimum amount of residues (in air, water and soils)
  - with higher selectivity and yields (less by-products)
  - more based on renewable raw materials (i.e. biomass)
  - more economical (including environmental economics)

This is called '**Industrial Ecology**'



Evolution...


1995
Public emotion environnemental and societal constraints
SUSTAINABILITY
Raw materials
1953
Physical Chemical and Biological transformations
Product
end use property
1953
Energy
waste
2000
1970
Information control

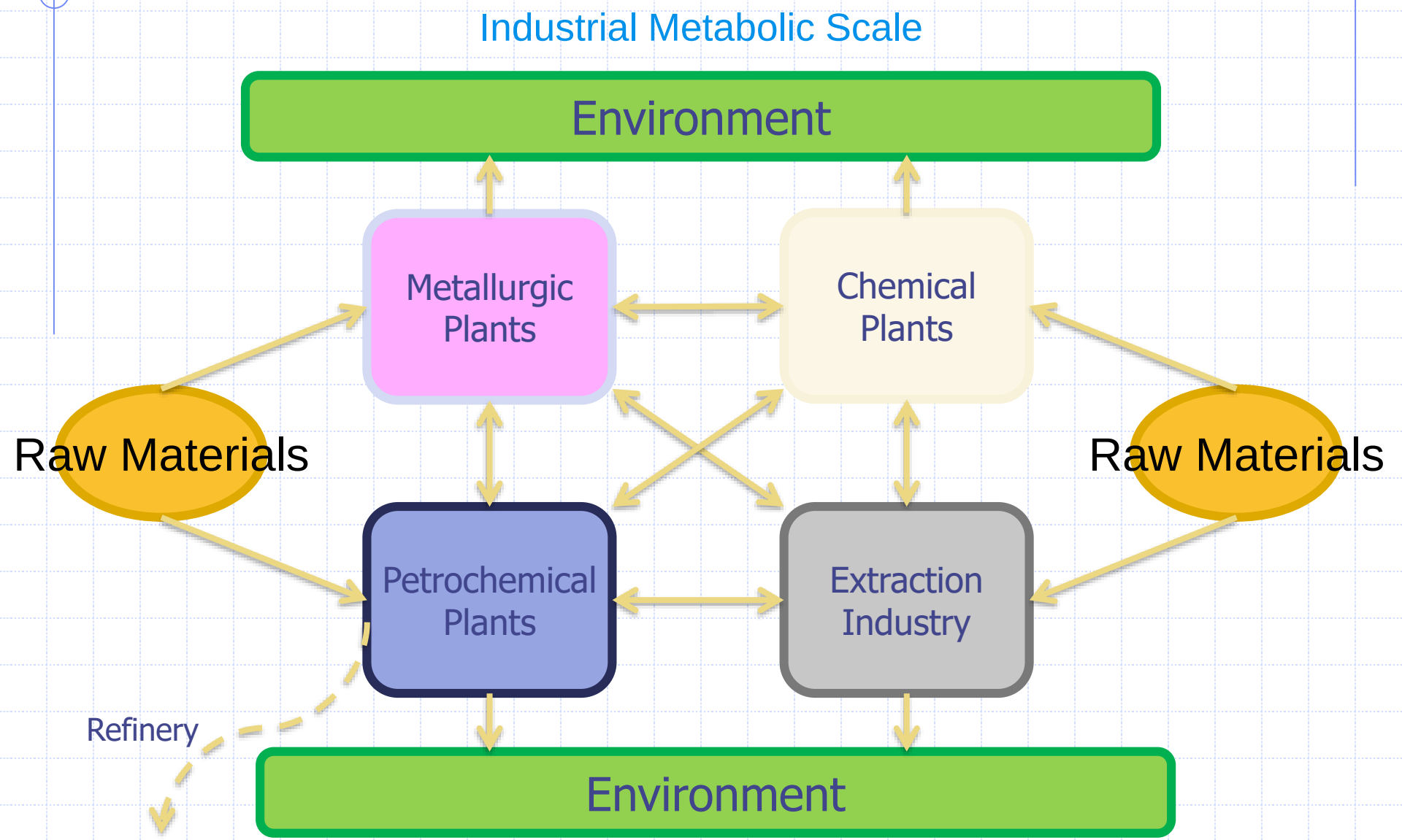
Summary of tools to study sustainability of industrial processes

- Risk Analysis and Evaluation Techniques (Process Controllability)
- Environmental Modeling
- Life Cycle Analysis
- Economical and financial analysis
- Sustainability Indicators Analysis
- ….

Process Simulation

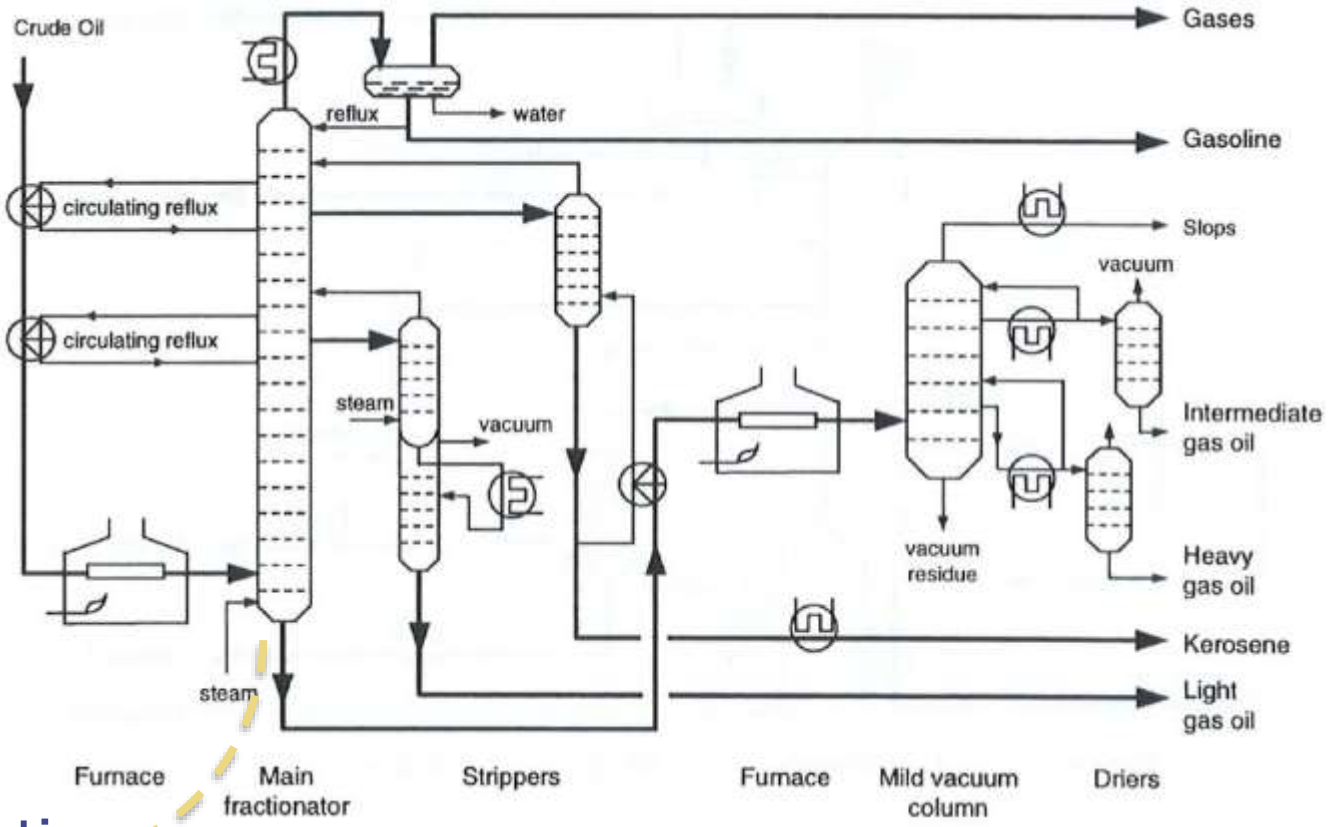
Industrial Ecology Process

Macroscale Analysis: Industrial Ecology



Mesoscale Analysis: Refinery

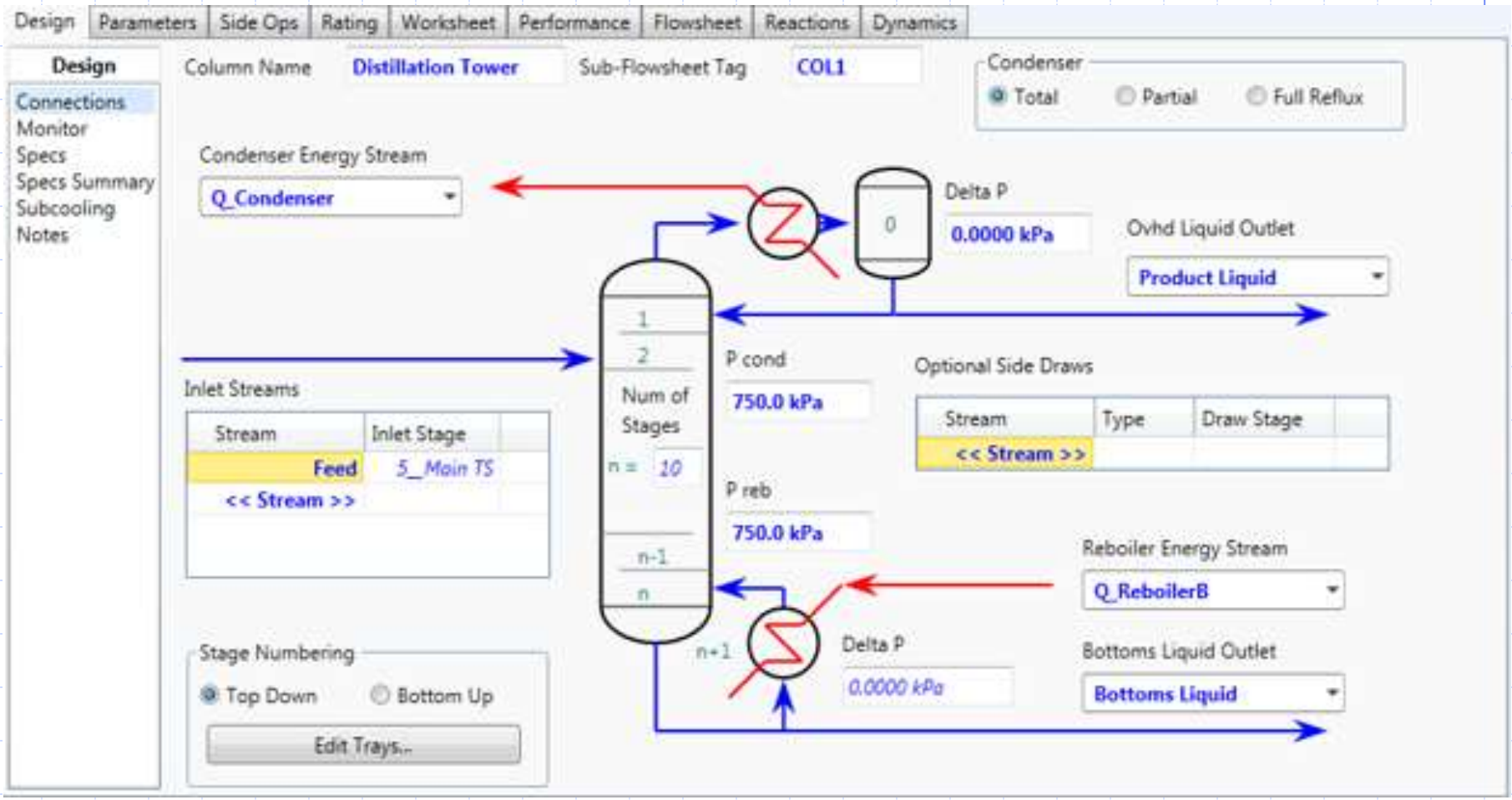
Process Engineering Scale



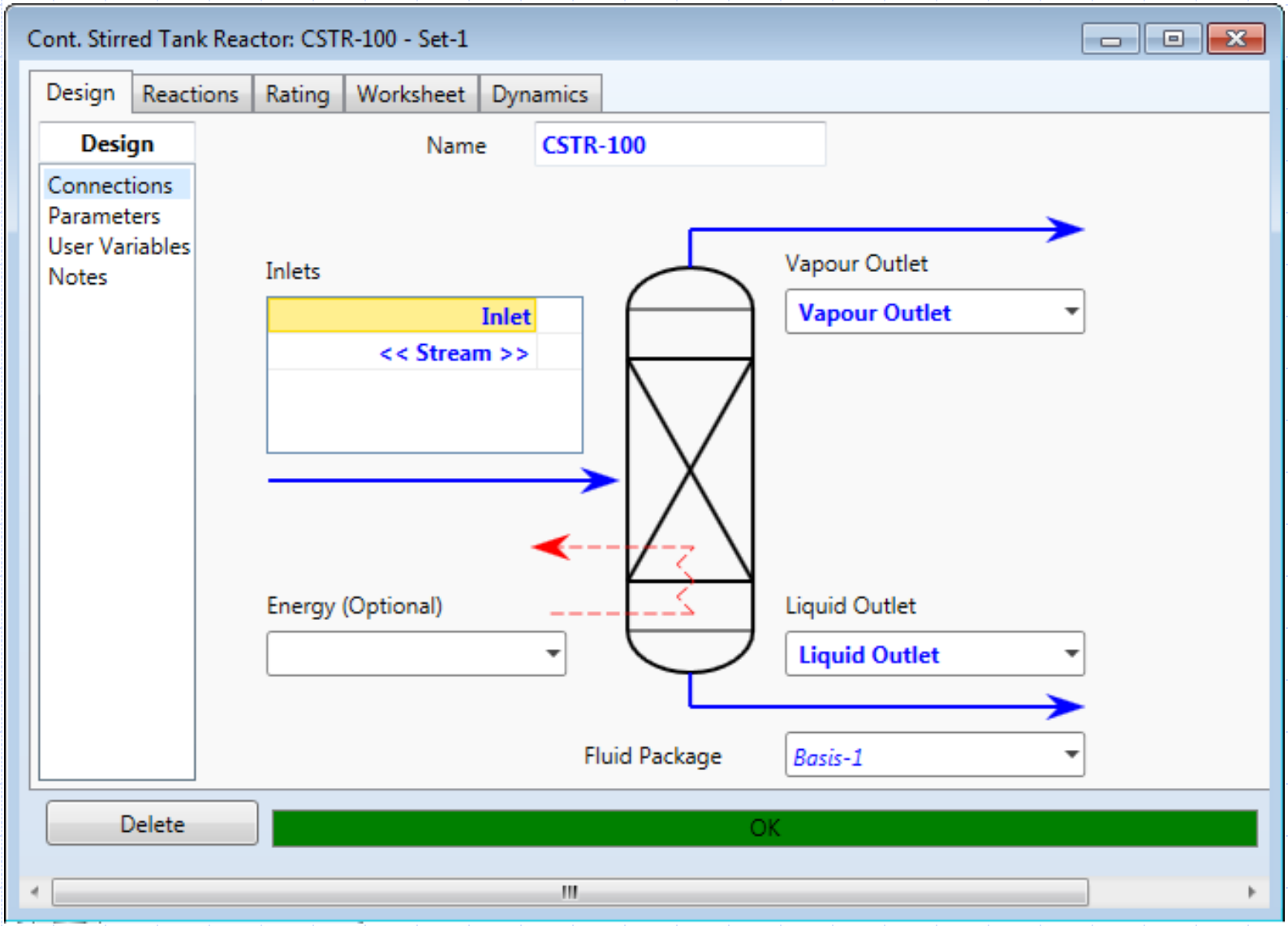
Separation Tower

Microscale Analysis: Separation Tower

Process Engineering Scale

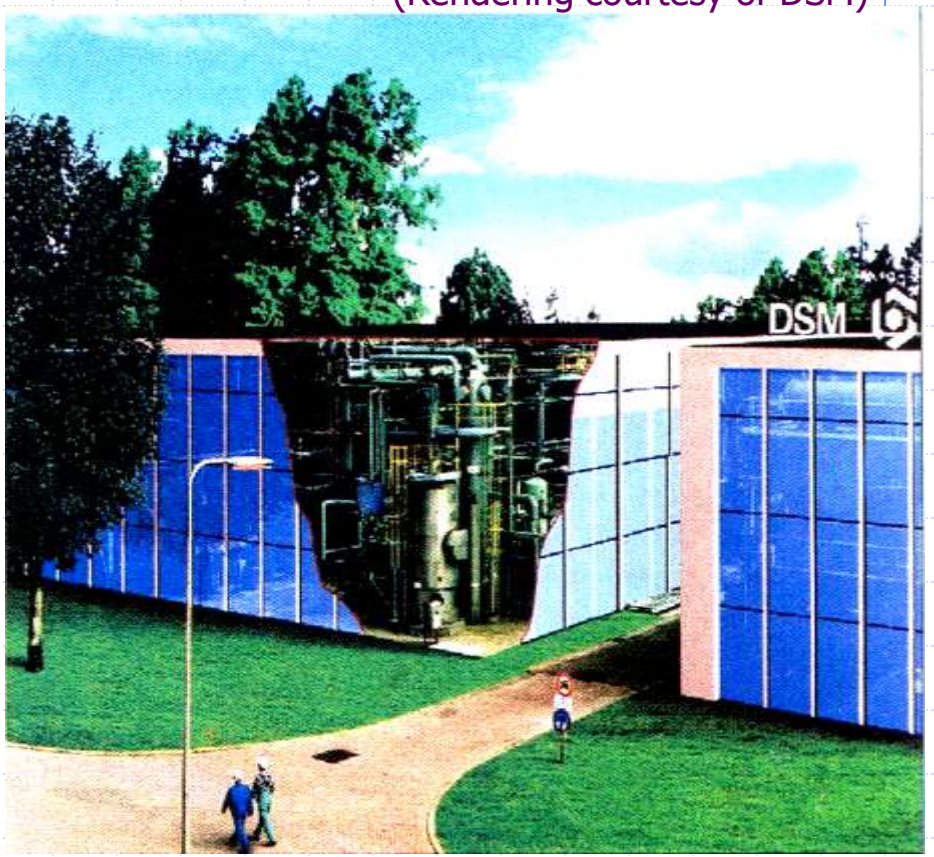


Microscale Analysis: CST reactor



A vision… how a future plant may look vs. a conventional plant.

(Rendering courtesy of DSM)

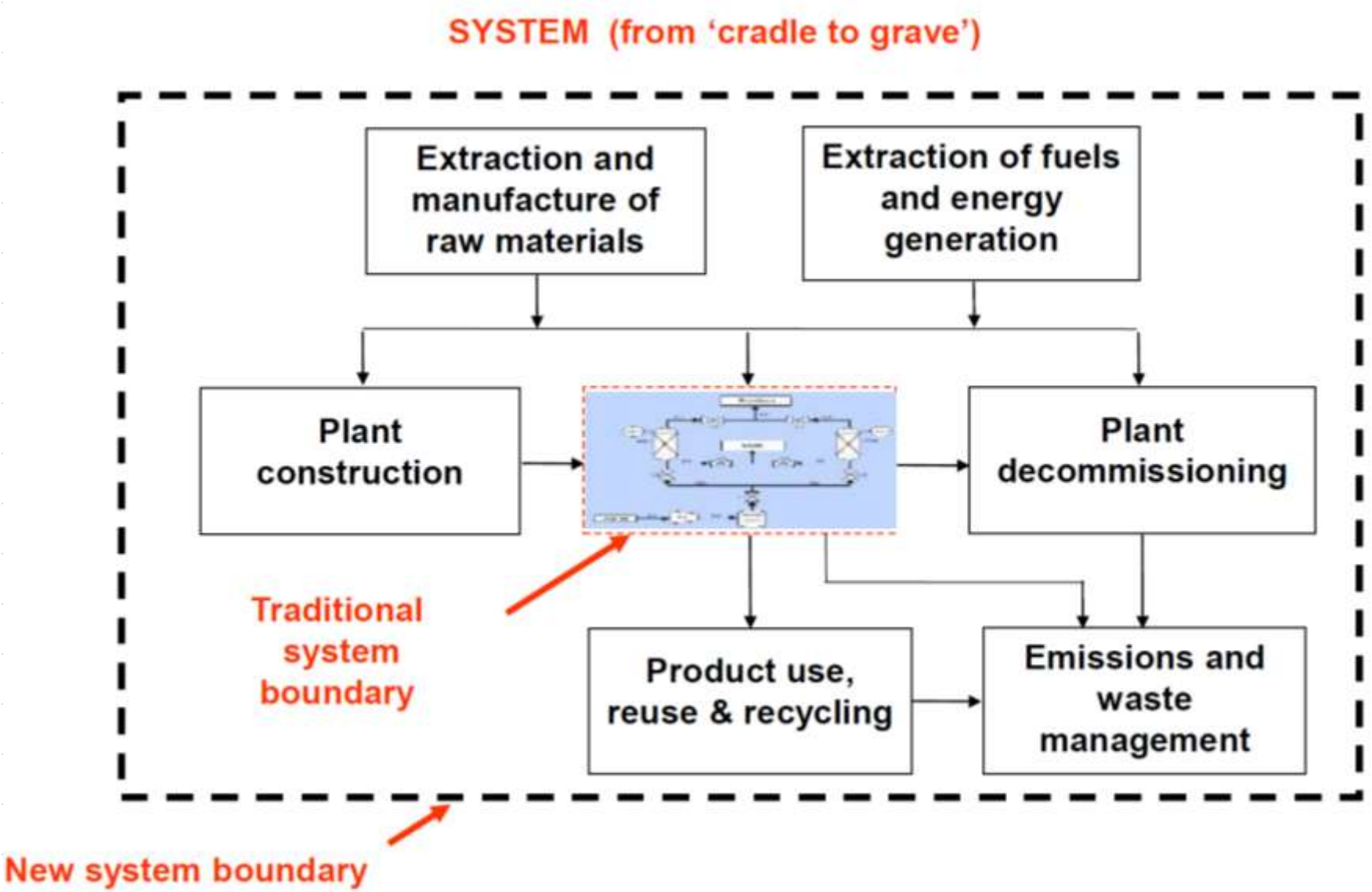


OPERATING with NON POLLUTING PROCESSES involving

PROCESS INTENSIFICATION

SAVINGS ABOUT 30 % (RAW MATERIALS + ENERGY + OPERATING COSTS)

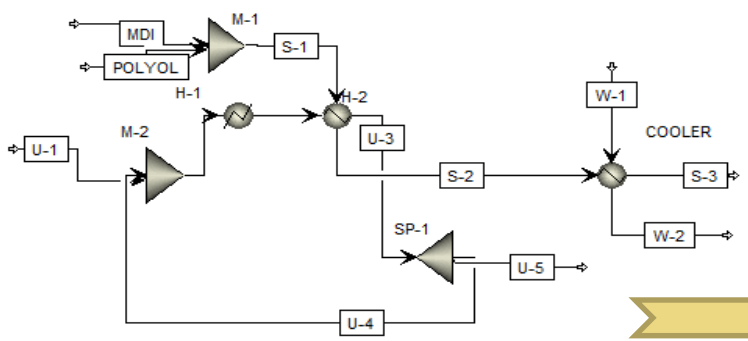
Issues: system boundary definition



Process simulation, multiscale modeling and life cycle assessment

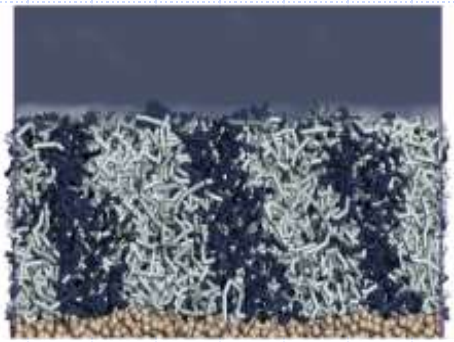
Process design

Material and energy balances



Product design

Multiscale modeling for material properties



Goals definition & scope

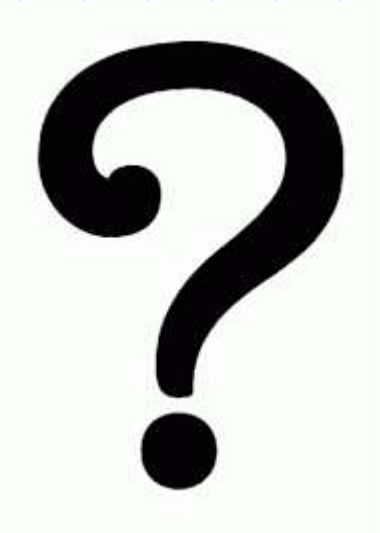
Inventory analysis

Environmental impact analysis

Results interpretation

Environmental life cycle assessment

- The assessment of environmental impacts of products or processes from "cradle to grave"



Environmental life cycle assessment

- "Cradle to Grave"
  - Raw material extraction
  - Manufacturing
  - Transportation
  - Usage
  - Disposal
- Environmental impacts
  - Greenhouse gases
  - Particulates
  - Water withdrawal
  - Toxics
  - Land use

Just a few examples

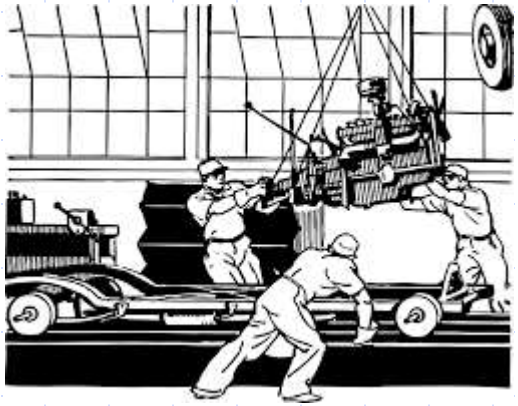
Wide range of **interesting** questions…

- Paper or plastic grocery bags
- Cloth or disposable diapers
- Digital or hardcopy books (and music)
- Plastic water bottles or tap water

Plastic Versus Paper Versus Re-Usable: Does it Really Matter?

Wide range of **useful** questions

- What aspect of my product's life cycle has the biggest impact on the environment (and why)?
  - Driving, building or fueling a car?



  - And what should we focus on to reduce impacts?

Wide range of **useful** questions

- How do our dietary choices impact the environment?
  - Small and local versus large and distant?
  - Omnivore versus vegetarian?

  - And how significant are the differences?

How many **Earths** do we need?

(Biocapacity/human ecological footprint) x365 = earth overshoot day

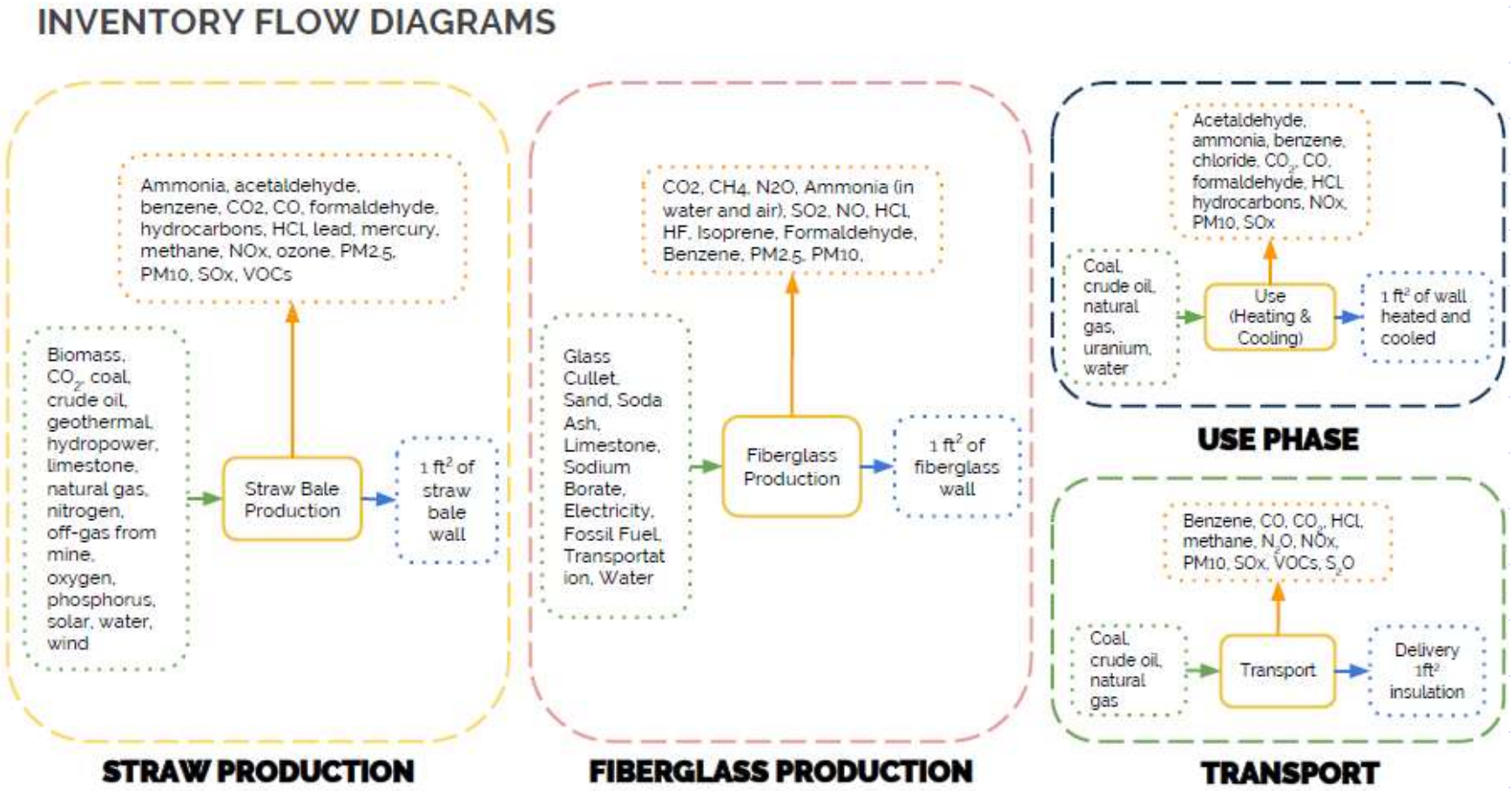
Source: Global Footprint Network National Footprint and Biocapacity Accounts 2019

Global Footprint Network
Advancing the Science of Sustainability

Why LCA?

- In “meeting needs of present without compromising our ability to meet future needs”, we are faced with obstacles and complexities
  - Corporate pressure
  - Social pressures
  - Regulatory gaps, overlap and barriers
  - Uncertain objectives/goals
  - Lack of tools to measure progress
- Intuition not a sufficient framework for analysis!
- LCA = systematic and quantitative method for comparing and improving products and policies

Straw-bale vs fiberglass insulation



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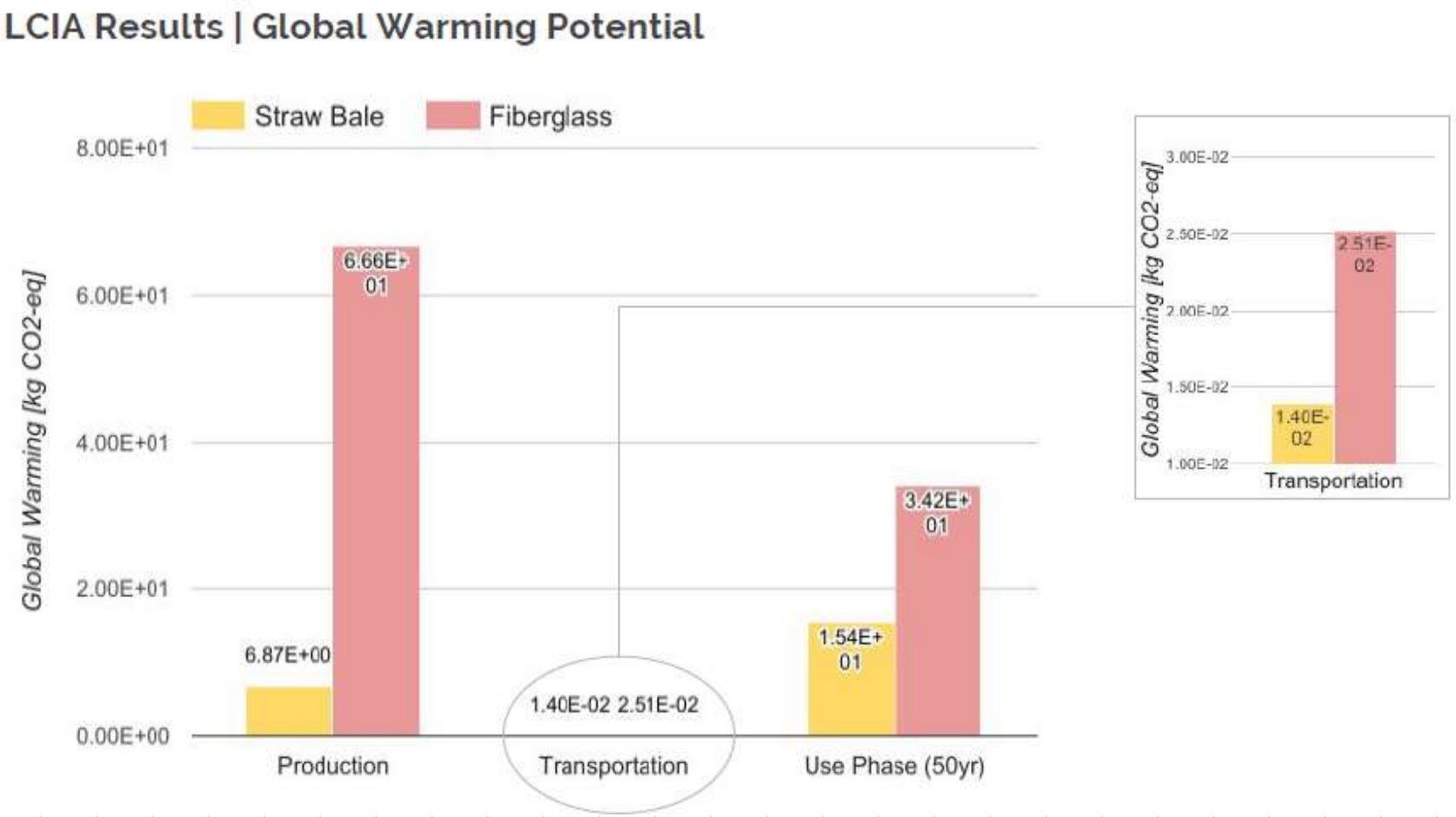
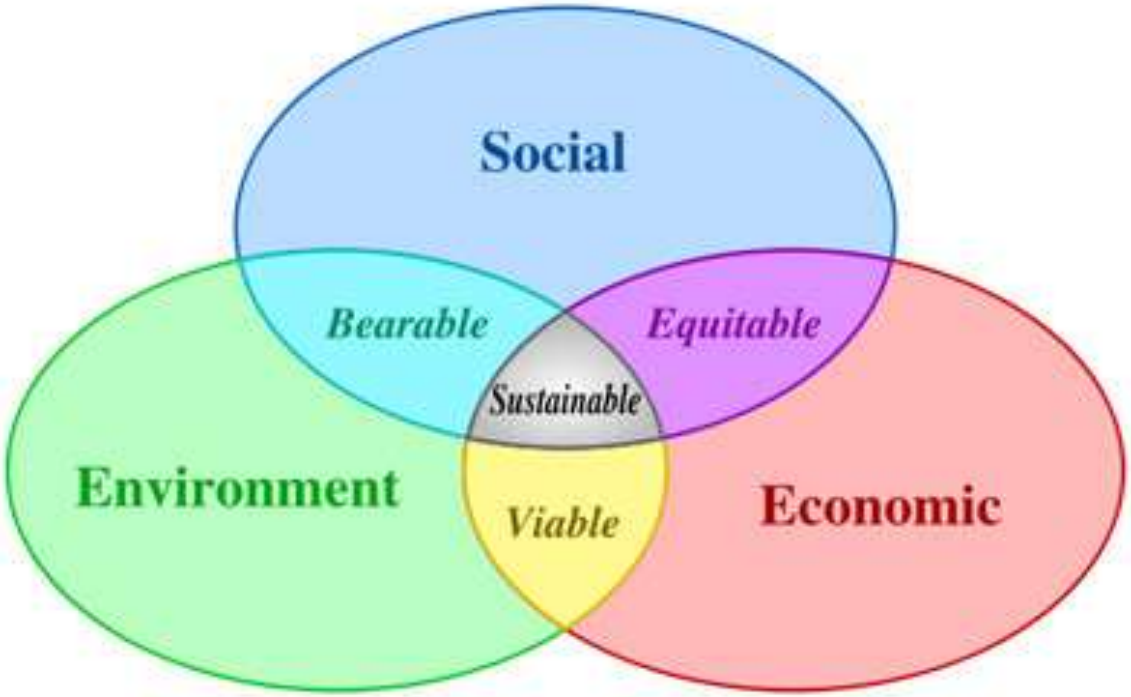


And … there are careers in LCA

- There are careers in LCA
  - Companies and government agencies
    - Assess products, processes, policies
  - Some consulting firms specialize in LCA services
  - Peer review
    - Standards dictate a peer review for any publicly released study with comparative assertions
    - Growing business area
- LCA is a familiar concept to chemical engineers
  - Material and energy balances
  - Thermodynamics and transport phenomena
  - Unit operation design
  - Process design
  - Process simulation and optimization

Re-linking cost and environment

- This is a course on sustainability
- LCA is a tool to assess the ripple effects of economic, social, and environmental choices
- Goal: life cycle THINKING.



Objectives

- To provide theoretical and applied competences to **set up and solve LCA studies.**
  - **D1 - Knowledge and understanding skills**: to provide the theoretical expertise required to develop LCA analysis.
  - **D2 - Ability to apply knowledge and understanding**: to develop in autonomy LCA studies using professional software.
  - **D3 - Autonomy of judgement**: to select the most appropriate strategy to set-up and LCA study.
  - **D4 - Communicative skills**: to expose, by means of a written, oral and graphical exposition, the results coming from an LCA study.
  - **D5 - Learning skills**: to identify the information required for the LCA study and will know how to obtain data from scientific literature databases, manuals and textbooks.

Course program

- Introduction
- Global warming, climate changes and their relationships with energy
- 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
- The International Environmental Product Declaration (EPD) system and case studies
- Development of an LCA model.
  - Description of LCA software openLCA and its use.
  - Calculation examples and hands-on exercises.

Teaching methodology

- Classroom lectures
  - PPT slides available in MOODLE: https://moodle2.units.it//
- Timetable
  - Thursday 14.15 – 17.00 /with 15 minutes break each hour)
- Demo of user interface of commercial SW
  - OpenLCA
  - SIMAPRO
- Hands on (hybrid mode)
  - OpenLCA
- Exame
  - Oral with a LCA case study presentation

Text books

- Recommended Textbook:
  - H.S. Matthews, C.t. Hendrickson, D.H. Matthews, Life Cycle Assessment: quantitative approaches for decisions that matter, 2014, open access textbook, retrieved from www.lcatextbook.com
- Other materials
  - Baumann H and Tillman A-M, The Hitch Hiker's Guide to LCA: An Orientation in Life Cycle Assessment Methodology and Application, Student literature, 2004.
  - Life Cycle Assessment. Training Kit material. UNEP-SETAC Life cycle initiative: http://www.lifecycleinitiative.org/resources/training/lca-life-cycle-assessment-training-kit-material/
  - O.Jolliet , T. Corbière, M. Thérézien, Life Cycle Assessment: Distance Education Course Ecole Harvard School of Public Health EPFL-Swiss Federal Institute of Technology-Lausanne, Ecosystem management, GECOS, CH-1015 Lausanne, SWITZERLAND available at: www.sciencenetwork.com/lca/goal_scope.pps
  - Lifecycle Assessment: Principles and Practice. US Environmental Protection Agency Report -EPA/600/R-06/060 May 2006 Available for download at http://www.epa.gov/nrmrl/std/lca/lca.html
  - European Platform on Life Cycle Assessment. ILCD Handbook. General guide for Life cycle assessment. Provisions and action steps. EU DG JRC IES, 2010, http://eplca.jrc.ec.europa.eu/?page_id=86
  - openLCA manuals