From sludge drying follow-up using X-ray microtomography to LCA of processes: 13 years research at the LGC

LABORATORY of CHEMICAL ENGINEERING

Processes and Sustainable development

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Université de Liège

LGC PROCÉDÉS ET DÉVELOPPEMENT DURABLE GÉNIE CHIMIQUE

Introduction to the Laboratory of Chemical Engineering

Université de Liège

LGC CHEMICAL ENGINEERING

University of Liège, Belgium

- 9 faculties, 1 institute, 1 school

Philosophy & Letters

Applied Sciences

Law and Criminology school

Veterinary Medecine

Sciences

Psychology and Education

Medecine

gembloux agro bio tech

Architecture

HEC ULg Management School - University of Liege

- ✓ 38 bachelors
- ✓194 masters
- ✓ 68 complementary masters

Human and Social Sciences

Faculty of Applied Sciences

- 4 departments
  - Aerospace and Mechanical Engineering
  - ArGEnCO = Architectural, Geological, Environmental and Civil Engineering
  - Electrical Engineering and Computer Science
  - Applied Chemistry

Department of Applied Chemistry

- 3 groups – About 60 people

✓ Analysis and Synthesis of Chemical Systems – Cryotechnology laboratory

(Pr G. Heyen, Pr J.-L. Bozet, Dr M.-N. Dumont)

✓ Catalytic and electrochemical engineering - Nanomaterials

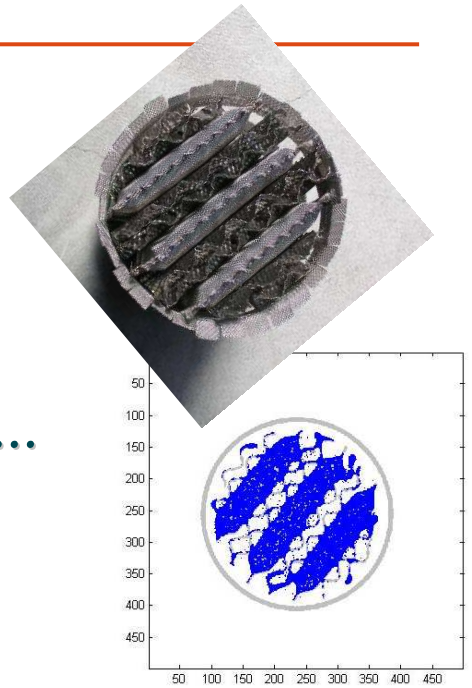
(Pr J.-P. Pirard, Pr B. Heinrichs, Dr N. Job, Dr S. Lambert, Dr C. Gommes)

✓ Chemical Engineering

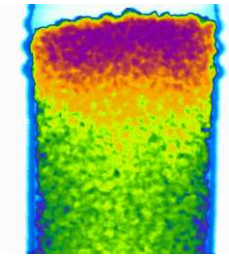
(Pr M. Crine, Pr D. Toye, Pr A. Léonard)

http://www.chimapp.ulg.ac.be/

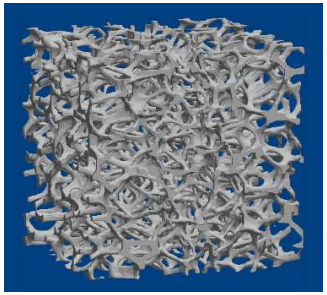
LGC Research topics



- ✓ **Hydrodynamics in polyphasic systems**
  - o Packed columns and trickled bed reactors
    - ↳ absorption, distillation, reactive distillation, …
  - o Bubble columns
    - ↳ water treatment, G/L contactors, …
- ✓ **Mixing in stirred (bio)reactors**
  - o Study of rheologically complex fluids
- ✓ **Treatment of gas streams**
  - o VOC adsorption on activated carbons
  - o Aerosols capture
  - o Gas cleaning



LGC Research topics



- ✓ **Treatment of waste**
  - o Biomethanation
  - o Drying
- ✓ **Convective drying of deformable materials**
  - o Residual sludges
  - o Resorcinol-formaldehyde xerogels
- ✓ **Characterization of porous materials using µCT**
- ✓ **LCA studies of processes**
- ✓ **Set up of downstream processes**
  - o Settling → dewatering → drying

In brief …

1998 Chemical Engineer - University of Liège

FRS-FNRS Research Fellow: convective drying – sludge – X-ray µCT

2003 PhD Thesis: Study of wastewater sludge convective drying: texture follow-up using X-ray µCT

2004 FRS-FNRS Postdoctoral Researcher: convective drying – carbon xerogels - modeling

Extension of X-ray µCT applications

Postdoc research stay in Bordeaux (Laboratoire 'TREFLE')

2008 FRS-FNRS Research Associate: drying – relations between process/product

2009 Academic position at ULg: Processes and Sustainable development

Development of existing LCA activities

…

3 main research topics

- Drying of deformable materials
  - Both experimental and modeling approaches
  - Long expertise in sludge drying
  - Relation between drying process and product quality
- Characterization of porous materials by X-ray microtomography
  - Initially developed to follow sludge texture during drying
    - Cracks, shrinkage, moisture profiles
  - Extension to different types of cellular materials
  - Now used for product-oriented-engineering approach
- Environmental management: Life Cycle Assessment studies, environmental reporting

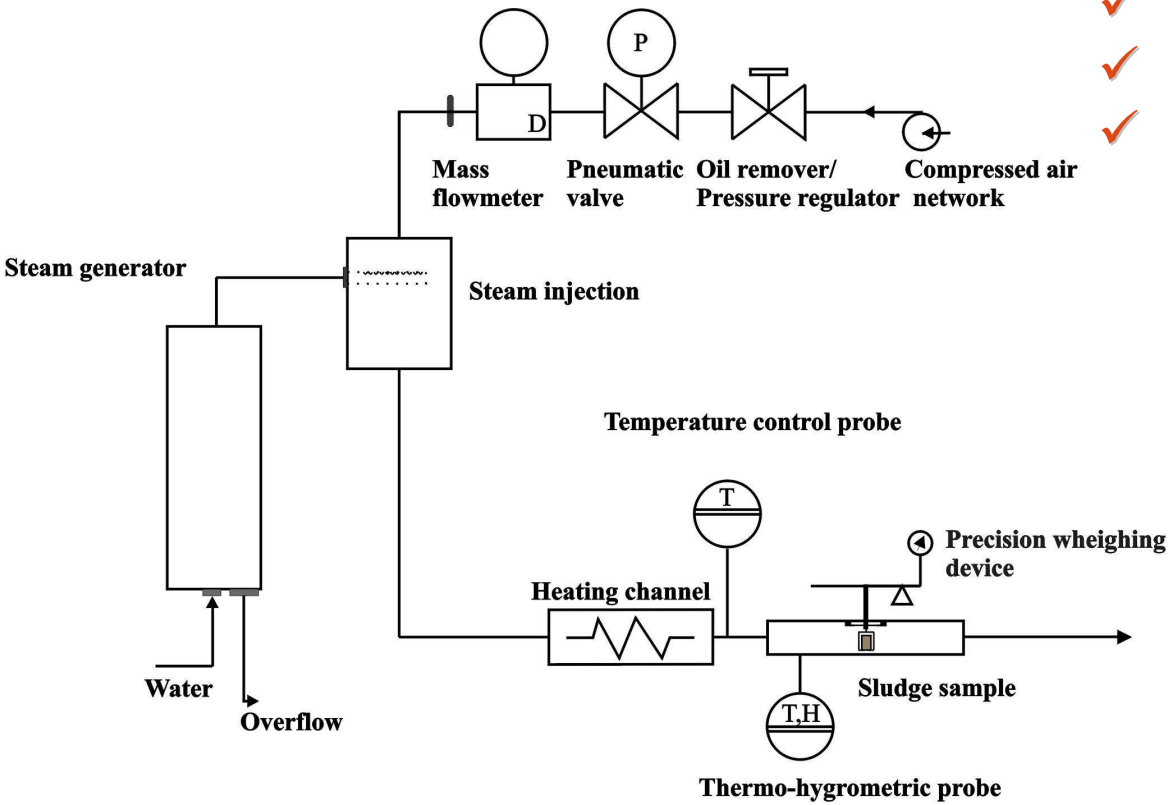
About drying …

Convective drying of deformable materials

- Thermal drying = widely used separation process
  - High energy consumption : 10 to 15% of Europe industrial energy use
  - Need for process optimisation
    - Material behaviour
    - Relevant drying models
- Impact of drying on quality of dried product
  - Shrinkage, cracks, moisture profiles, …
  - Need of characterization tools
- Focus on two main types of materials
  - Sludges
  - Resorcinol-formaldehyde xerogels
- Both experimental data and modeling approach

Equipment available

- Micro-dryer

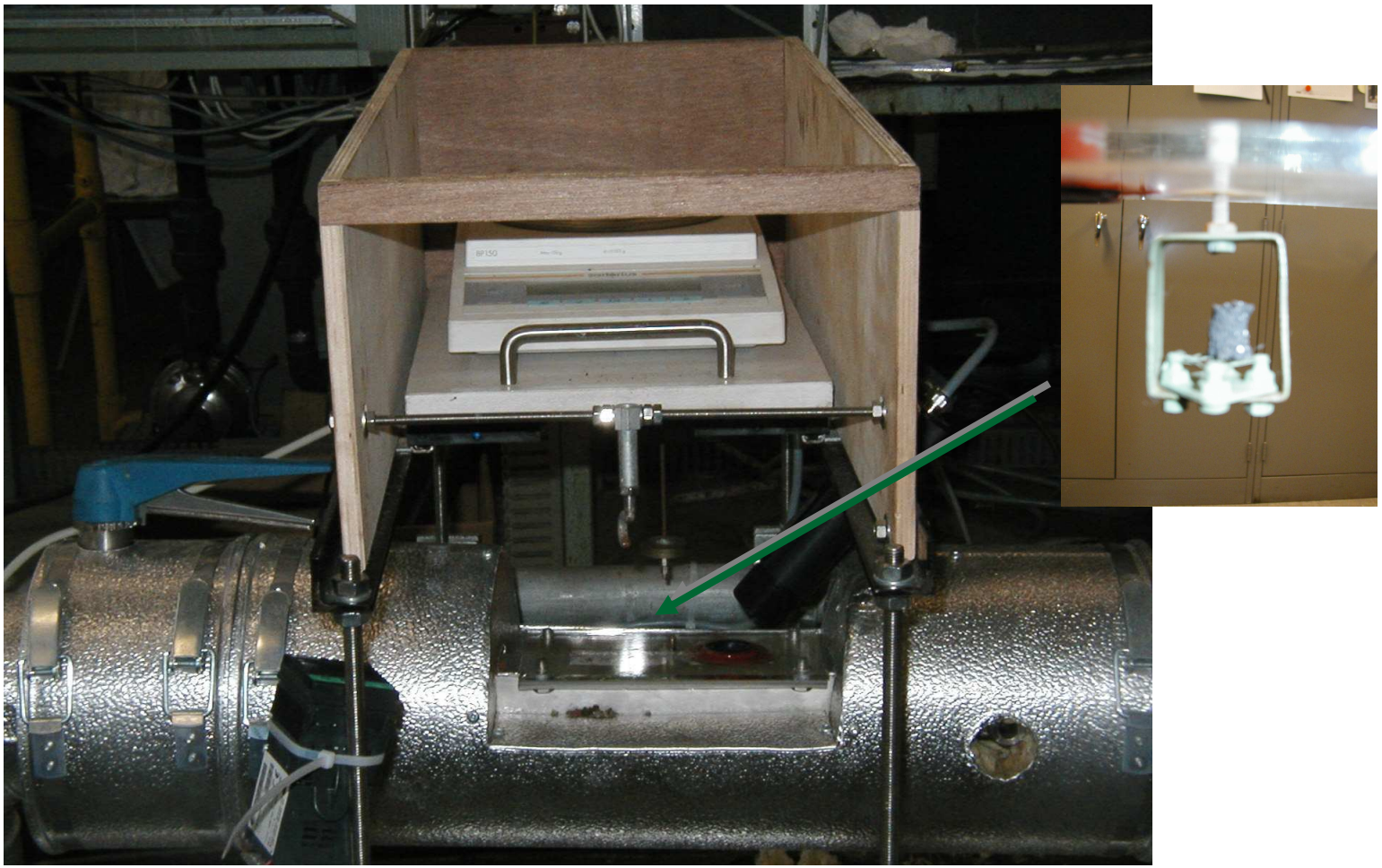


- ✓ Convective drying
- ✓ Individual sample: 1 – 5 g
- ✓ Control of 3 operating conditions
  - ✓ Temperature
  - ✓ Velocity
  - ✓ Humidity

Equipment available

- Micro-dryer

✓ Continuous follow-up of sample mass



Equipment available

- Pilot-scale dryer

- Extrusion

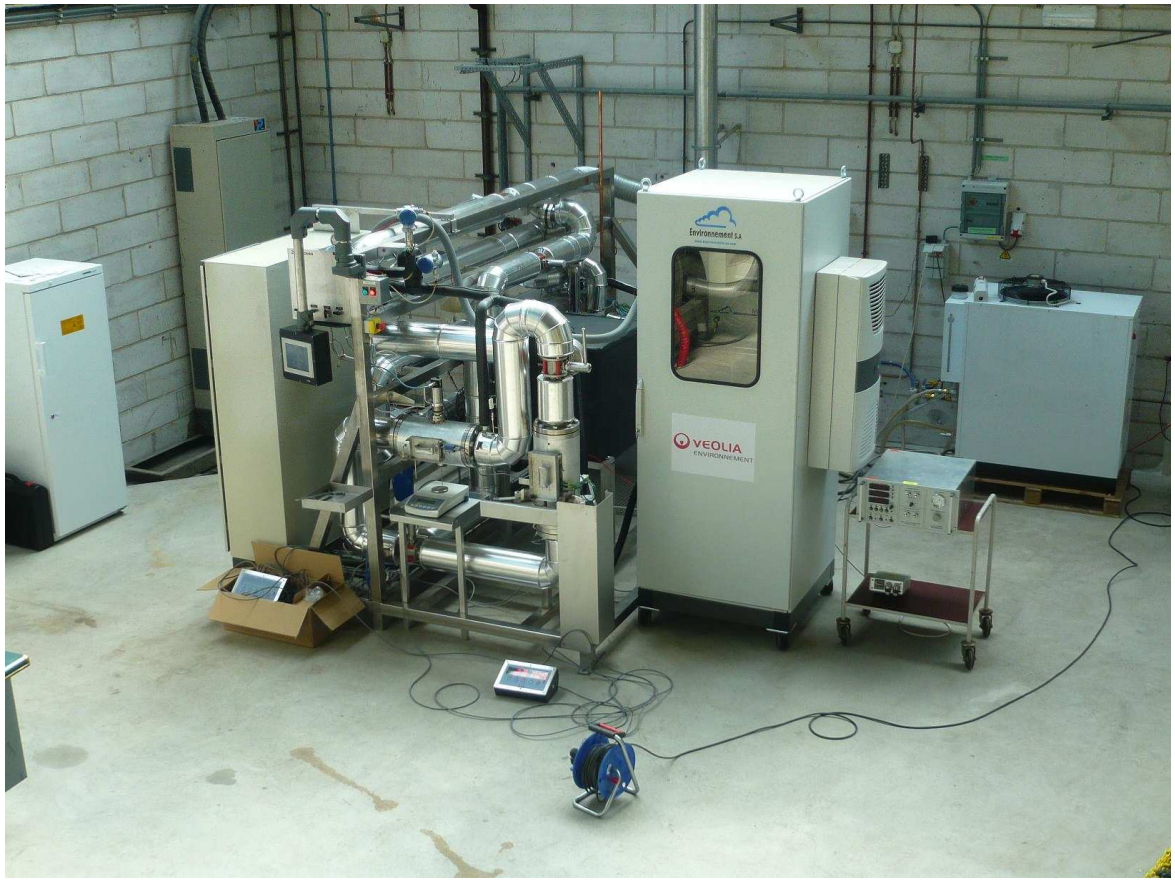
Sevar pilot scale dryer

- Fixed bed (cross flow)

- Capacity
  - 1 to 3 kg
  - Up to 200 kg water/m²h

Equipment available

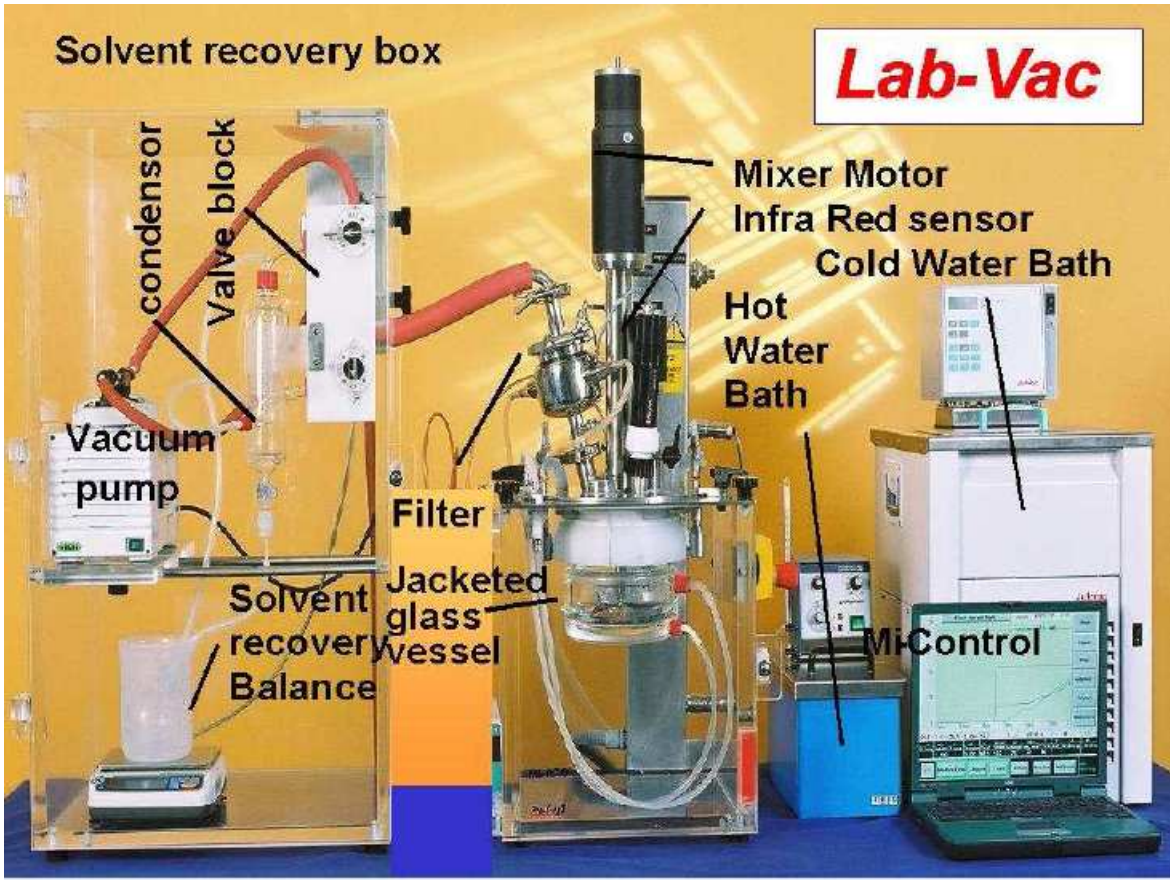
- Veolia dual scale dryer



- Small cell
- Fixed bed (cross flow)
- Gas line analyzer

Equipment available

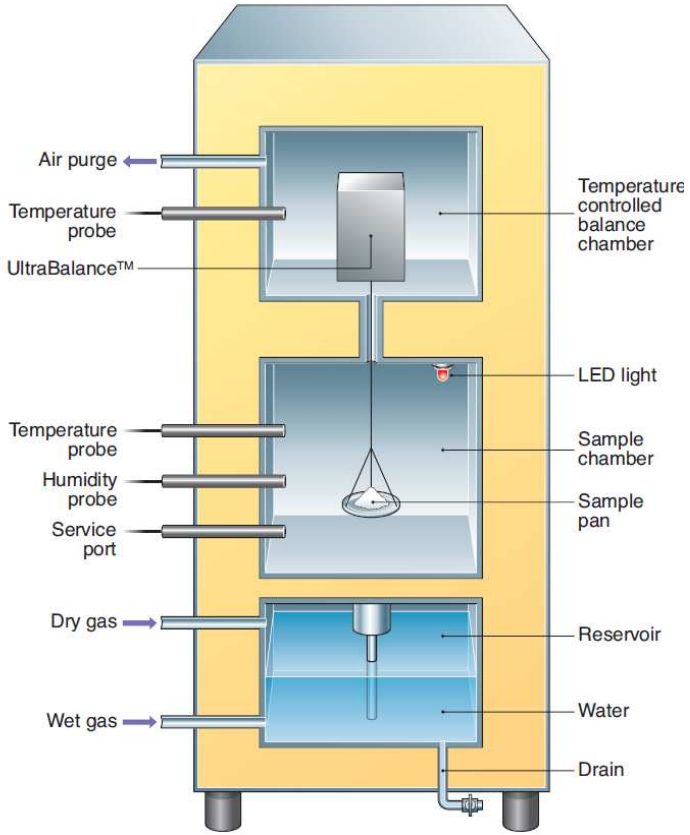
- Vacuum agitated contact dryer

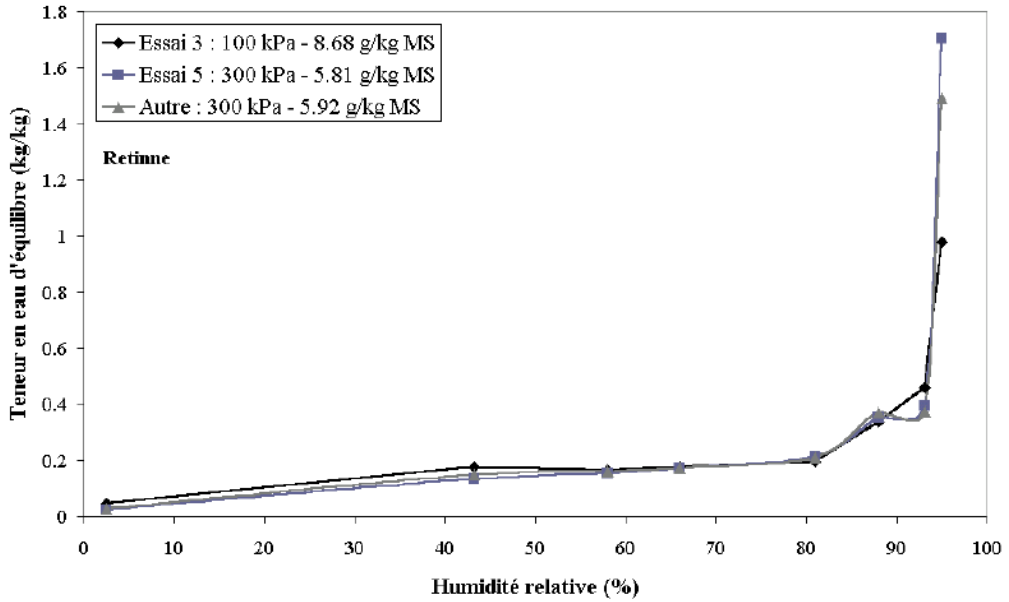


- Thermosensitive products

Equipment available

- Dynamic vapour sorption



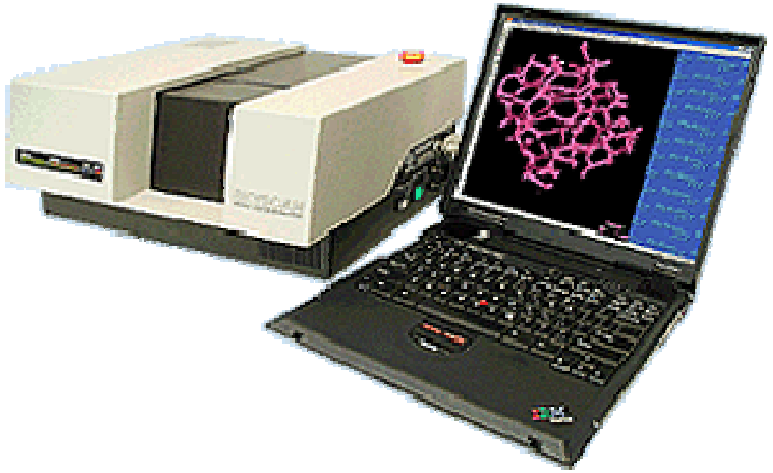


Equipment available

- X-ray tomographs
  - Non destructive 3D imaging technique
  - Follow-up of sample texture
    - External exchange area → drying kinetics
    - Cracks → drying quality
    - Internal moisture profiles → model validation
    - Sludge bed permeability → sludge rheology

Equipment available

- Microtomograph



Purchase year: 2000

- **Source: 40 kV - 1 mA - Cone beam**
- **Detector: 768 x 576 pixels**

  8-bit CCD Camera
- **Pixel size: 41 µm**
- **Max sample size: ∅: 30 mm – h: 25 mm**

Equipment available

- Microtomograph

Purchase year: 2006

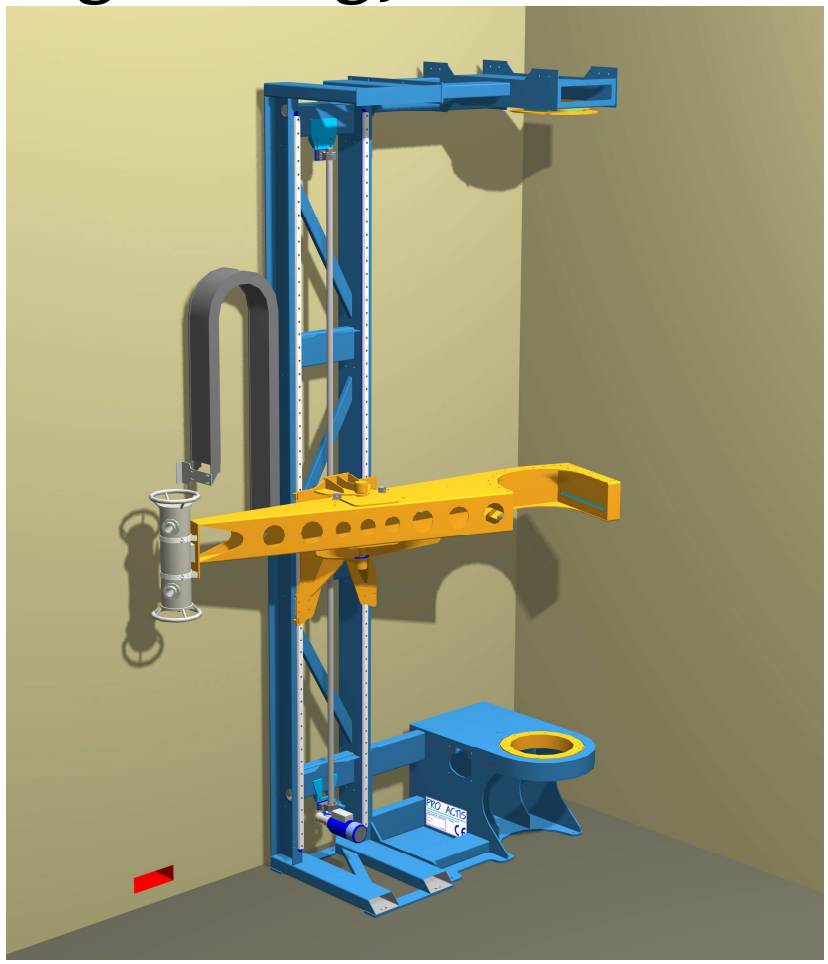
- **Source: 100 kV - 250 mA - Cone beam**
- **Detector: 4000 x 2300 pixels**

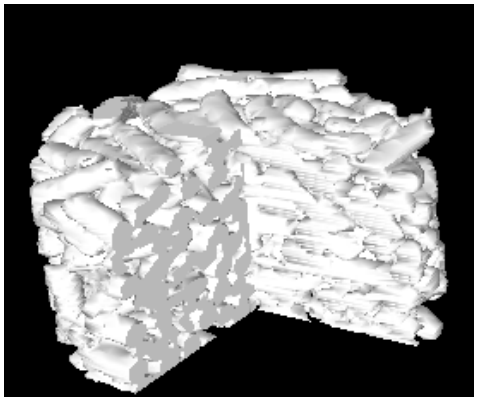
  12-bit CCD Camera
- **Pixel size: from 34 to ≈ 2-3 µm**
- **Max sample size: ∅: 35 mm (68 mm with camera offset)**

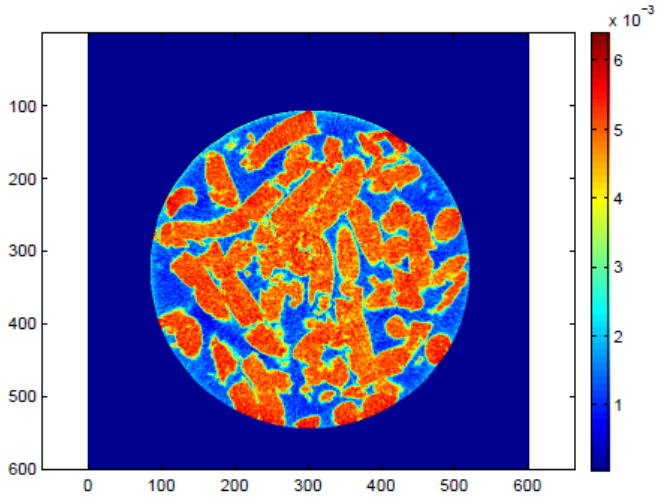
  h: 35 mm (70 mm with camera offset)

Equipment available

- High energy ‘macro’ tomograph







About sludge drying

- Origin of urban residual sludges
  - Activated sludge wastewater treatment plant (WWTP)
  - Production of excess sludge during biological process

Oupeye - 446 500 PE

www.aide.be

About sludge drying

- Sludge processing within a WWTP
  - Applied to excess biomass produced by the biological treatment
    - Thickening
    - Stabilisation
      - Liming
      - Digestion (biomethanation)
      - Mechanical dewatering
        - Centrifugation
        - Belt filter
        - Press filter
    - Valorisation: in agriculture or for energy recovery

Europe :
About 50 to 60 million tons wet sludge/year

Drying

About sludge drying

- Sludge drying → several advantages
  - Mass and volume reduction
  - Stabilisation – Hygienisation
  - Texture improvement
  - Increase of calorific value

Flanders
32% sludge dried in 4 dryers
2 fluidised bed dryers
2 stage dryers

- Sludge drying = complex unit operation
  - Depends on sludge properties
    - Composition, rheology, treatment, storage conditions, …
  - Depends on operating conditions
  - Produces gaseous emissions (pollutants, odors, …)
  - Highly energy consuming
    - Needs global energy optimization on the process site

A lot of investigated topics …

Drying kinetics
Discontinuous pilot scale convectif dryer

Léonard & Crine, IDS 2000 (CD-ROM)

Influence of sludge origin on drying kinetics

Léonard et al., Env Tech, 25, 1051-1058 (2004)

Study of gaseous emissions related to sludge drying

Fraikin et al., ECSM 2010
Fraikin et al., SFGP 2009

Follow up of texture, shrinkage, humidity profiles, at the extrudate scale

Léonard et al., Drying Tech, 20, 1053-1069 (2002)
Léonard et al., Drying Tech, 21, 1507-1526 (2003)
Léonard et al., Drying Tech, 22, 1695-1708 (2004)
Léonard et al., Can J Chem Eng, 83, 127-131 (2005)

Influence of backmixing on drying kinetics (fixed bed)

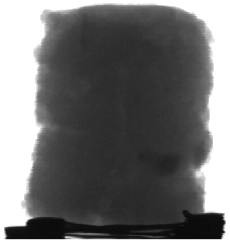
Léonard et al., IDS 2006, Vol B, 767-772 (2006)

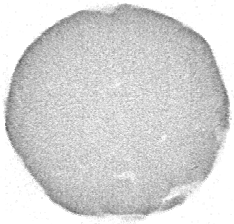
Influence of liming and mixing on drying kinetics

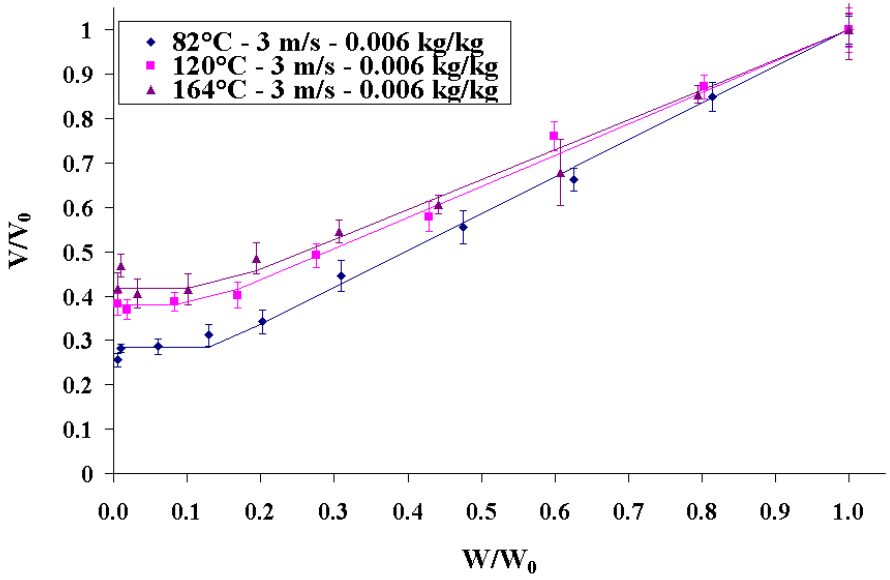
Léonard et al., ECSM 2008, 2010

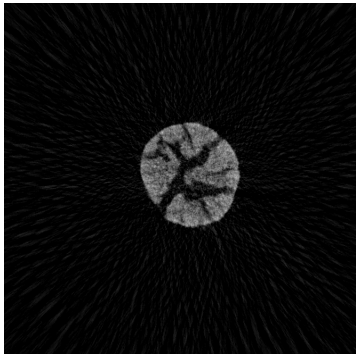
Follow-up of structural changes

- Shrinkage = necessary to study drying mass flux
- Cracks in relation with quality

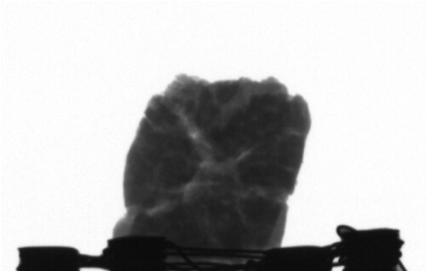








Cracks

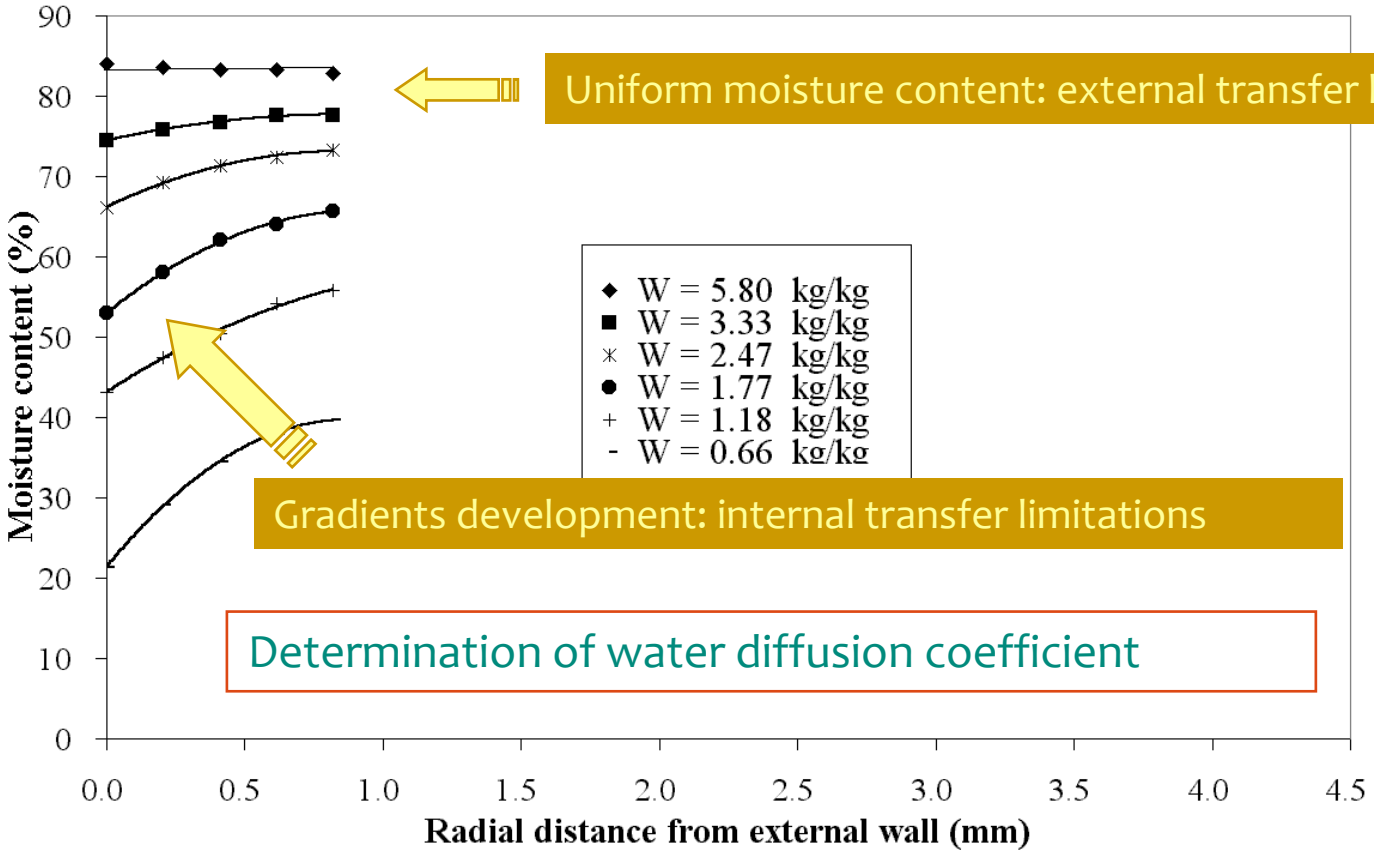


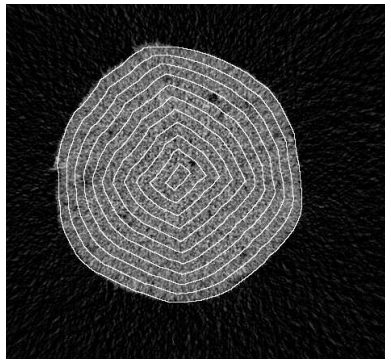
Height

X-ray microtomograph
Micro dryer scale

Follow-up of internal moisture profiles

- Understanding of mass transfer + model validation



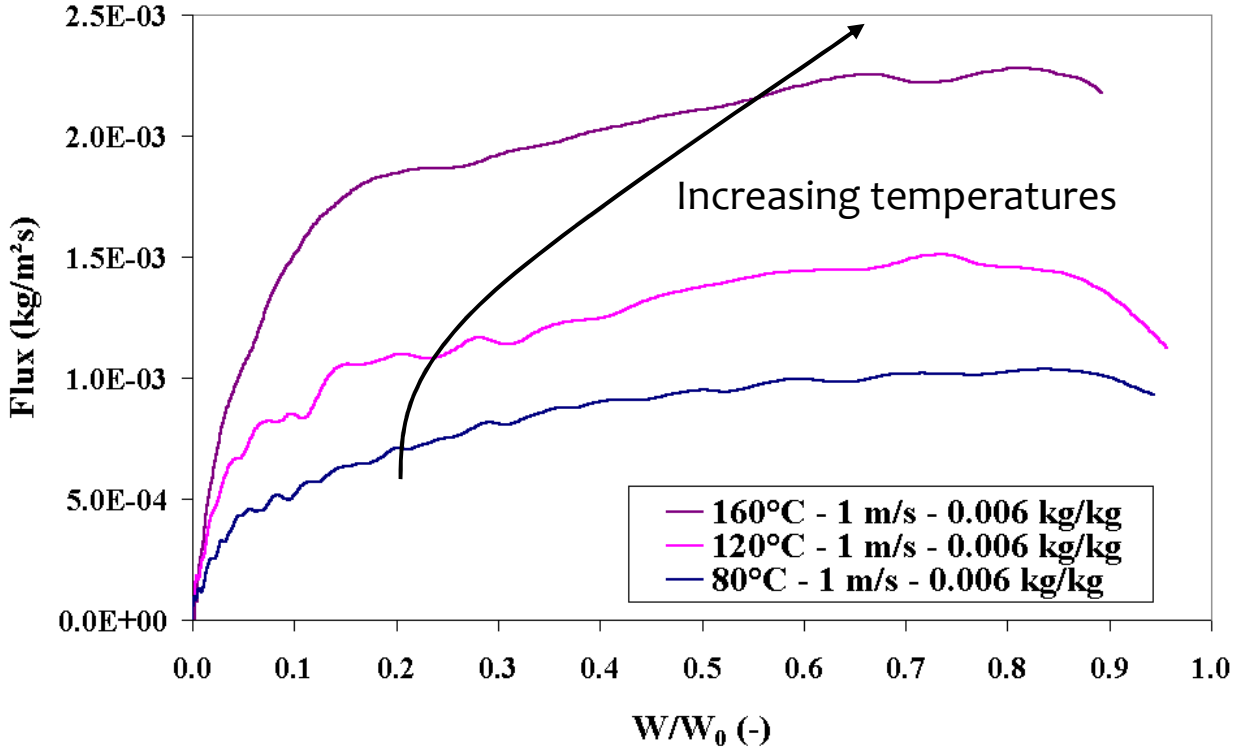


X-ray microtomograph
Micro dryer scale

Use of a calibration curve : moisture content = f(grey level)

Impact of operating conditions

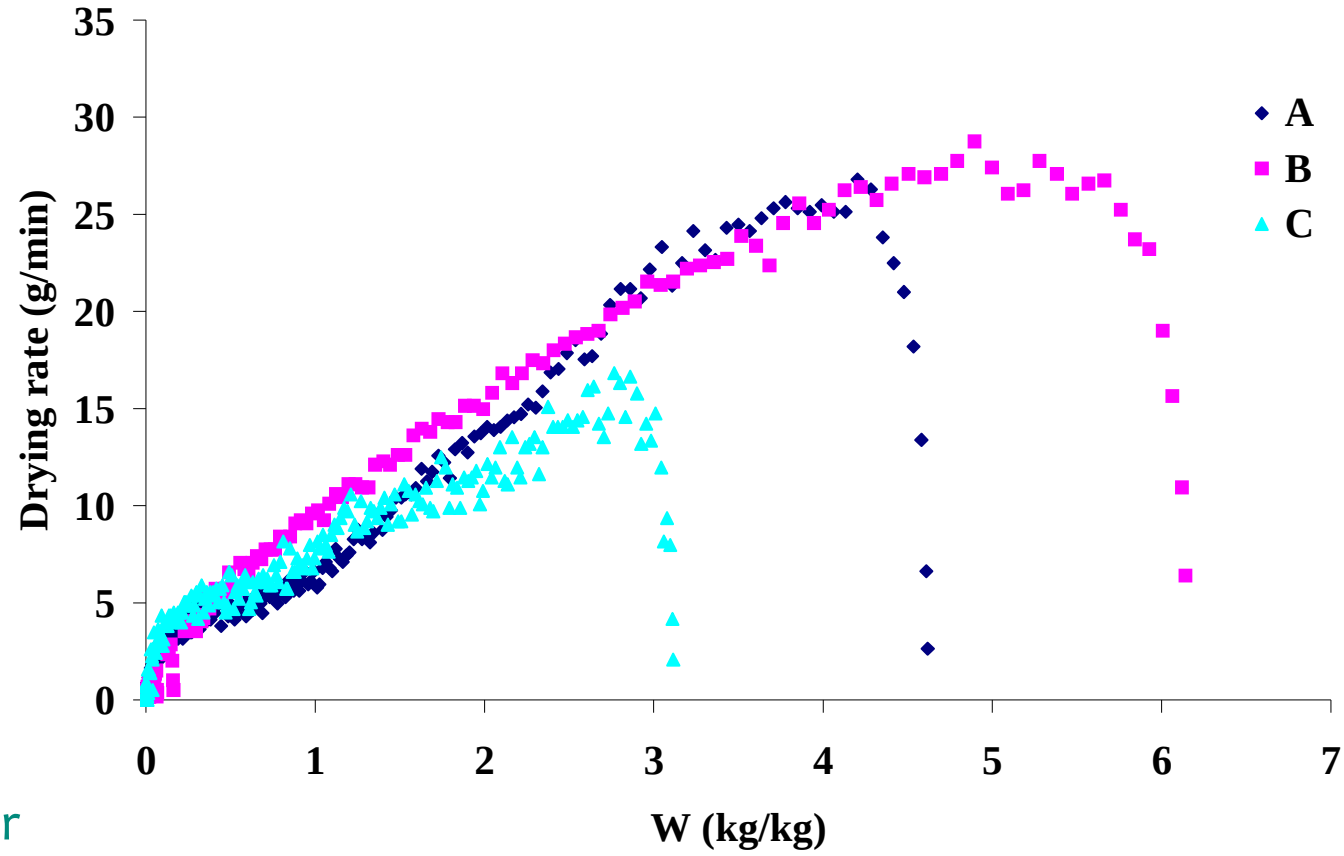
- Influence of temperature



Microdryer

Impact of sludge origin

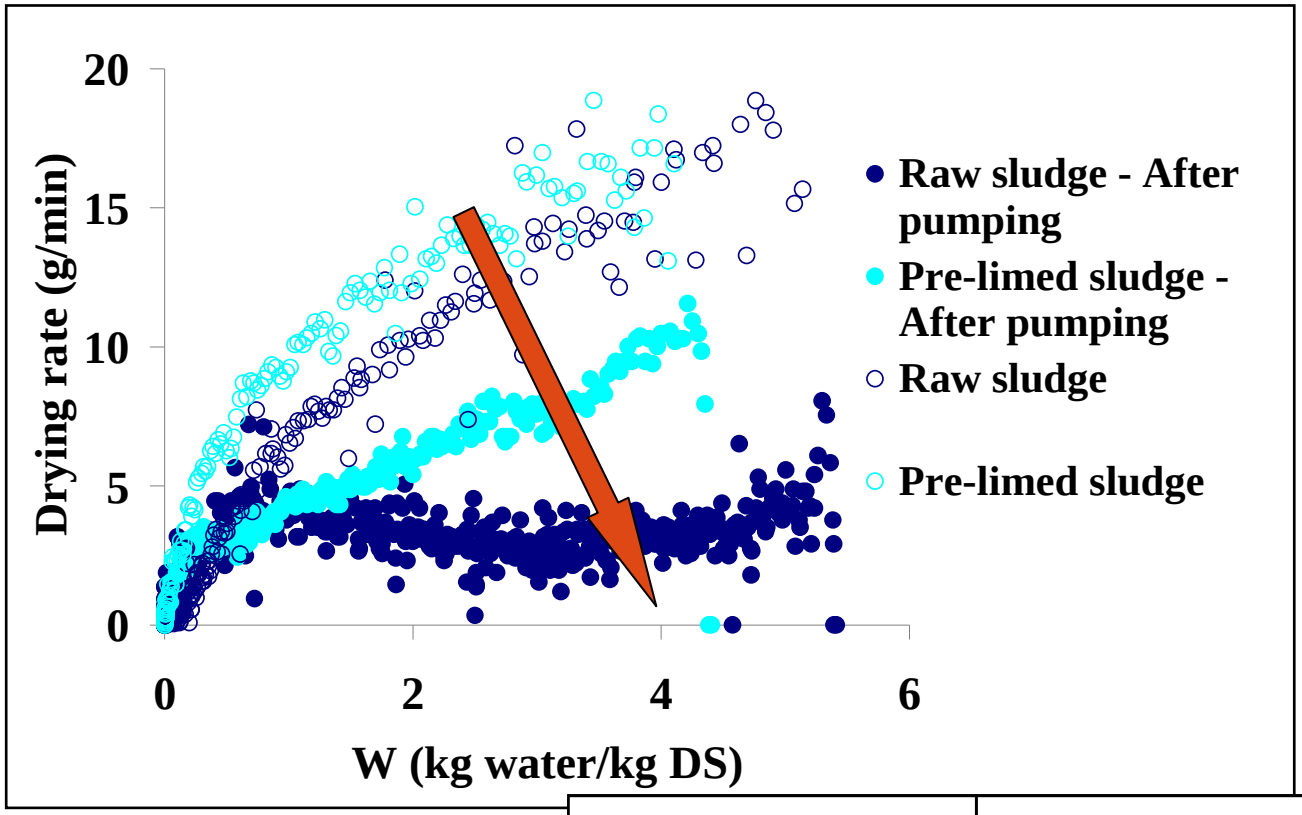
- Max drying rate: ratio up to 3:1



Pilot scale dryer

Impact of sludge pumping

- Influence of pumping on drying kinetics



Pilot scale dryer

	Specific evaporation capacity (kg/m²h)
Raw sludge	21.4
Pumped sludge	9.9

Impact of sludge pumping

- Importance of textural properties

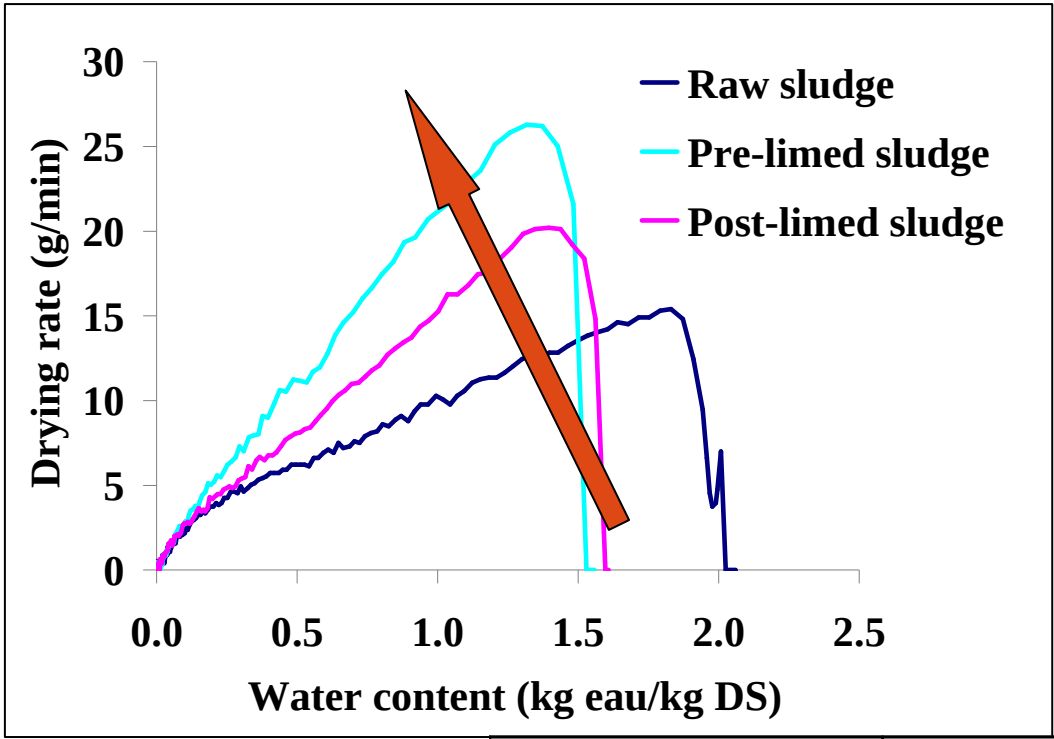
Pumping

Pre liming

Pumping

Impact of sludge liming

- Influence of liming on drying kinetics

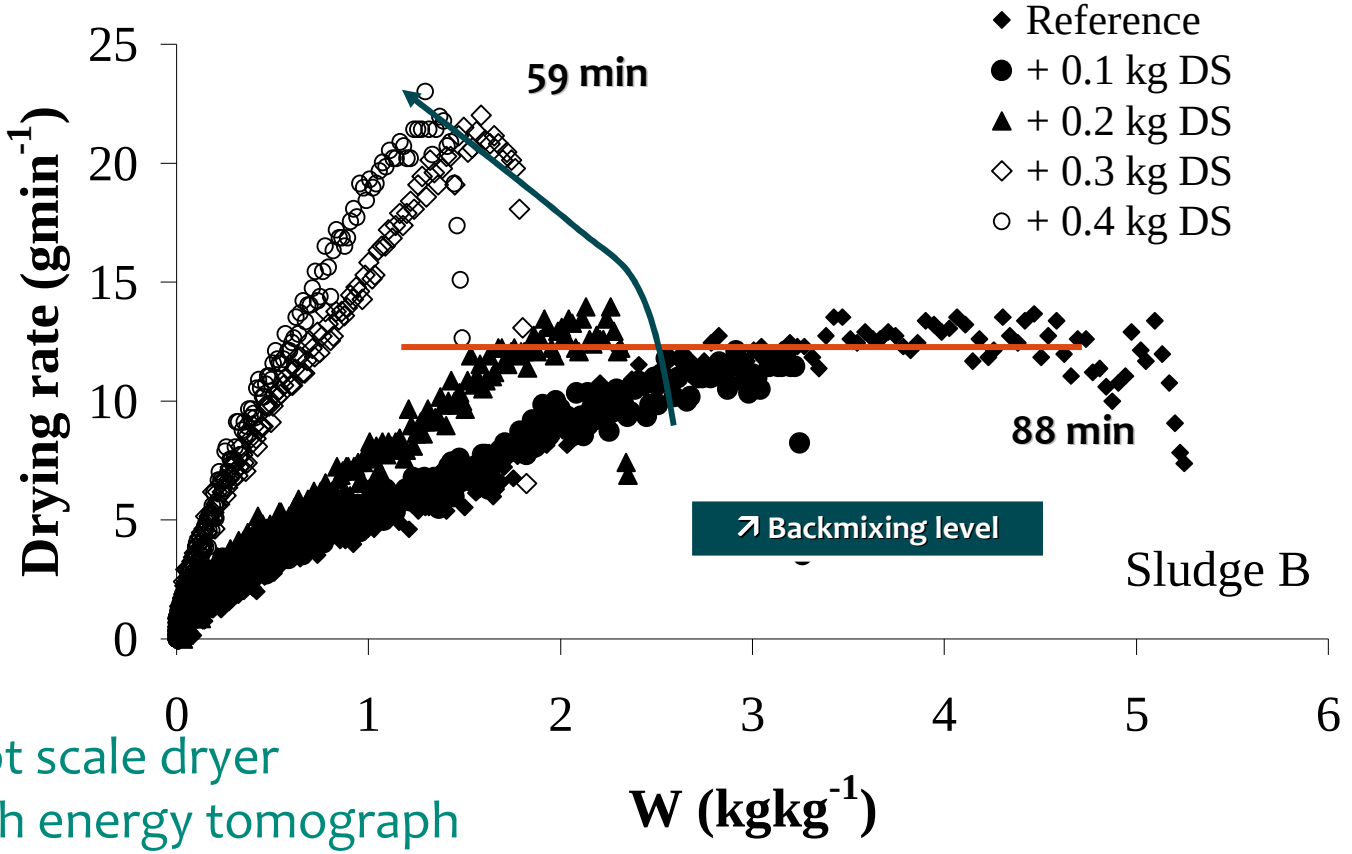


Pilot scale dryer

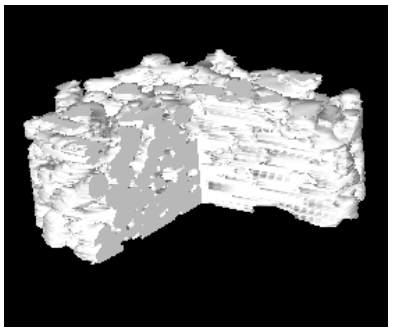
	Specific evaporation capacity (kg/m²h)
Raw sludge	24.3
Post-liming	28.9
Pre-liming	37.0

Impact of back-mixing

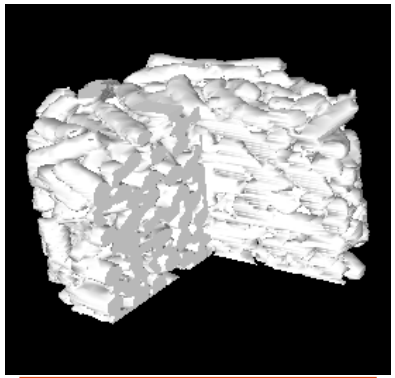
- Recirculation of dried product → way to correct 'bad texture'



Pilot scale dryer
High energy tomograph



1000 g – 16% DS
Raw sludge

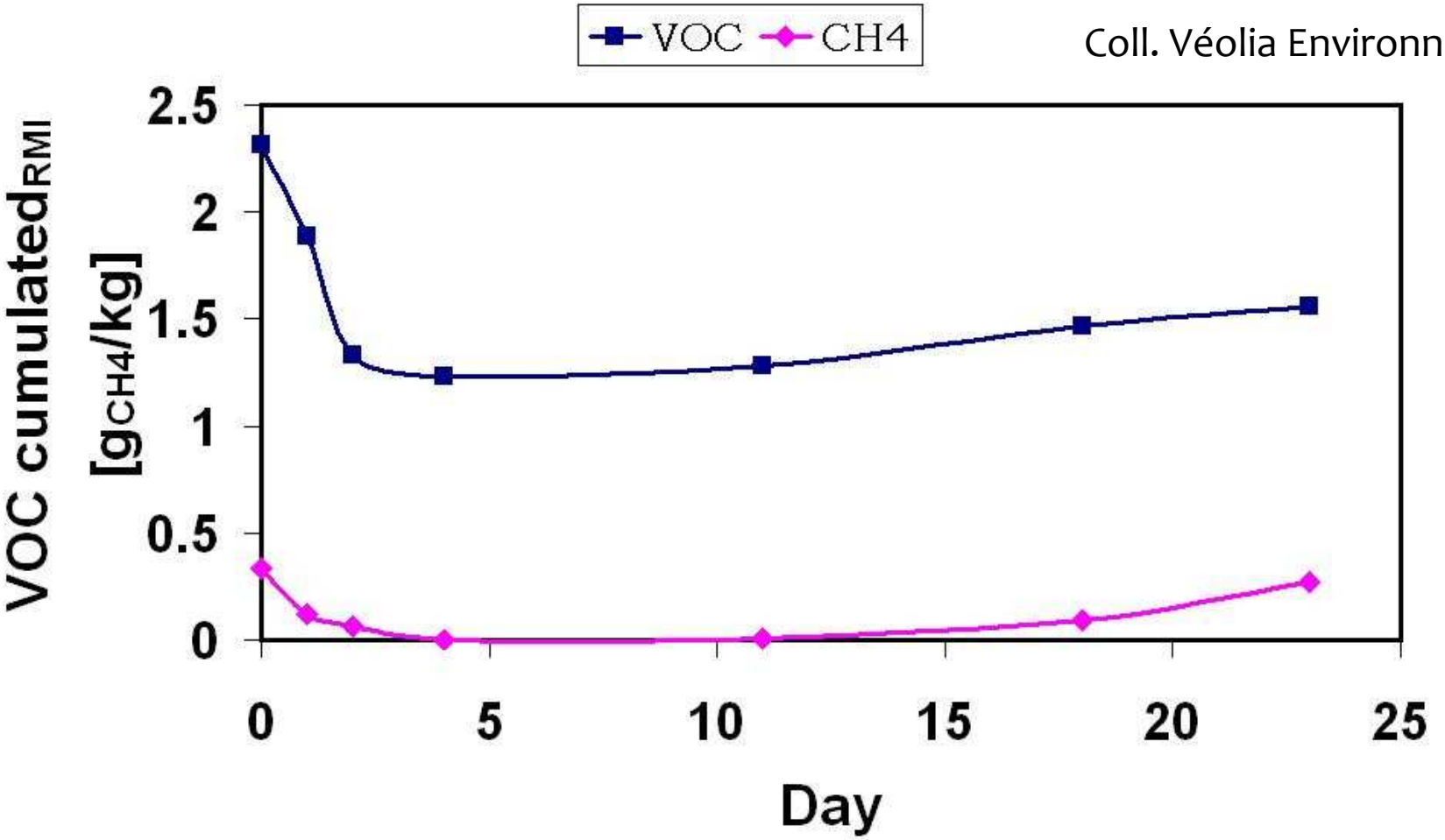


1400 g – 40% DS
+ 400 g DS

Follow-up of gaseous emissions

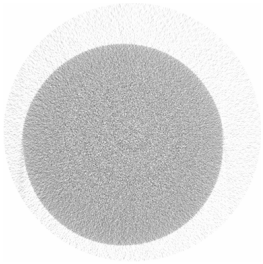
- Evolution of VOC with storage duration digested sludge

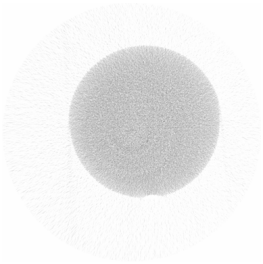
Coll. Véolia Environnement

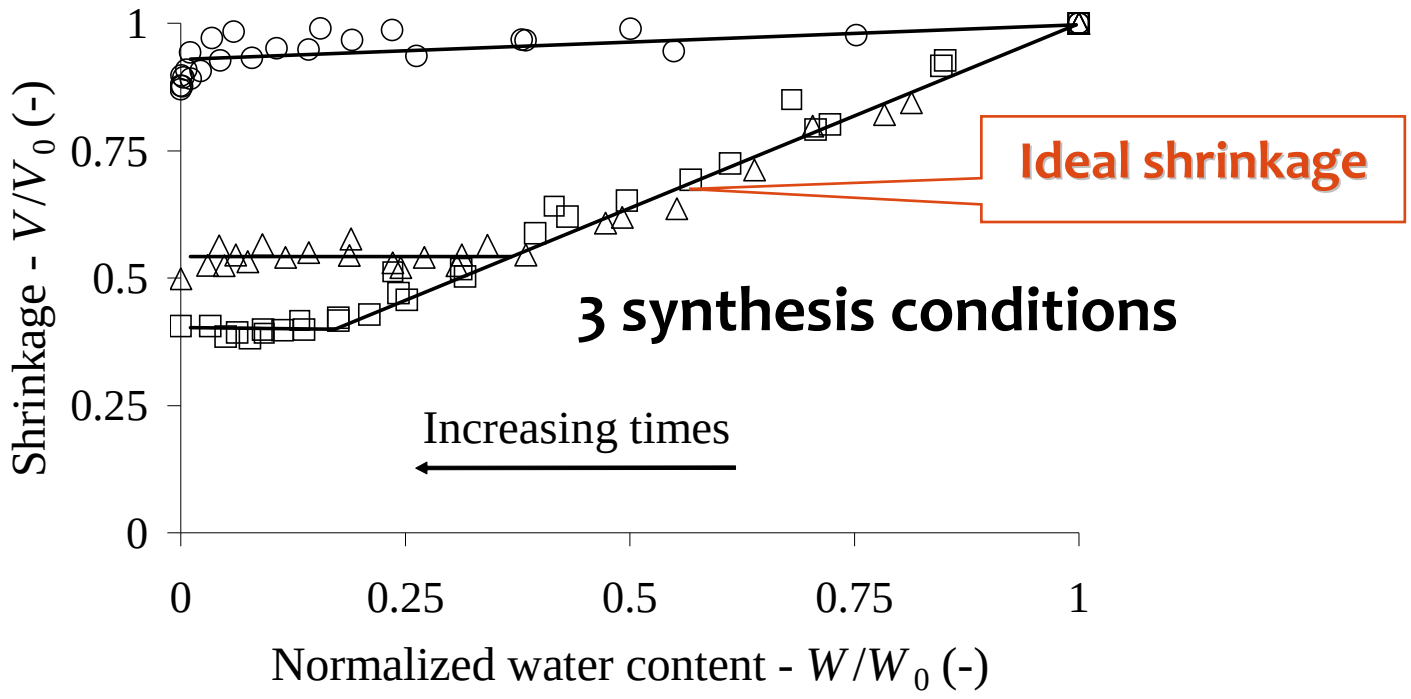


About RF xerogels drying

- RF resins = model material
  - degree of shrinkage can be easily controlled
  - tunable pore texture







About RF xerogels drying

- RF resins = precursors of carbon materials

Formulation → Gelation 70°C – 24h → **Convective drying** → Pyrolysis 800°C – N_2 flow

pH controls the pore texture

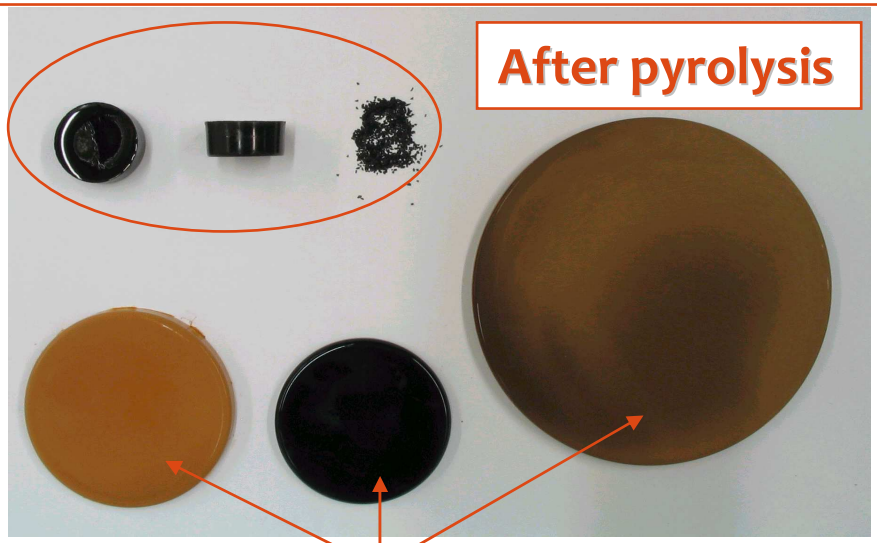
- **microporous**
- **micro-mesoporous**
- **micro-macroporous**

N. Job et al., Carbon, 2004, 3, 619-28

A. Léonard et al., Carbon, 2005, 43, 1808-11

N. Job et al., J Non-Cryst. Solids, 2006, 352, 24-34

Crucial step for the production of monolith



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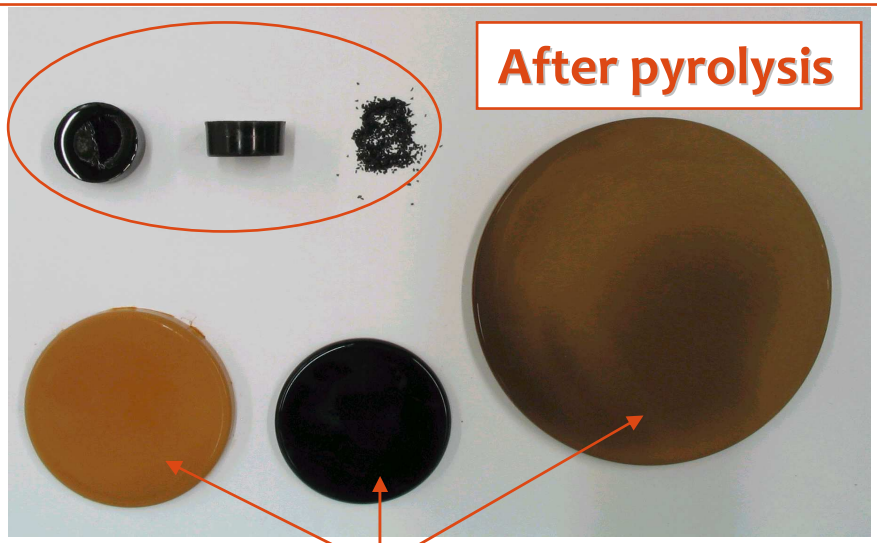

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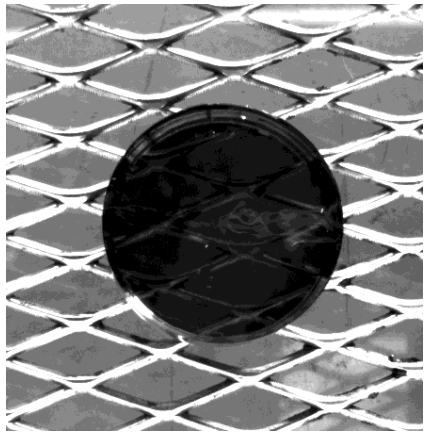
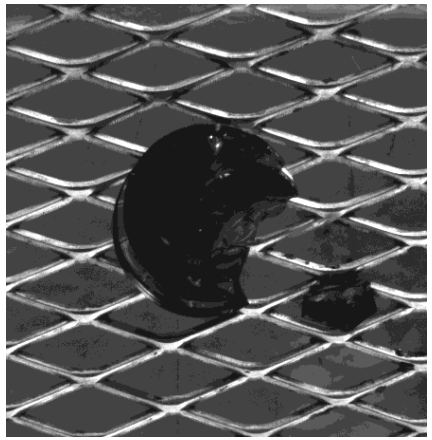
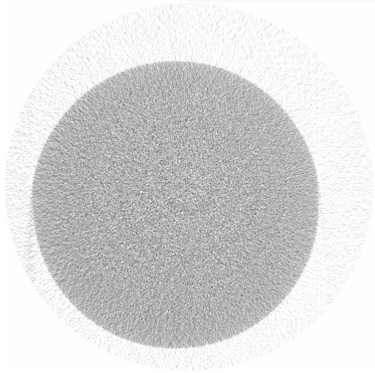




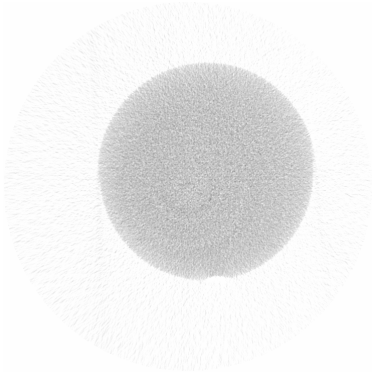
N. Job et al., Carbon, 2006, 44, 2534-42

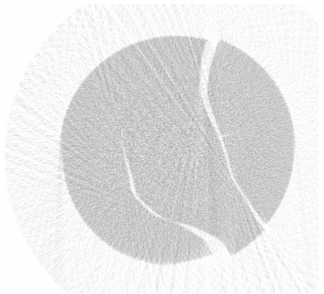


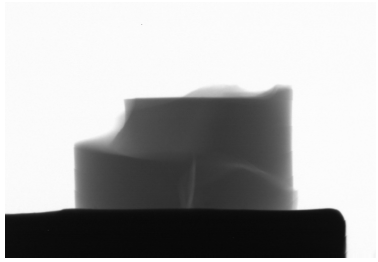
T = 30 °C

T = 70 °C

R/C = 300
pH = 6.6





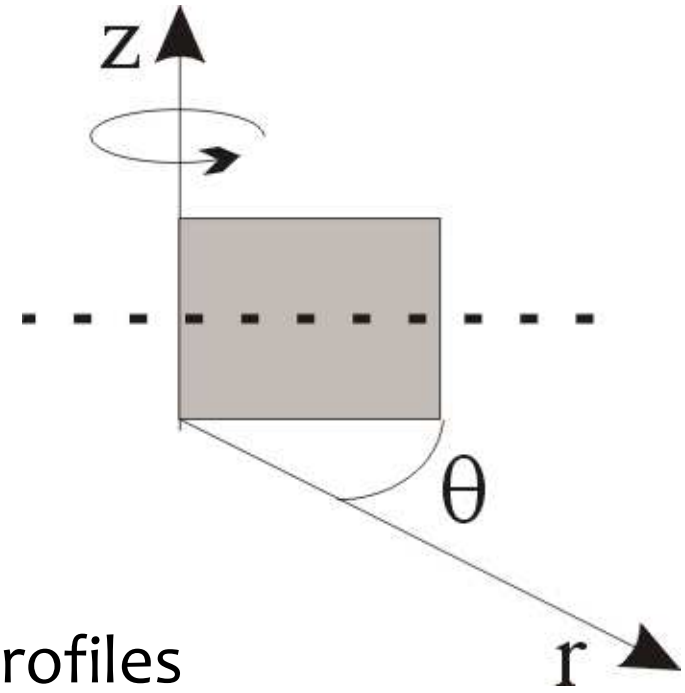


Monolith needs drying control
Thermo-hygro-mechanical coupling

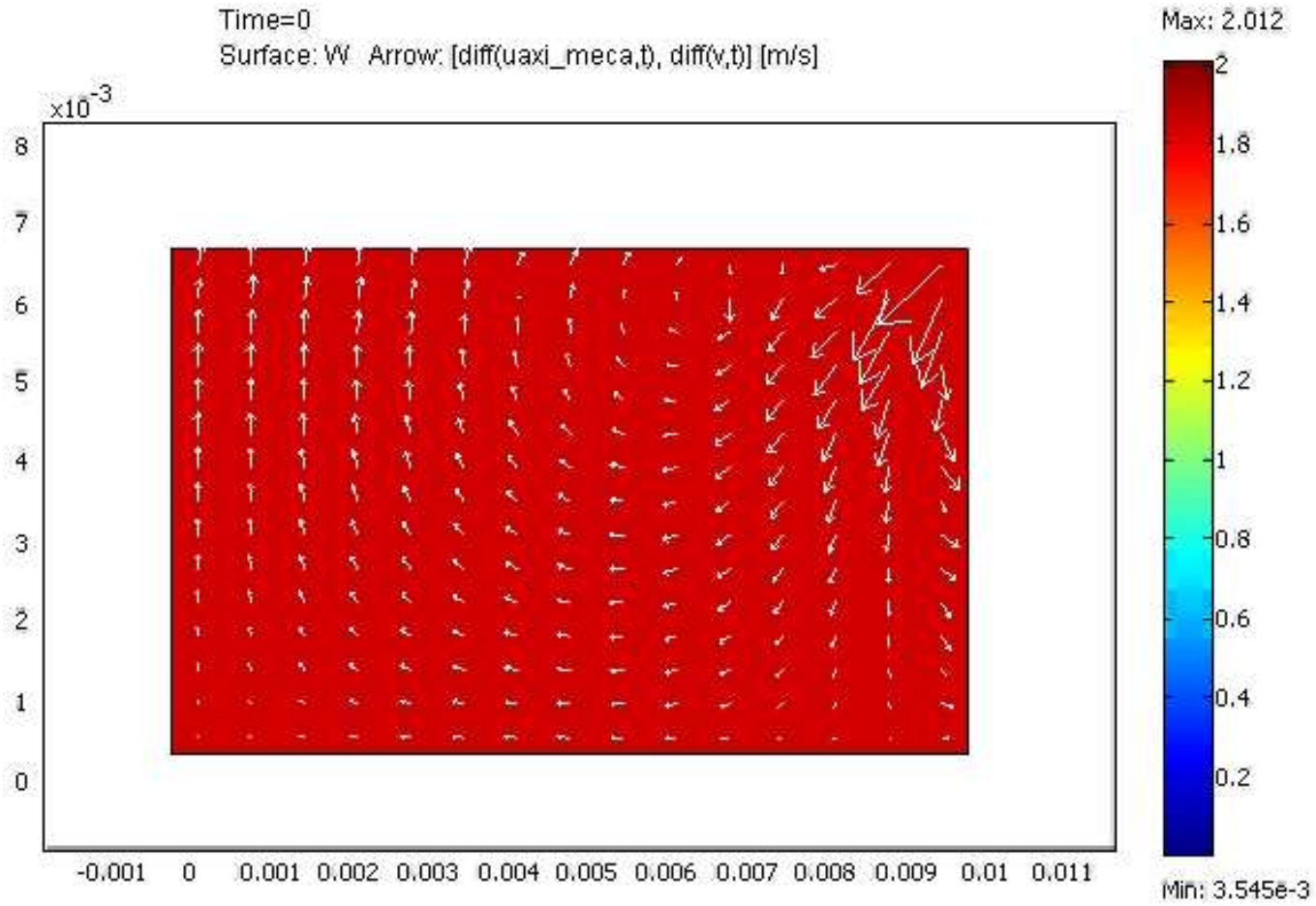
Thermo-hygro-mechanical simulation

- Development of drying simulation model
  - Gel = ideal shrinking medium
  - Saturation throughout the drying process
  - Eulerian coordinates + solid velocity
    - mechanical coupling
  - ALE method for resolution

    = Arbitrary Lagrangian Eulerian
    - moving boundaries
  - 2D axisymmetric geometry
  - Comsol Multiphysics™
- Comparison with experiments
- Validation using internal moisture profiles

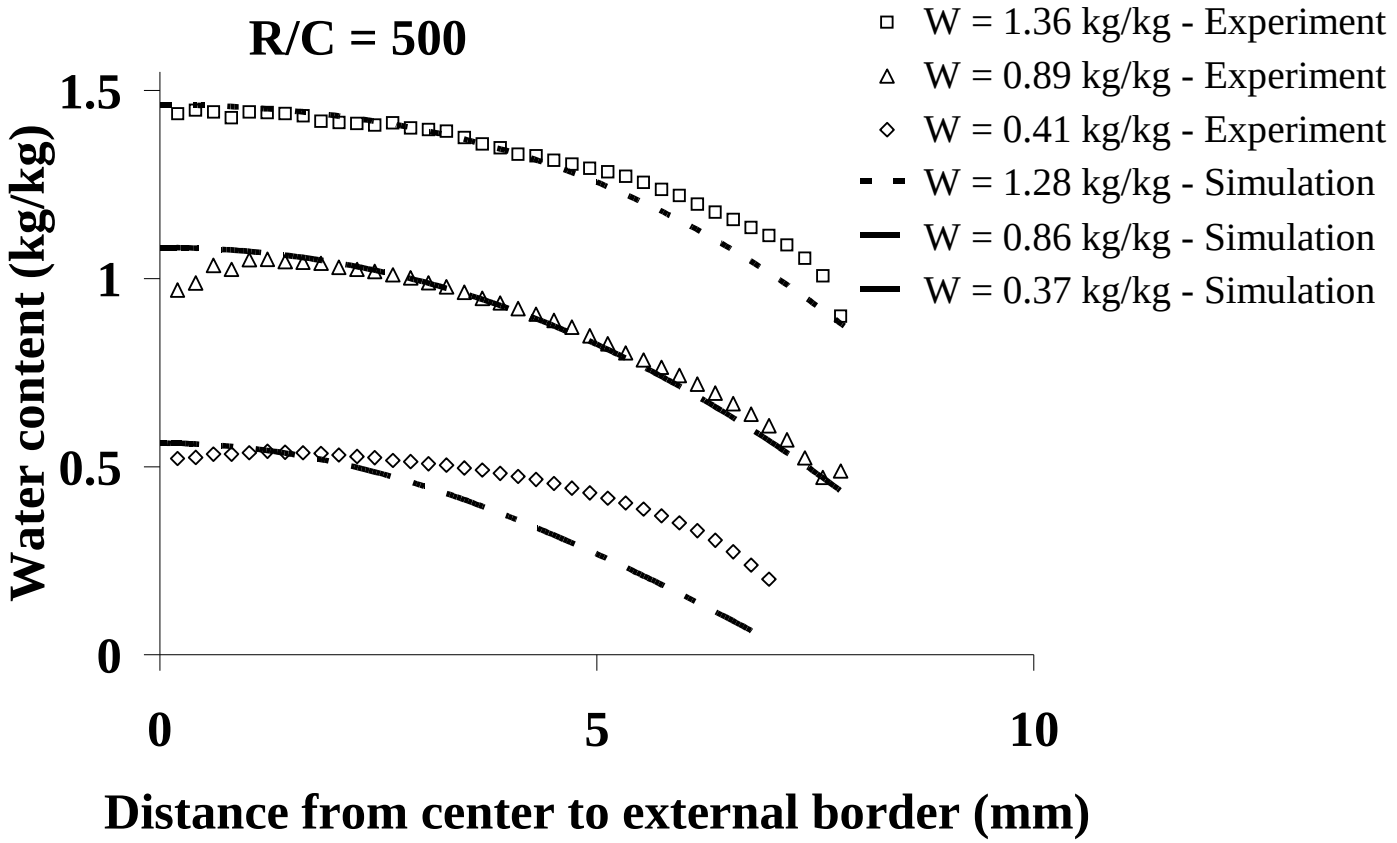


Thermo-hygro-mechanical simulation



Thermo-hygro-mechanical simulation

- Experimental vs simulated moisture profiles



- Rather good agreement
- Improvement for small water contents

About X-ray microtomography …

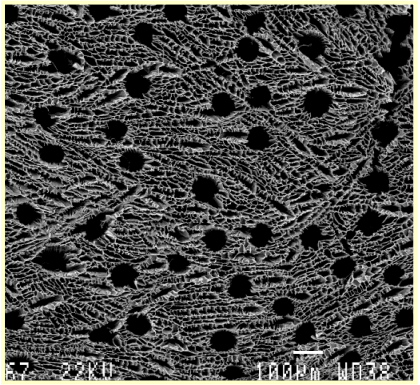
Research context

- Product engineering or product design approach

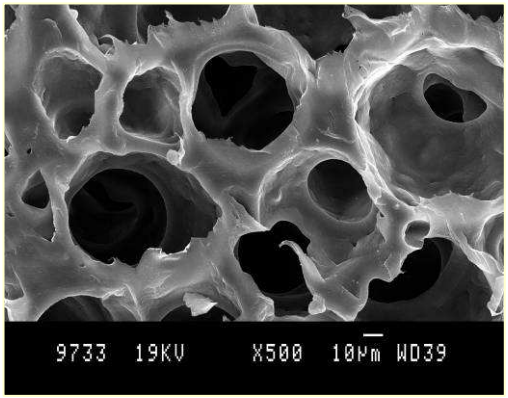
  - End user properties, defined by macroscopic properties, depends on microstructure
  - Microstructure influenced by production process: synthesis, mixing, dewatering, drying, …
- Need for multiscale characterization tools
- Key role of X-ray microtomography, coupled with image analysis
- Development of application oriented algorithms

Research context

- Limitations of classical characterisation techniques
  - Mercury porosimetry: 3.5 nm< d_p<150 µm
  - N_2 adsorption-desorption: 2 nm< d_p<50 nm
  - Pycnometry
  - SEM, TEM: destructive, mostly 2D

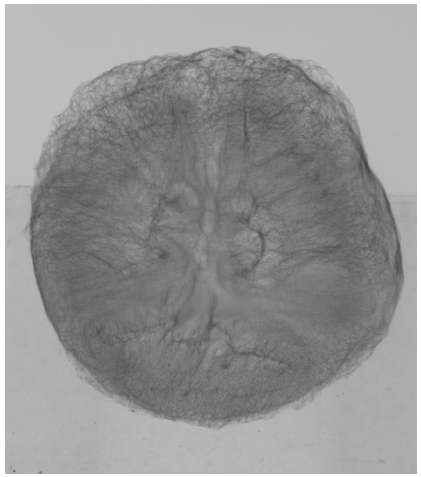


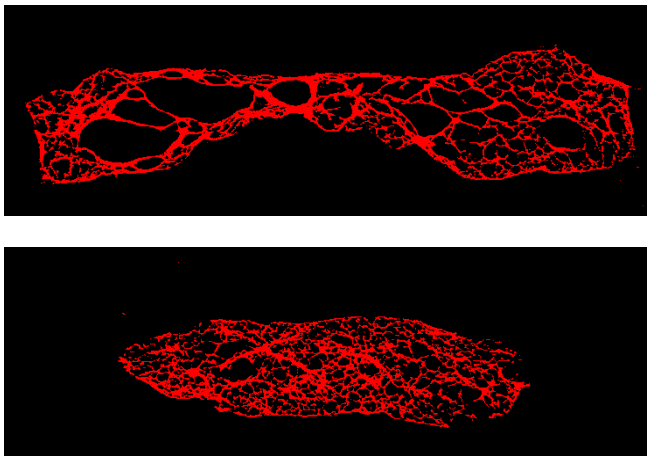
- Microtomography
  - 3D characterisation
  - Non destructive technique
  - No specific sample preparation
  - d_p> 2 µm

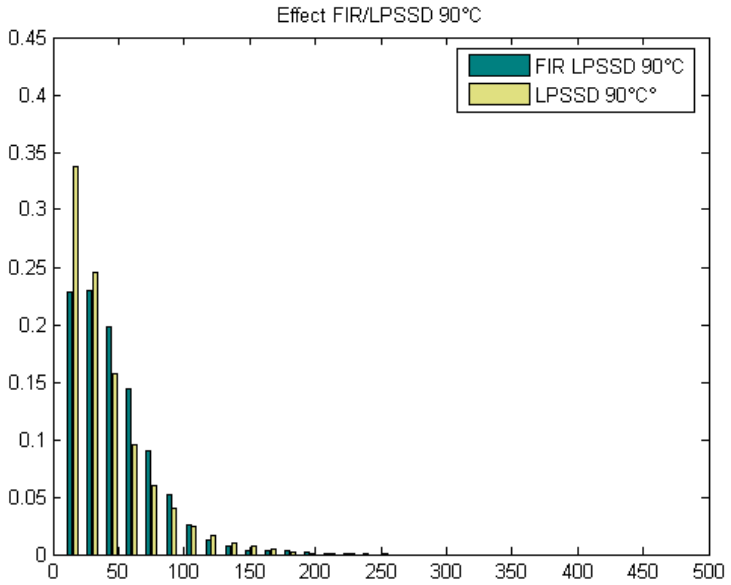


Impact of drying on product quality

- Dried bananas







Radiograph

2D cross sections

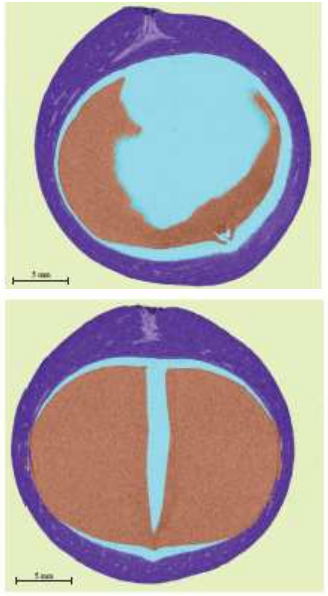
Léonard et al., J. Food Eng. , 85(1), 154-162 (2008)

Relation between drying conditions, structure and properties
→ « crispyness », rehydration, …

Impact of drying on product quality

- Macadamia nuts

Radiograph



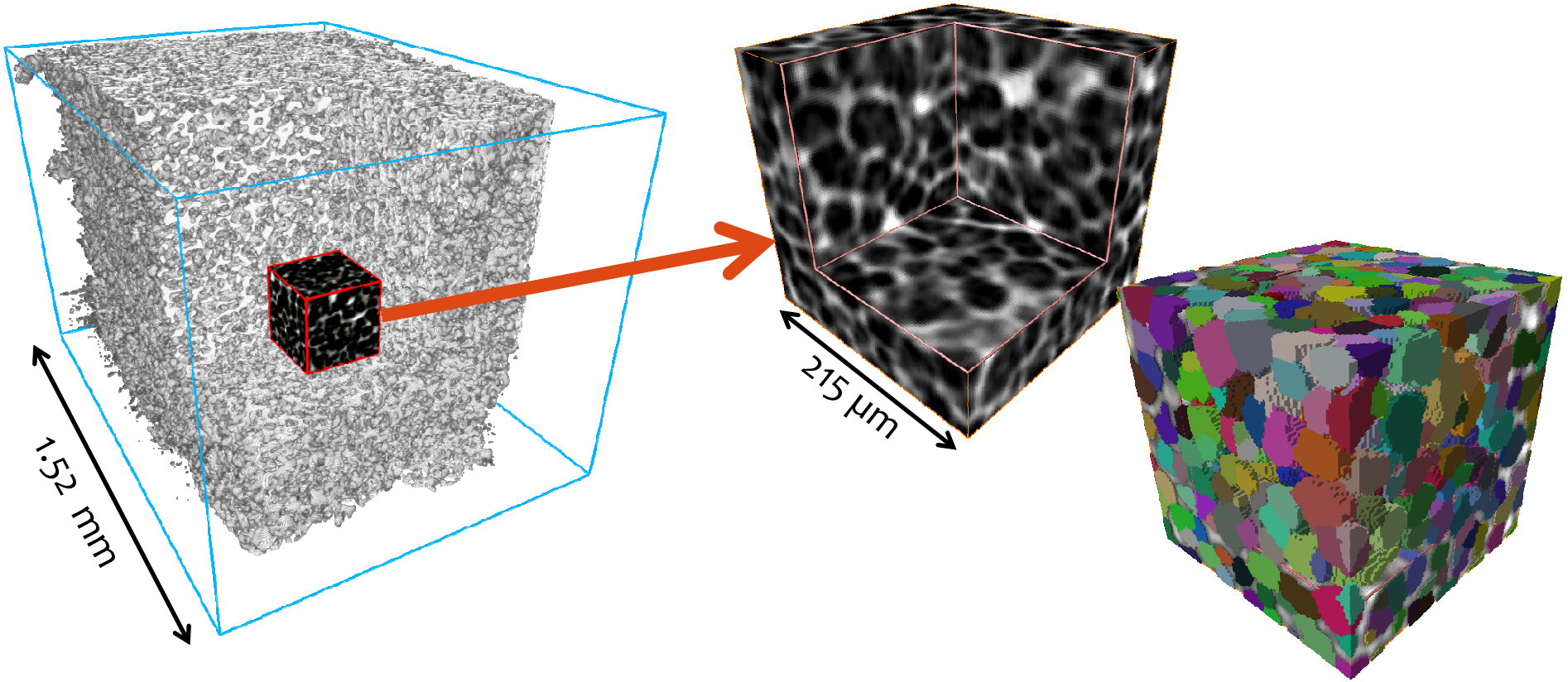
2D cross sections

3D image

Relation between type, drying, microstructure and conservation

Characterization of polymer foams

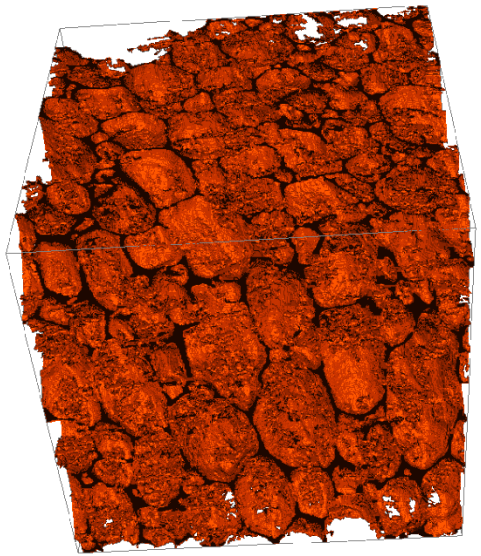
- 3D microstructure of nanocomposites foams



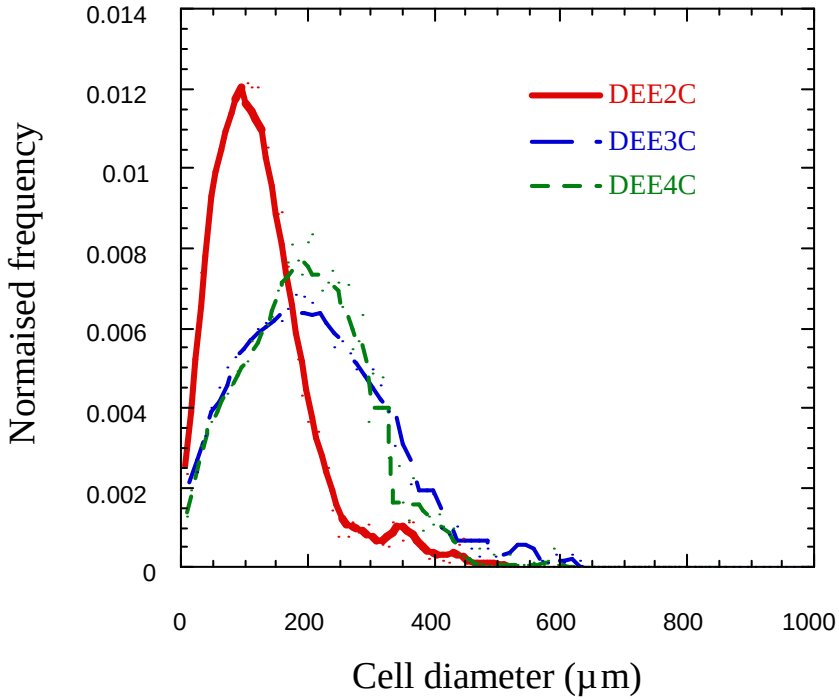
Relation between electrical conductivity and cell morphology

Characterization of biobased foams

- Carbon foams based on renewable biomass (Pr. A. Celzard, Nancy)



Tondi et al., Microsc. Microanal. (sous presse)

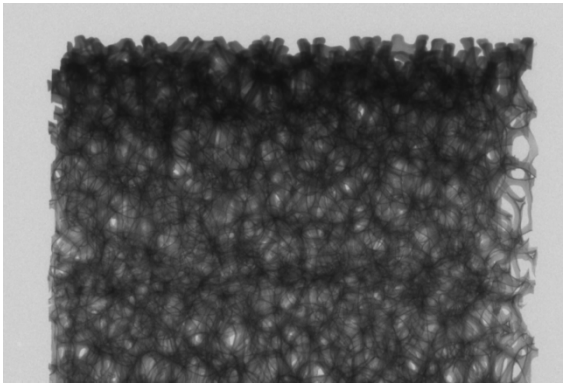


Relation between morphology and synthesis conditions

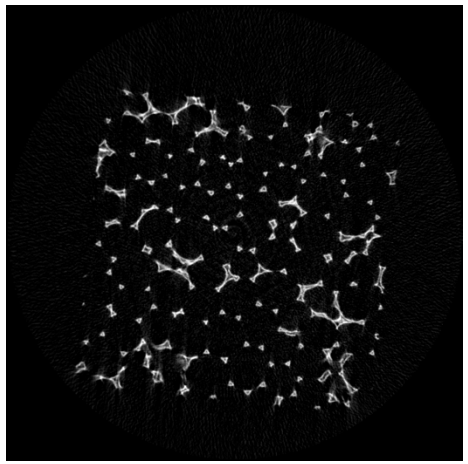
About X-ray microtomography

Characterization of structured packing

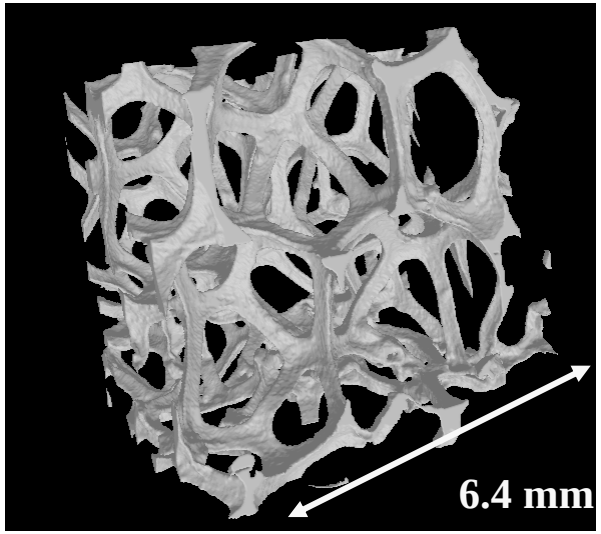
- Metallic foams (PhD S. Calvo)



Radiographie



Section 2D



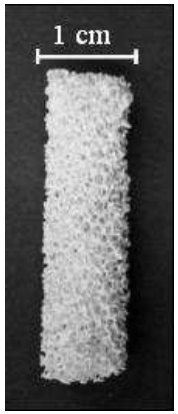
Vue 3D

Calvo et al., Chem. Eng. Process., 48(5), 1030-1039 (2009)

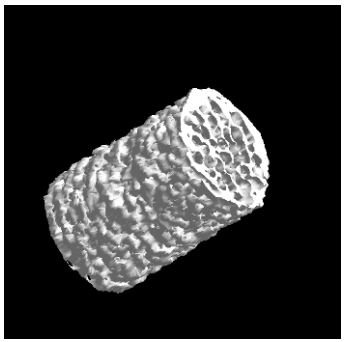
Flow simulation using LBM method

Impregnation of catalyst

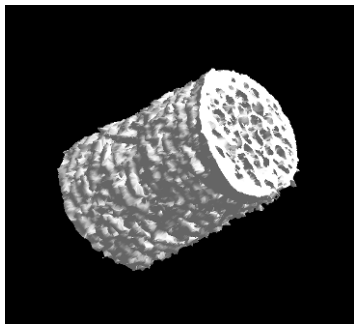
- Pd-Ag/SiO_2 xerogel catalyst on alumina foam



Alumina foam

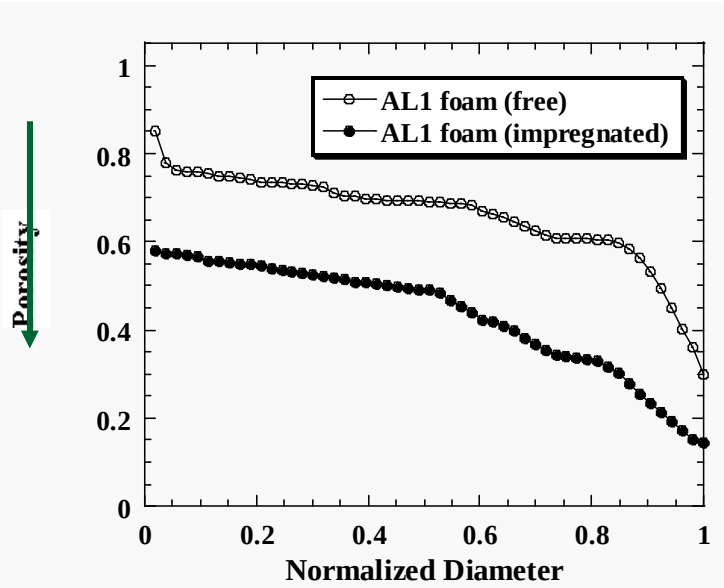


Before impregnation



After impregnation

Impregnation efficiency
Homogeneity

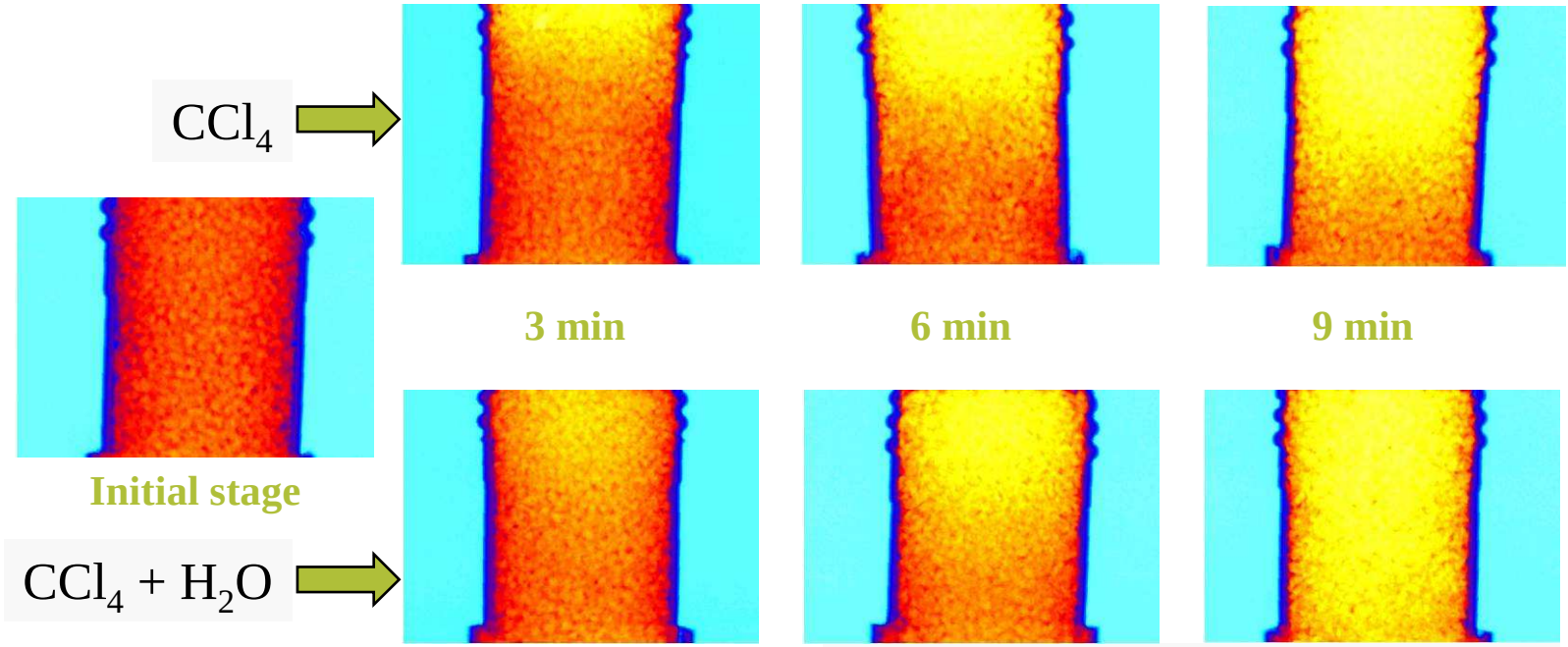


S. Blacher et al., Colloid Surface A, 241, 201-206 (2004)

Alié et al., Chem Eng J, 117, 13-22 (2006)

Follow-up of VOC adsorption

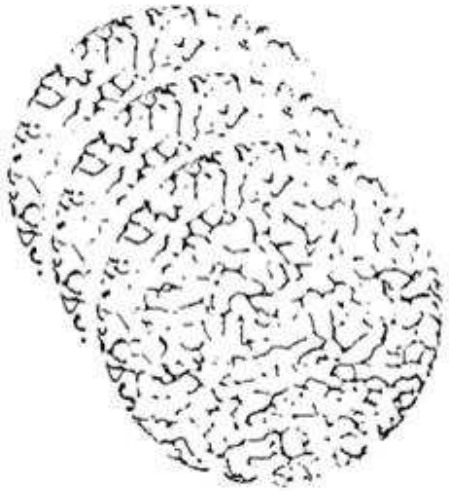
- Activated carbon filters



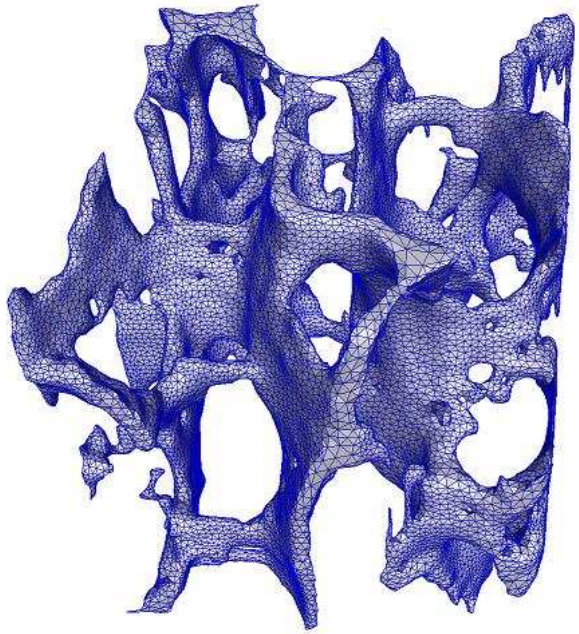
P. Lodewyckx et al., Adsorption, 12(1), 19-26 (2006)

Characterization of biomaterials

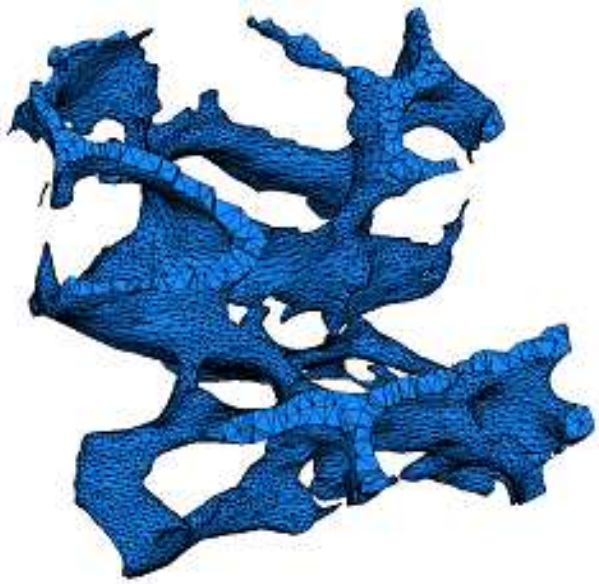
- Simulation of compression tests on deer antlers



2D sections



Surface mesh



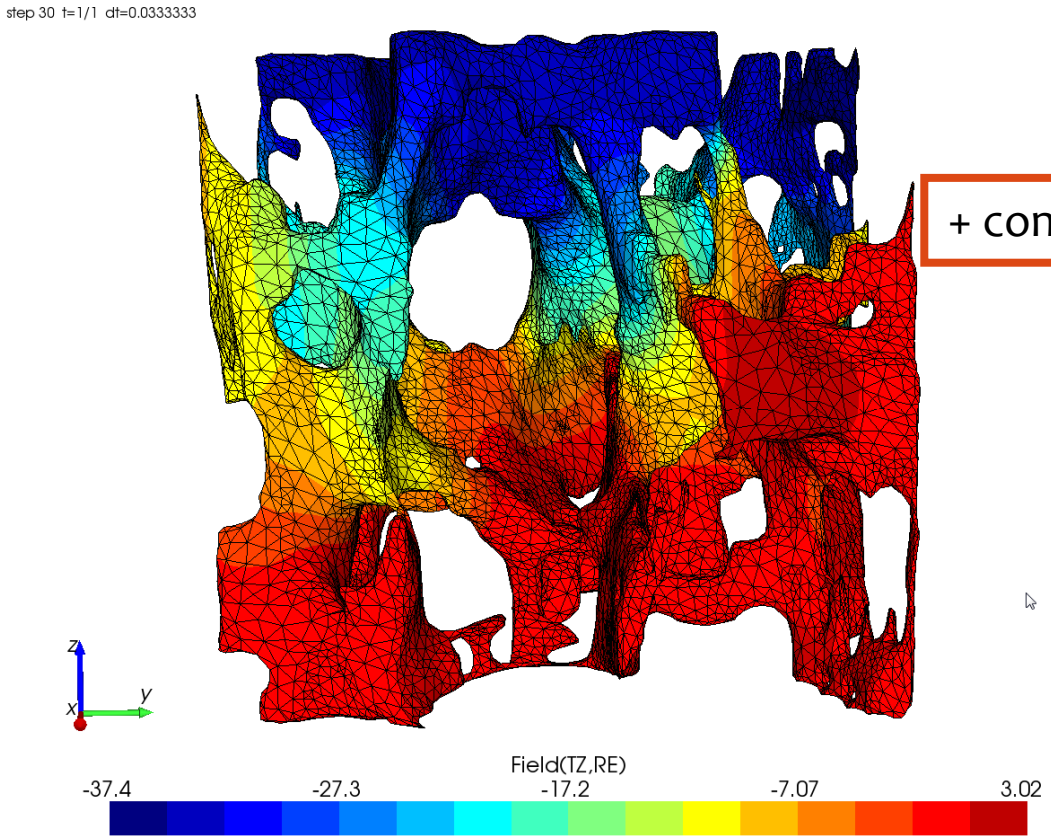
Volume mesh

TFE Charlotte De Bien (2010)

Coll. JP Ponthot – V. D'Otreppe – Dpt A&M

Characterization of biomaterials

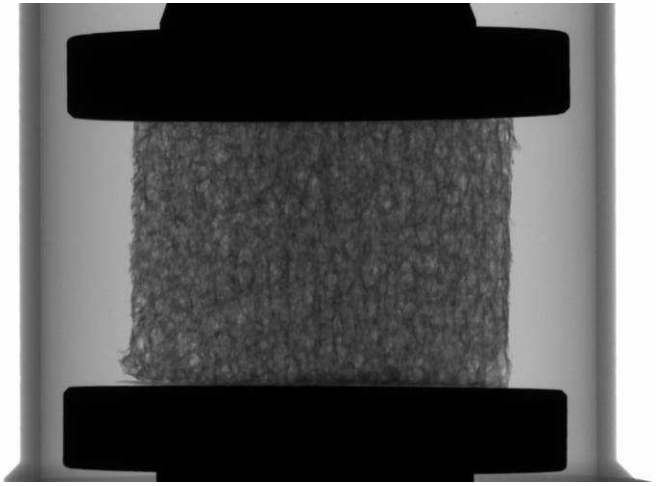
- Simulation of compression tests on deer antlers



TFE Charlotte De Bien (2010)

Coll. JP Ponthot – V. D'Otreppe – Dpt A&M

+ comparaison with in situ measurements



About LCA

LCA: a standardized methodology

- General framework defined by international standards ISO 14040 - 14044

- « studies all the environmental aspects and potential impacts associated with all the stages of a product's life from cradle to grave, i.e. from raw material extraction to end of life»
- Product = product, activity, system or process

LCA: a standardized methodology

- Life cycle includes
  - Raw material extraction
  - Production
  - Transport
  - Packaging
  - Distribution
  - Use
  - Maintenance - Repair
  - Reuse or recycling
  - Disposal
- « Cradle to grave » approach

http://sydney.edu.au/facilities/sustainable_campus/procurement/index.shtml

LCA: typical results

- Life cycle steps 'ranking' following their environnemental impacts
- Identification of susbtances responsible for major environmental impacts

CO_2 footprint = 1 inventory among many others

- Determination of categories with highest environmental impacts
  - Human health, climate change, ecotoxicity …

LCA: why ?

Internal

Strategy

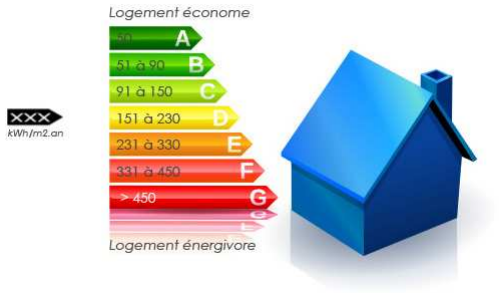
- Potential impacts of products on environment
- Investments decision support

R & D products/process

- Early identification of problems/opportunities
- Assistance in projects selection
- Assistance in defining objectives

Externa

Marketing

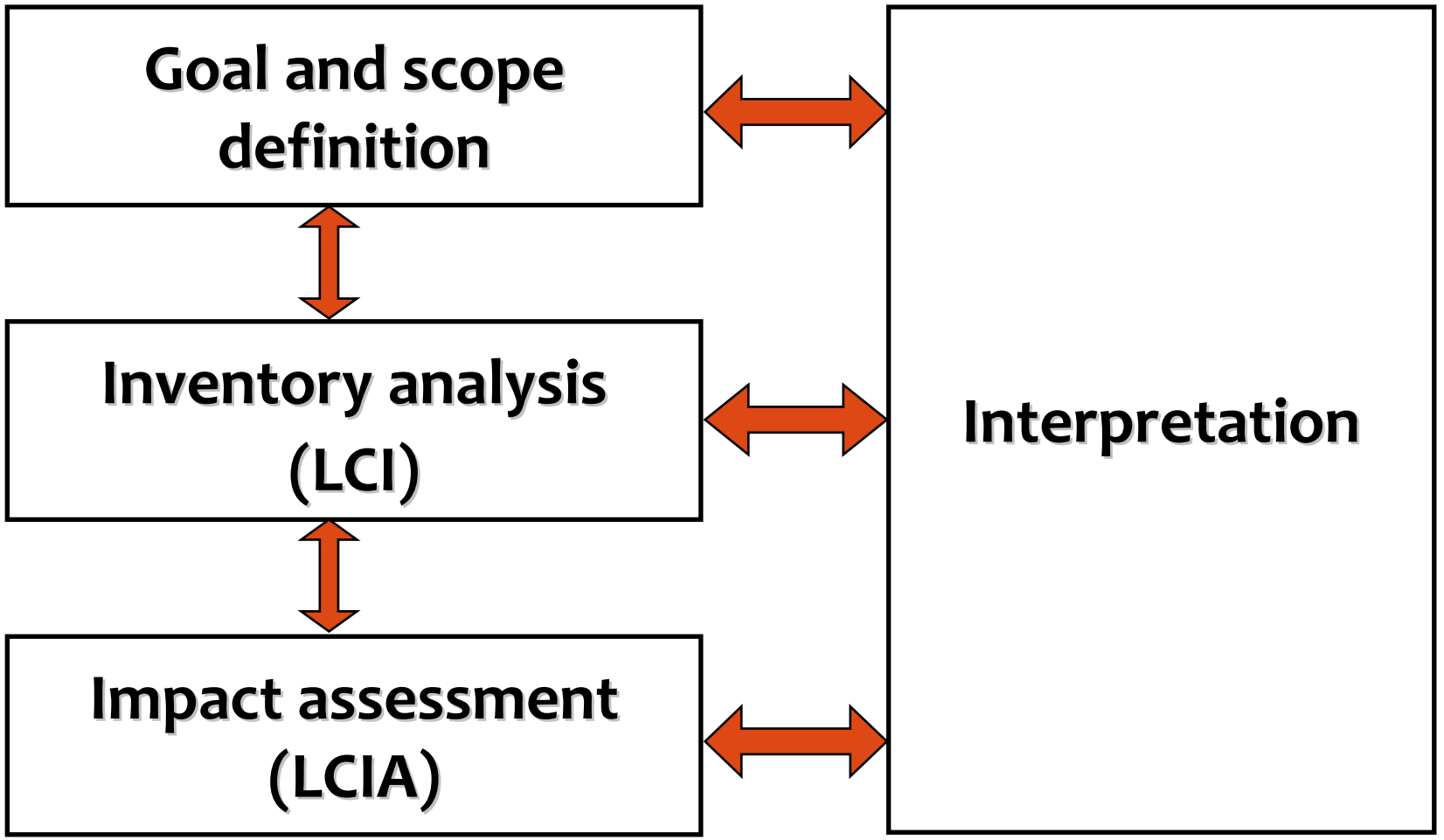


Policy

- Best information of authorities, consumers, etc. (legislation/regulation, eco-labels …)
- Comparative analyses

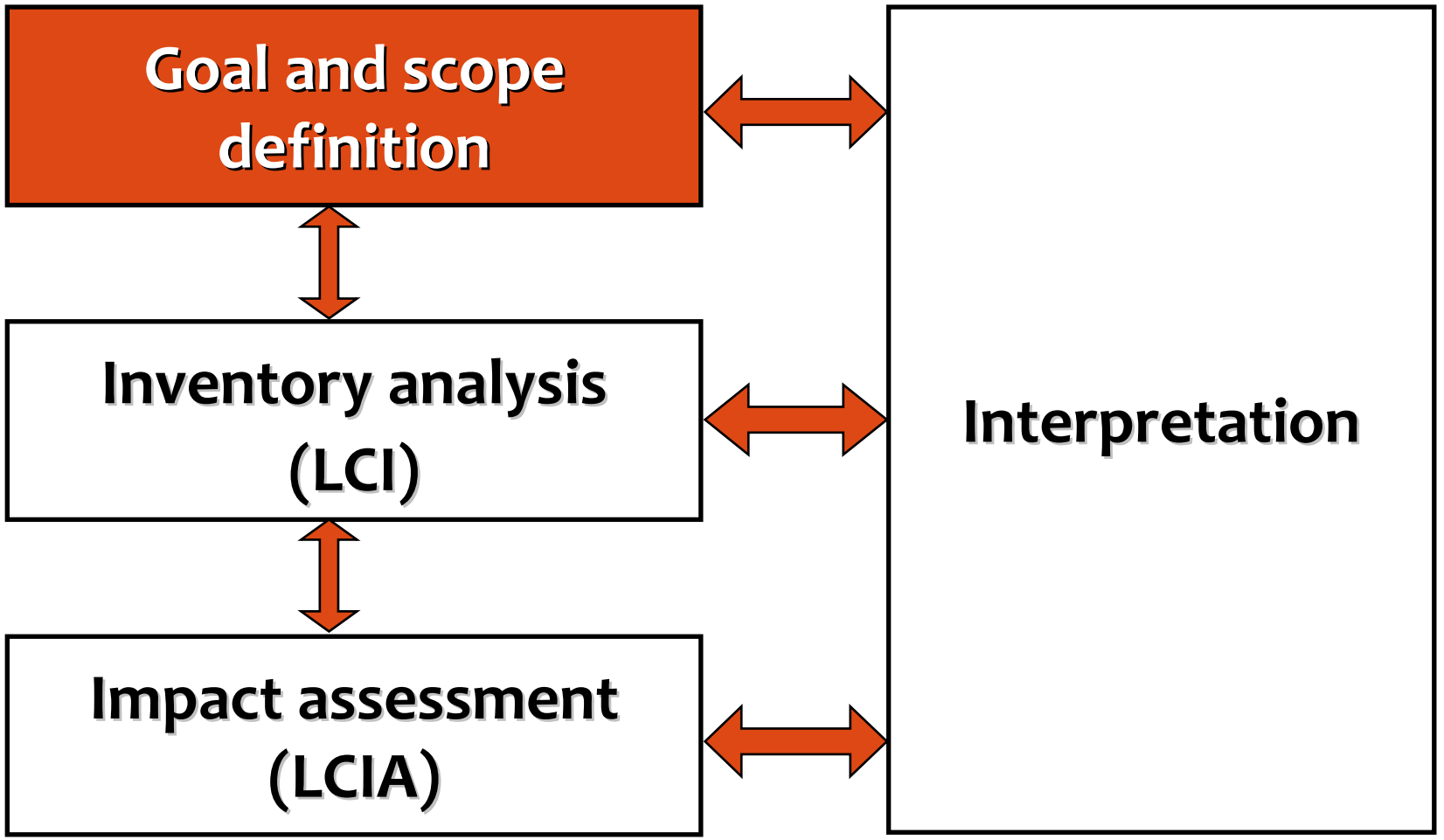
LCA associated steps

- Four steps defined by ISO 14040 – 14044



LCA associated steps

- Four steps defined by ISO 14040 – 14044



LCA: goal and scope definition

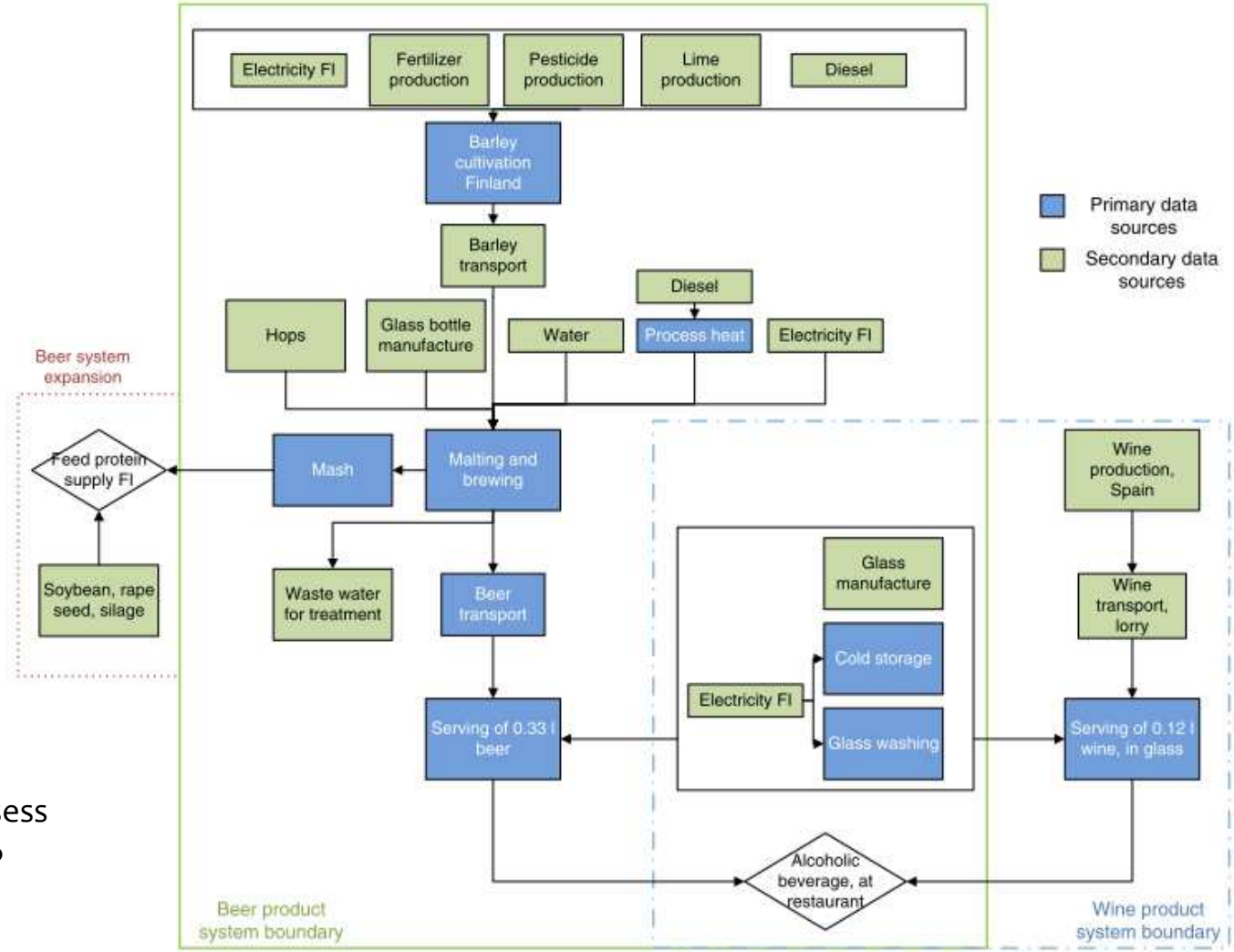
- Goal of the study
  - Why ?
  - For whom ?
  - …
- Scope
  - Choice of the functional unit
    - Production of 1 kg of yeast
    - Treatment of 1 ton of waste
    - Valorization of 1 ton of biomass
    - …

LCA: goal and scope definition

- Scope
  - Delimitation of the system boundaries
    - Determination of all the elementary processes to be included in the analysis
  - Process tree
  - Data quality requirements
  - Cut-off rules

LCA: goal and scope definition

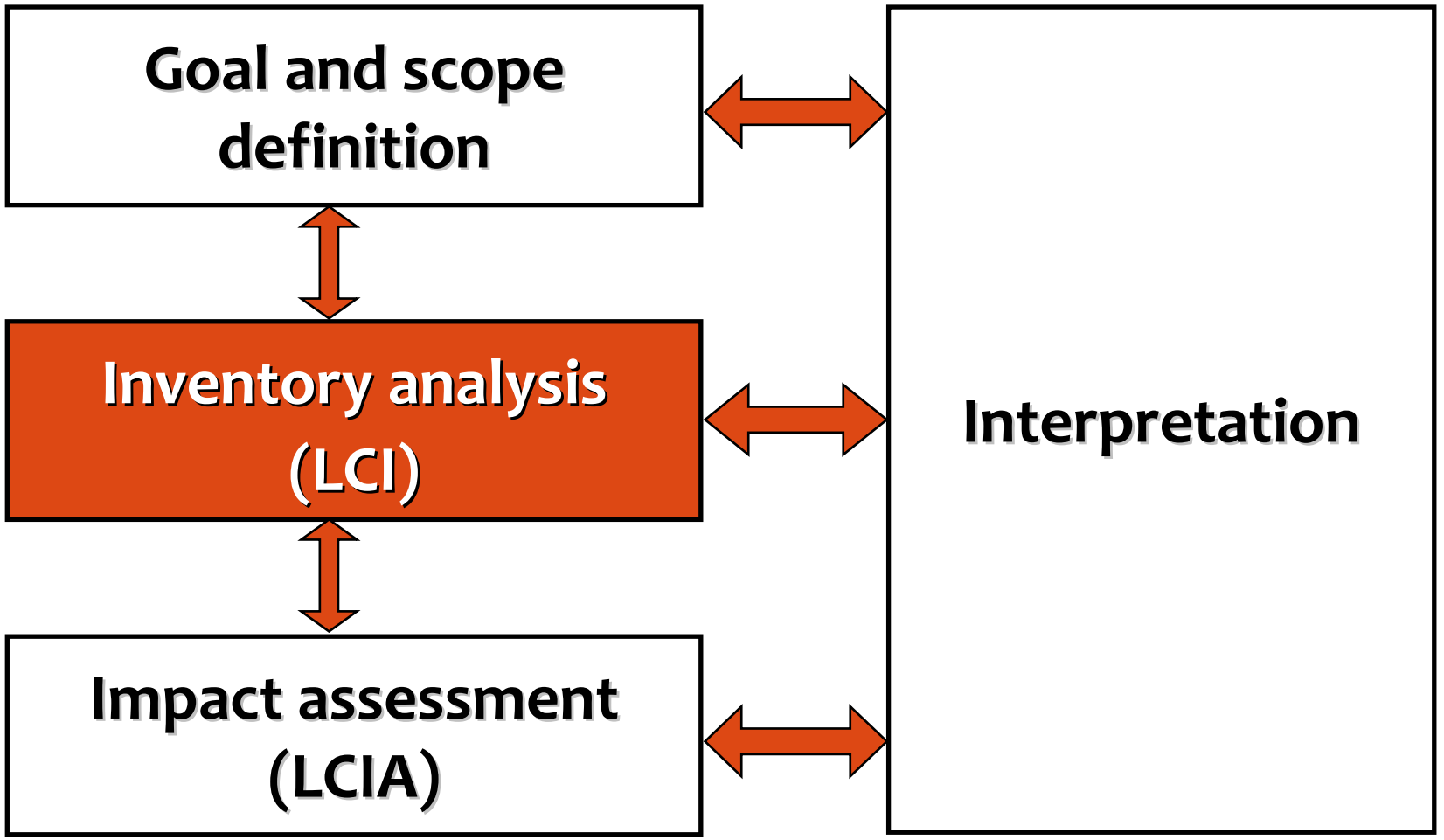
- Example: process tree + boundaries



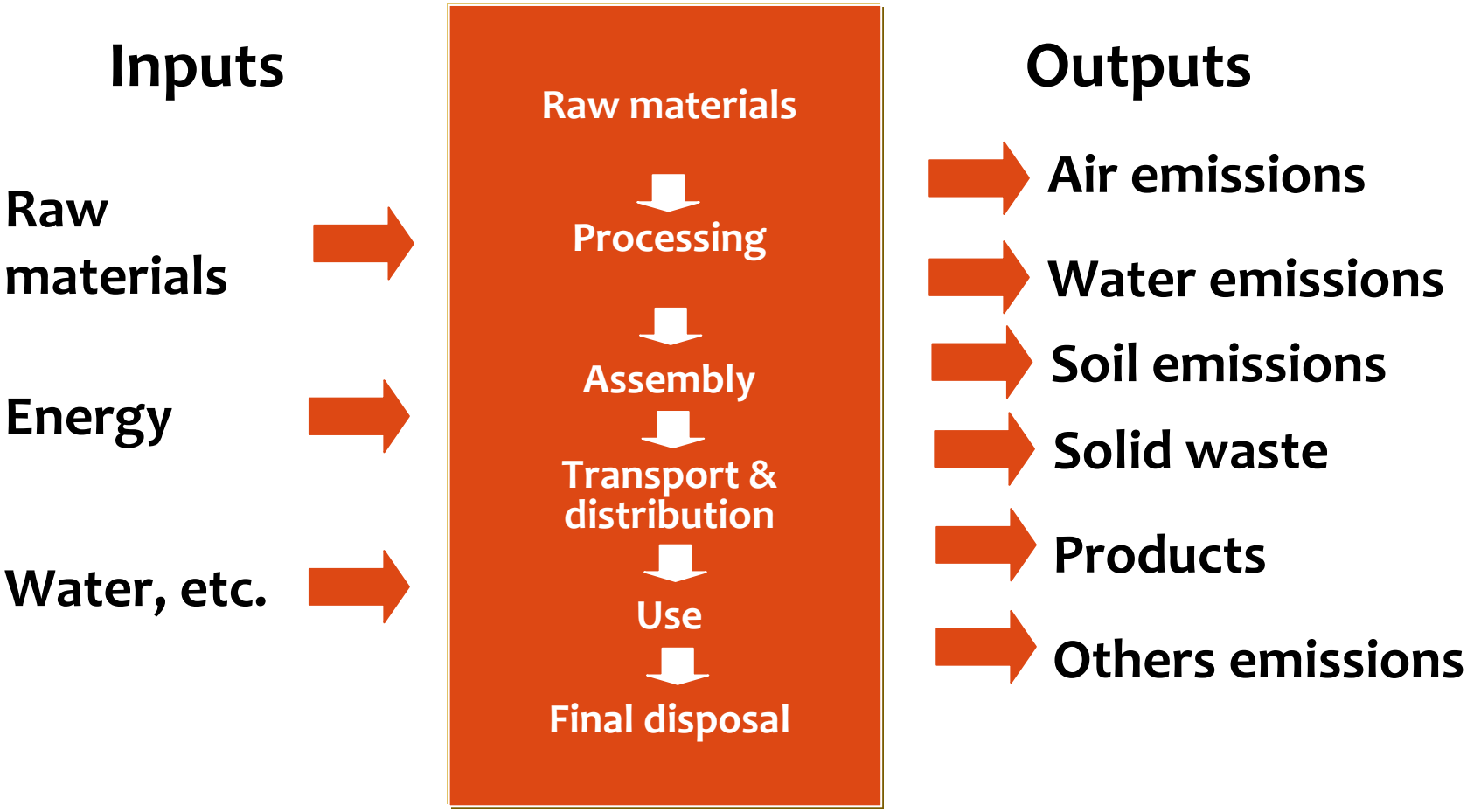
Int J Life Cycle Assess (2012) 17:277 – 286

LCA associated steps

- Four steps defined by ISO 14040 – 14044



LCA: Inventory

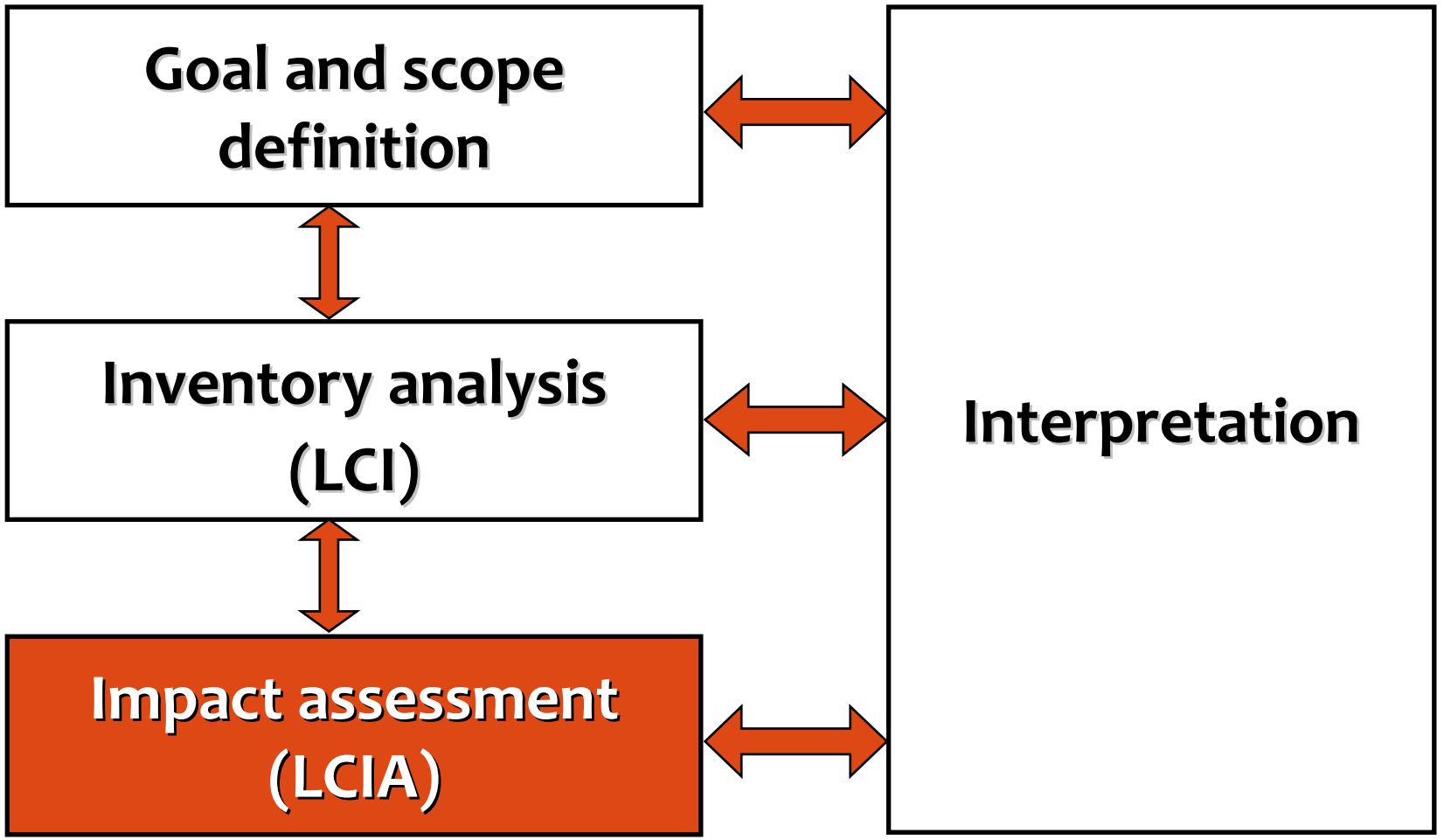


LCA: Inventory

- Practically …
  - Commercial databases
  - Data provided by industrials
  - (Inter)national databases
  - Scienfitic and technical literature
- But … data are ofter missing or quality is questioning
  - Process modeling
  - Data reconciliation
  - Knowledge of unit operations, …

LCA associated steps

- Four steps defined by ISO 14040 – 14044

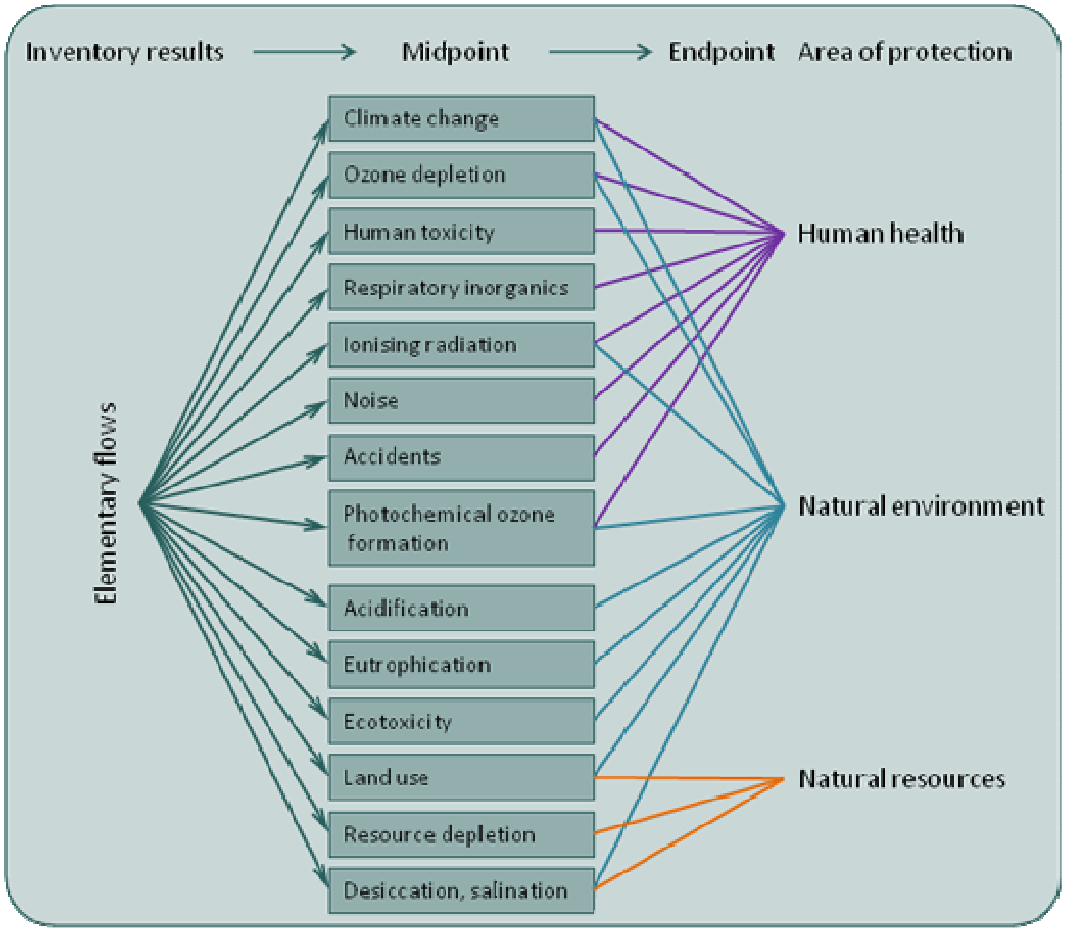


LCA: impact assessment

- Estimation of environmental impacts based on the inventory
- Mandatory elements
  - Selection of impact categories, indicators, methods
  - Classification
  - Characterization
- Optional elements
  - Normalisation
  - Grouping
  - Weighting

LCA: impact assessment

- Impact categories



http://lct.jrc.ec.europa.eu/assessment

LCA: impact assessment

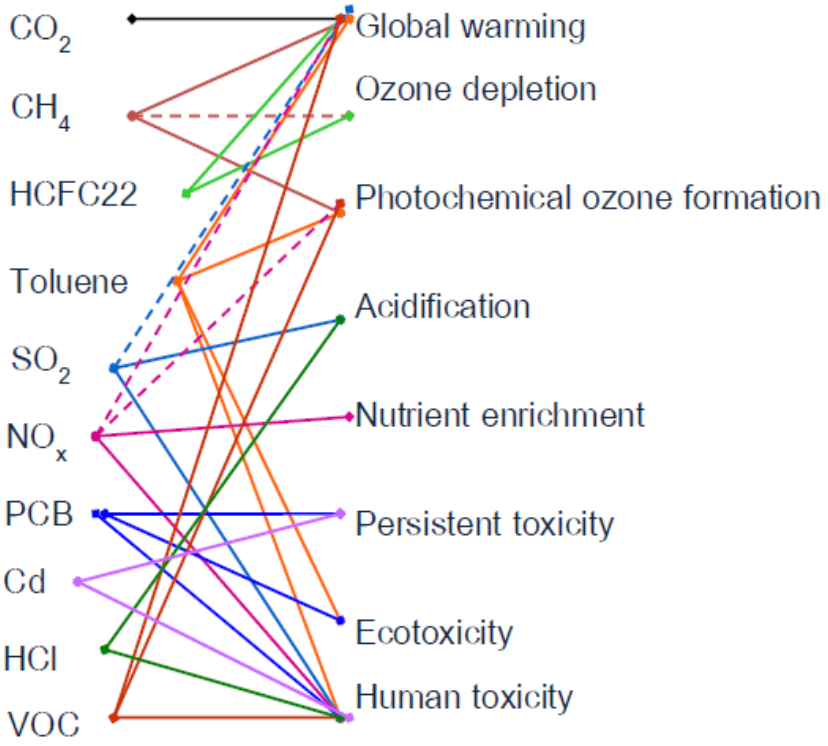
- Impact assessment methods

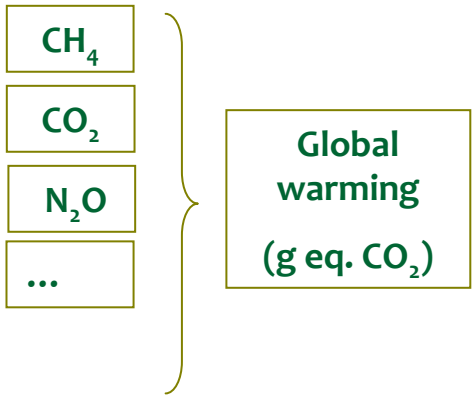
Method name	Temporal validity	Regional validity	Type of impact category (IC) indicators	Weighting principle
CML 2002	Present state (year 2002)	Global, except for acidification (Europe) and photo-oxidant formation (European trajectory)	Midpoint	No baseline method is proposed
ECO-indicator 99	Present state (year 1999)	Global for the impact categories (IC) climate, ozone depletion and resources. European model for the other IC. Acidification and eutrophication based on Dutch model, land use based on Swiss model.	Midpoint and Endpoint	Three options: Panel method is used for default weights. Monetization and a specific weighting triangle can also be used.
Eco-scarcity	Actual flows reflect 2004 state and critical flows correspond to 2005 political objectives.	Originally developed for Switzerland, but versions for Netherlands, Sweden, Norway, and Japan are also available.	Midpoint- distance to target principle. Endpoints indirectly considered by political targets.	Relative reduction of distance to target by multiplying by the square of the ratio of actual flow and critical flow.
EDIP	Present state (year 2003)	Global	Midpoint	Distance to political targets.
EPS 2000	Present state (year 1999)	Majority global, the largest exception is for Biodiversity where Swedish models are used.	Endpoint effects	Willingness To Pay to avoid changes on safeguard subjects.
ReCiPé	Present state (year 2010)	Europe, but global for climate change, ozone layer and resources.	Combination of midpoint and endpoint methodologies in a consistent way.	Three options: For midpoints a monetization method on the basis of the prevention costs is provided. For endpoints panel weighting is used and monetization on the basis of damage costs can be used.

http://www.tosca-life.info/wordpress/wp-content/uploads/2011/06/LCIAmethods.jpg

LCA: impact assessment

- Classification
  - Assignment of inventory results to the selected impact categories





LCA: impact assessment

- Characterization
  - Conversion of LCI results into representative indicators of impact using charaterization factor
  - Substances belonging to the same impact category are expressed in 'equivalent' units

$$\text{Inventory Data} \times \text{Characterization Factor} = \text{Impact Indicators}$$

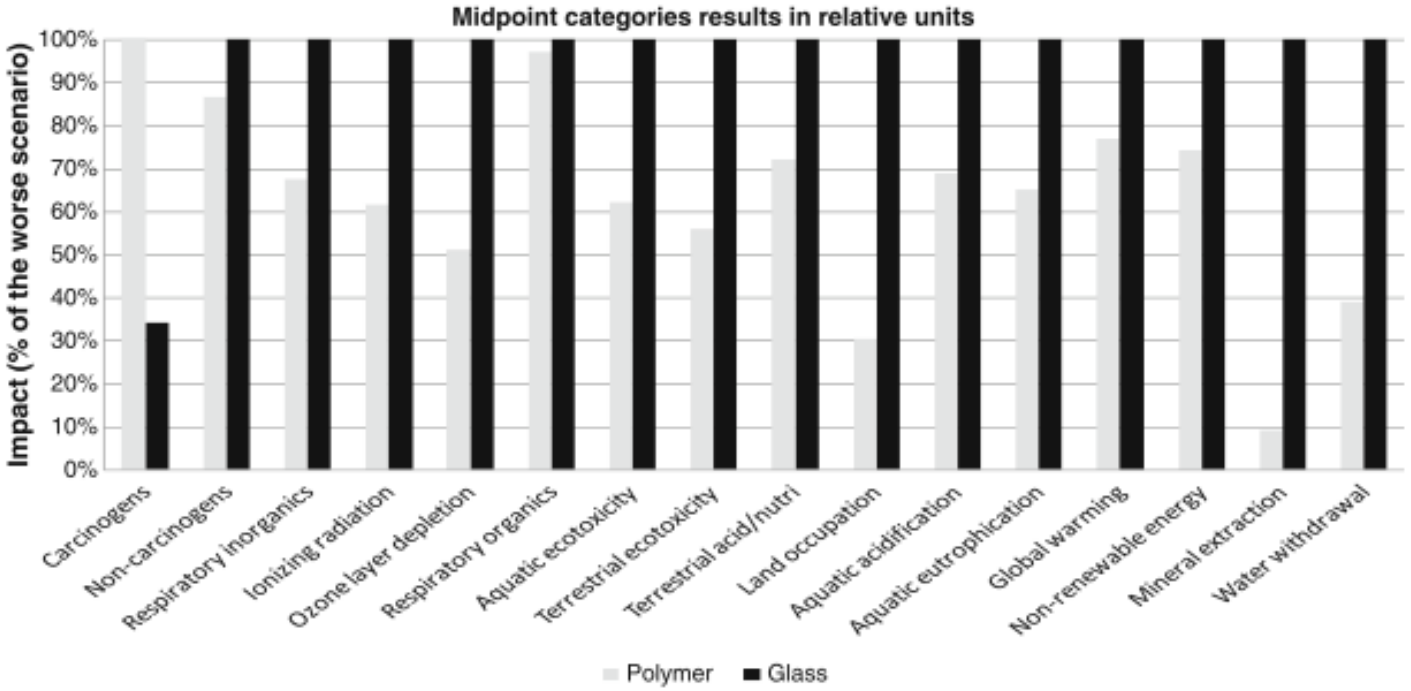
kg CO_2/FU
kg CH_4/FU
kg N_2O/FU

$\Rightarrow$ **eq-kg CO_2/FU**

Global warming:	eq-kg CO_2/FU
Acidification:	eq-kg SO_2/FU
Ozone depletion:	eq-kg CFC-11/FU
Fossil fuels:	MJ/FU
…	

LCA: impact assessment

- Characterization: example - Vials comparison



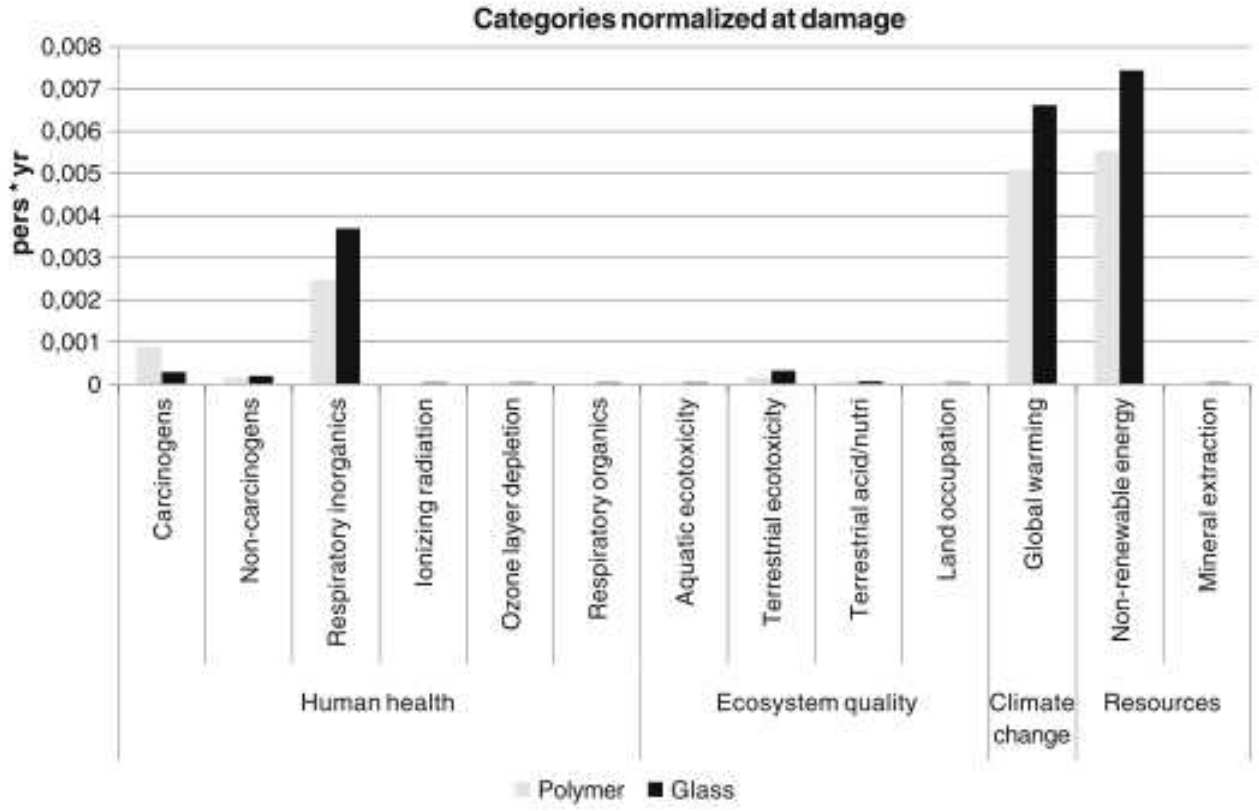
S. Belboom et al. Int J Life Cycle Assess (2011) 16:159-167

LCA: impact assessment

- Normalisation
  - Tool to express impact indicator data in a way allowing to compare among impact categories
  - Indicator normalisation by dividing results by a selected reference value such as global or regional averages
- Grouping
  - Impact categories are sorted and grouped, depending on the chosen impact assessment method

LCA: impact assessment

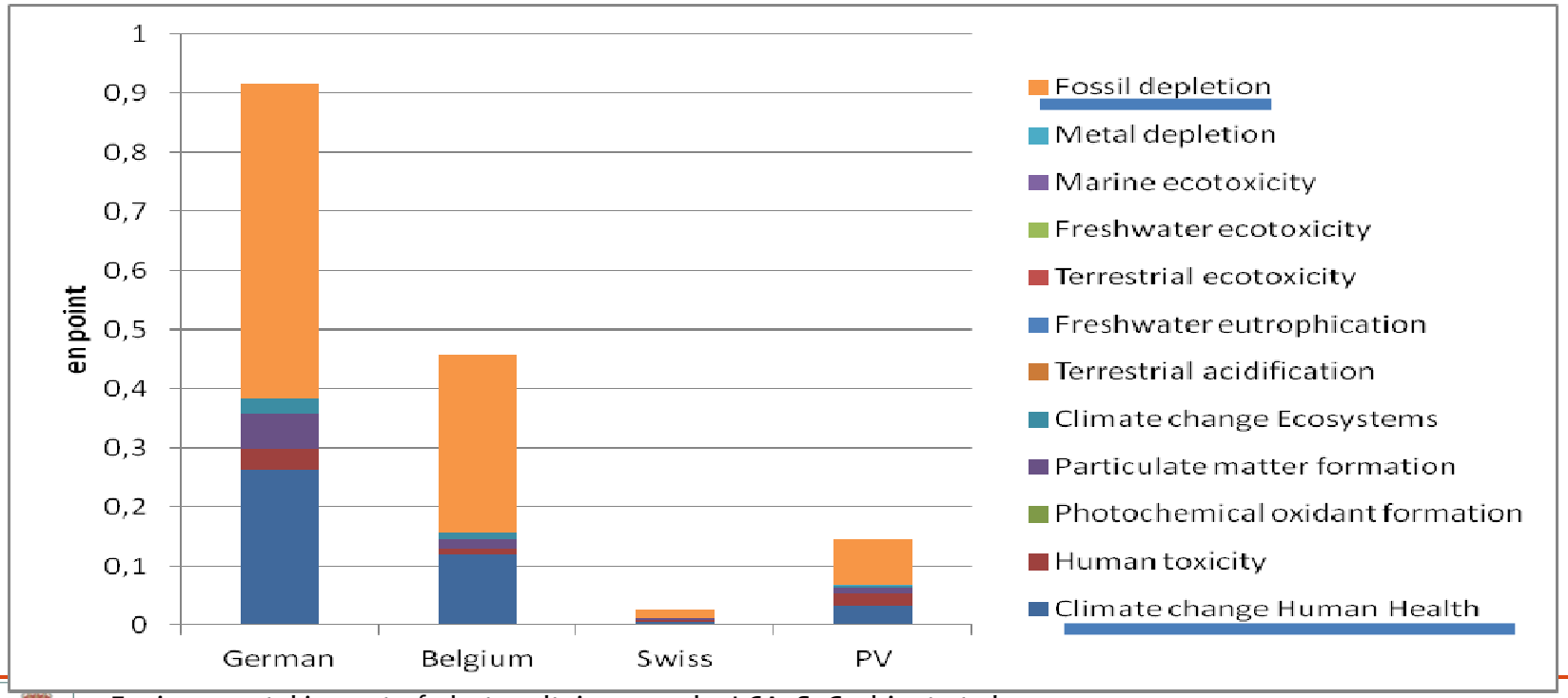
- Normalization/Grouping: vials comparison



S. Belboom et al. Int J Life Cycle Assess (2011) 16:159-167

LCA: impact assessment

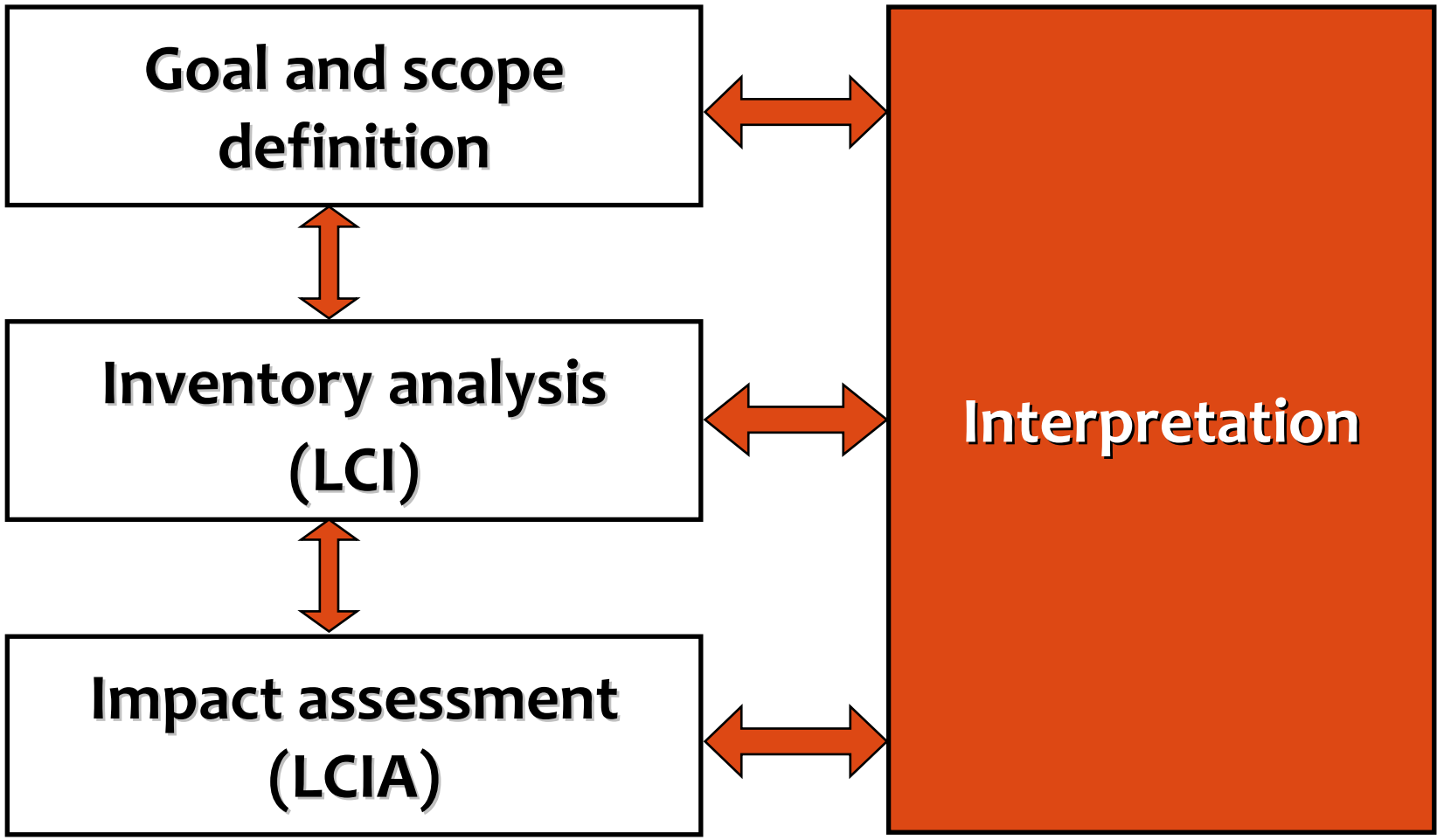
- Weighting
  - Indicator results for different impact categories are converted to a common unit by using factors based on value-choices → "Single score" result



Environmental impact of photovoltaic power by LCA, S. Gerbinet et al.
Congrès ACV, Lilles, 3-4 novembre 2011

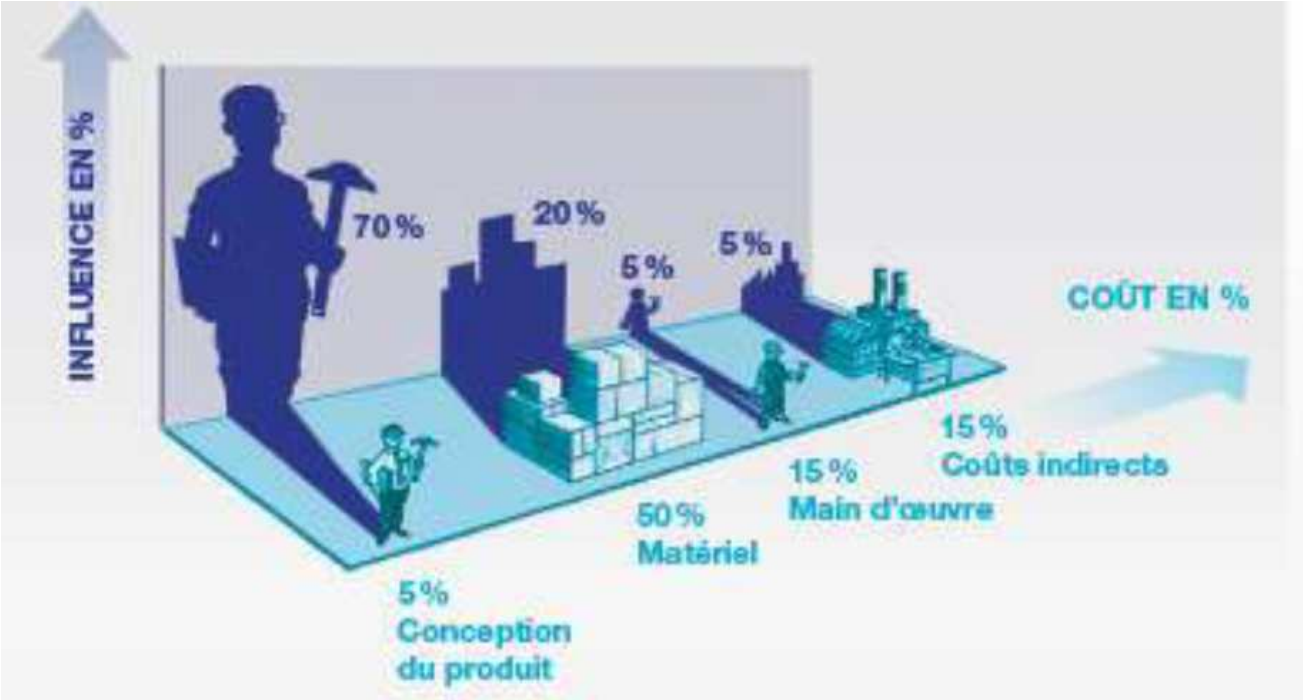
LCA associated steps

- Four steps defined by ISO 14040 – 14044



LCA = way to « ecodesign » new processes

- 70% of « the environmental impact » already fixed during the design step



Ecodesign = integration of environmental aspects into product or process design with the aim of improving the environmental performance throughout the whole life-cycle

L'écoconception, source d'innovation dans l'approche cycle de vie; l'expérience du Québec, Guy Belletête, Congrès ACV, Lilles, 4/11/2011

Expertise in environmental management

- LCA: more than 10 years of expertise
  - Evaluation of the environmental impact of processes
  - Redaction of environmental declarations
  - Development of databases
  - Academic research + external studies
  - Participation to several regional and European projects
  - …

Expertise in environmental management

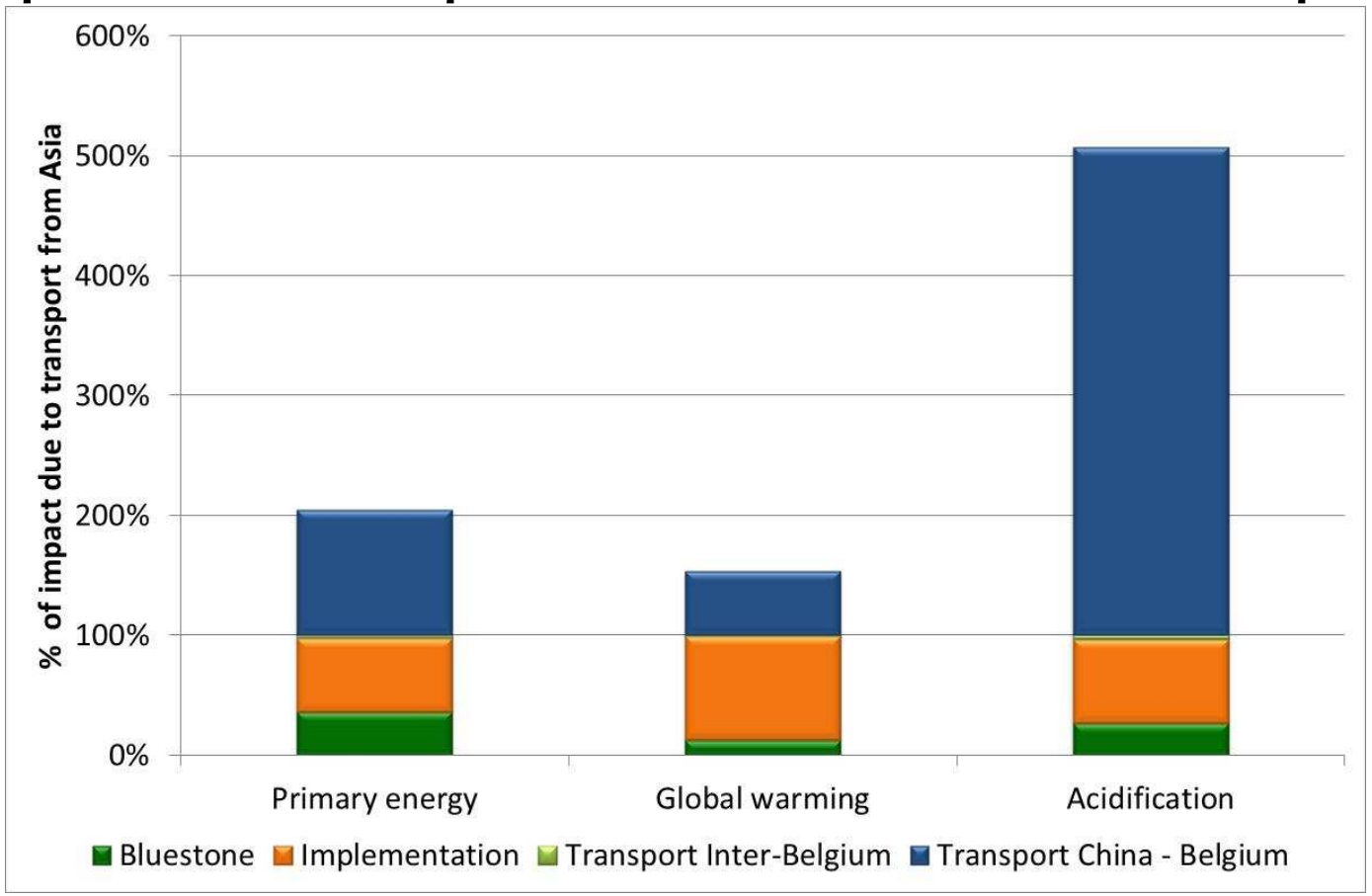
- LCA: some covered topics
  - Comparison of vehicles
  - Comparison of waste management scenarios
  - Comparison of packaging options
  - Comparison of several ways of renewable heat heat production
  - Comparison of several ways of renewable electricity production
  - Study of biofuels production
  - Study of agro-food by-products valorization ways
  - Impact of water management (whole anthropic water cycle)
  - CO_2 Life cycle inventory of a cement producer
  - Study of several fuel cells configurations
  - LCA training

Expertise in environmental management

- LCA: current projects
  - WALAID - Walloon Region
    - Valorization of the agrofood industry by-products
  - SOMABAT – FP7
    - Development of novel SOlid MAterials for high power Li polymer BATteries
      - LCA of the developped batteries + recyclability
  - Pierres et marbres de Wallonie
    - Realisation of environmental product declarations (FDES)
      - Blue stone, sand stone, …

Bluestone vs. Chinese stone

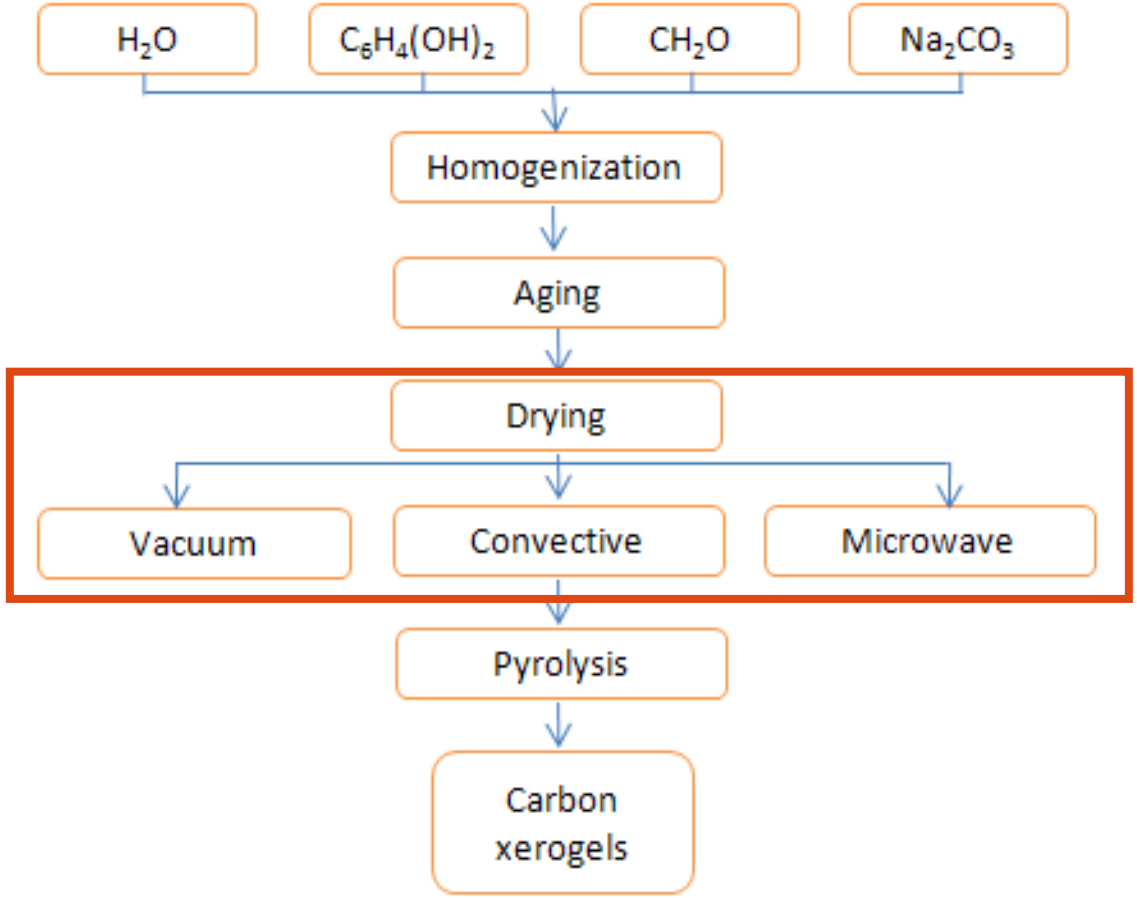
- Impact of transport on environmental impact



LCA as decision tool for sustainable choices in mineral materials field: environmental declarations of Belgian products and their foreign equivalents, S. Belboom et al. Congrès ACV, Lilles, 3-4 novembre 2011

Comparison of drying technologies

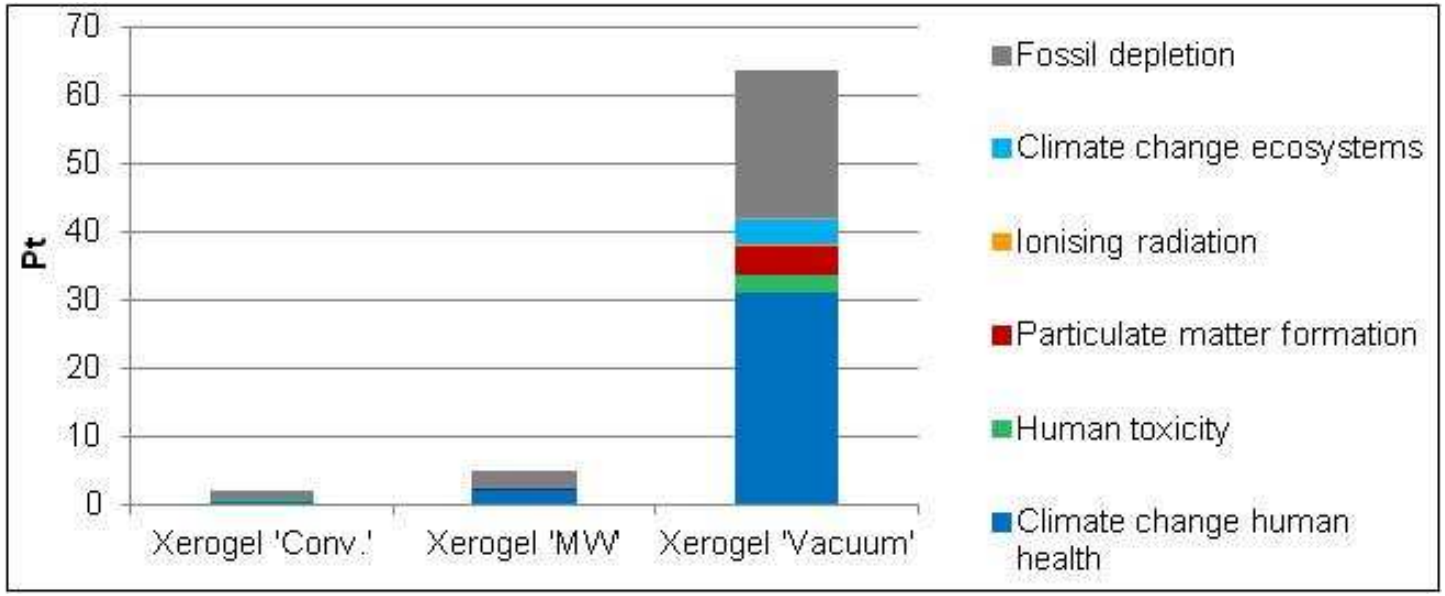
- Production of carbon xerogels: ecodesign approach



Analyse du cycle de vie de xérogels de carbone, R. Melon et al. Congrès ACV, Lilles, 3-4 novembre 2011

Comparison of drying technologies

- Weighted results



Best environmental choice = convective drying

Analyse du cycle de vie de xérogels de carbone, R. Melon et al.
Congrès ACV, Lilles, 3-4 novembre 2011

SOMABAT

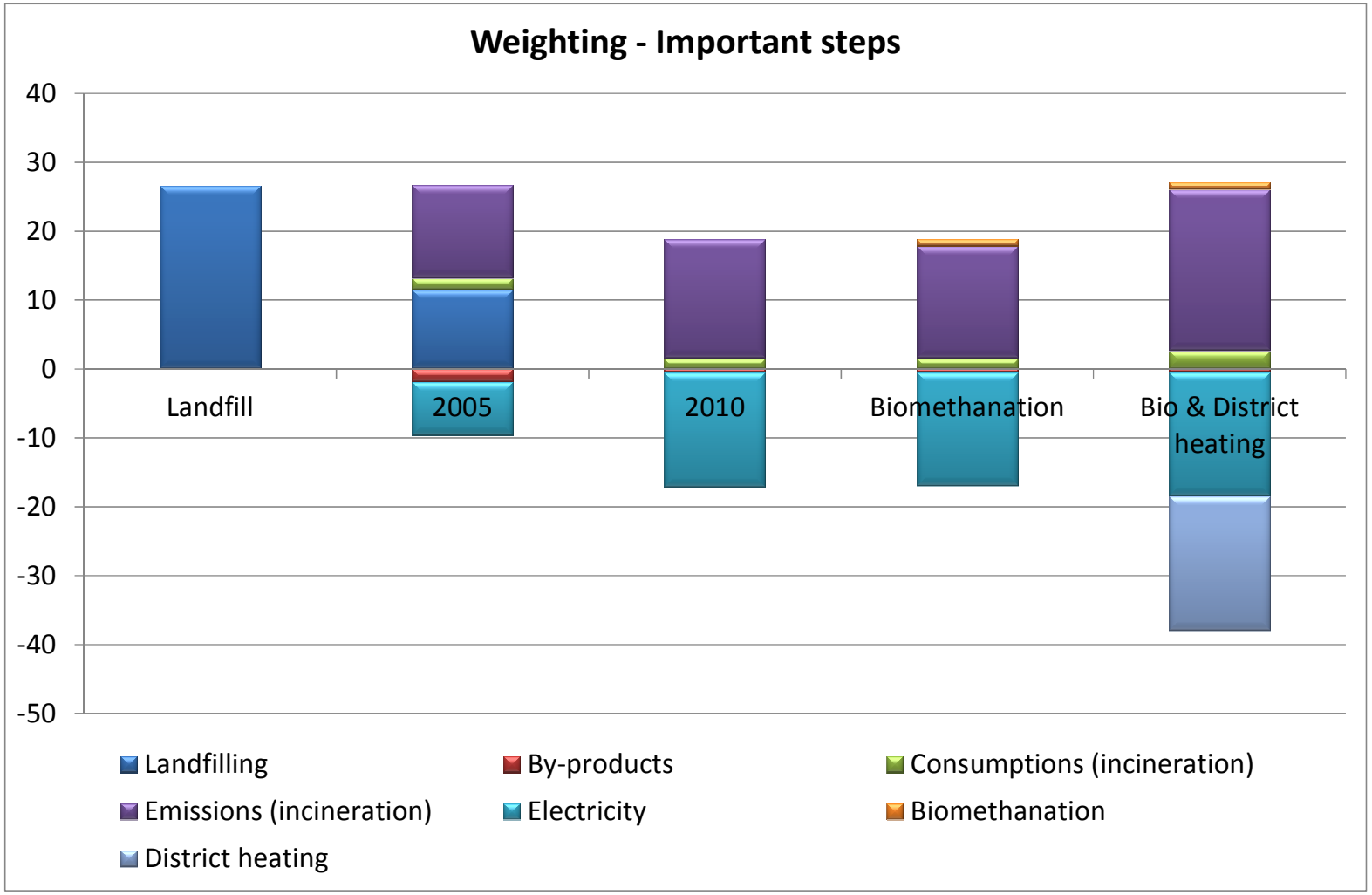
Comparison of waste treatment technologies

- Before 1970: wild landfilling
- From 1990 until 2009: waste grinding and sorting
- From 2009 until now: incineration of the whole waste fraction
- Short term project: methanation of the biodegradable fraction after collect and sorting






Comparison of waste treatment technologies

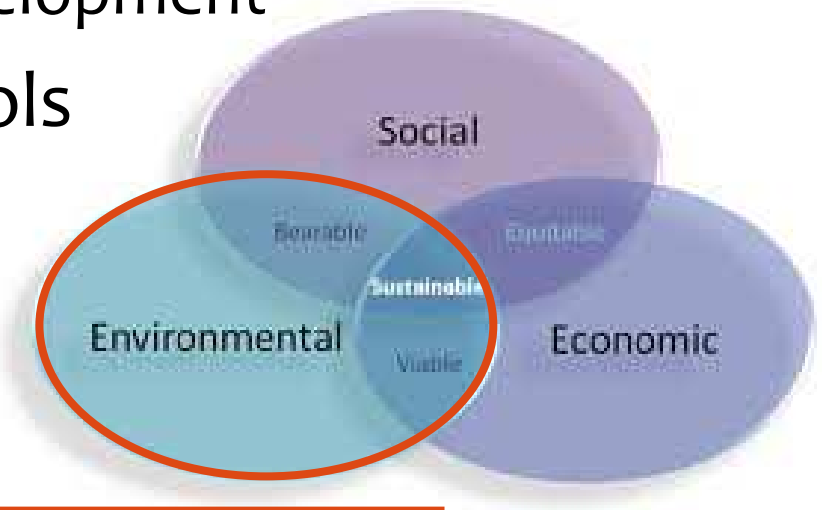


LCA … a nice tool but …

- Difficult to compare different environmental impacts
- Impacts related to equipments and infrastructure usually not taken into account
- Difficult to formulate « easy to understand » conclusions for non-experts
- Need to prevent for abusive and « out of context » use of results
- Clear statement of results validity (uncertainties, limit of the study, hypothesis, …)
- Availability and quality of data
- Need for more transparency about some subjective choices
- Need for new assessments methods: water use, land use/land use change, …

LCA … a nice tool but …

- LCA → environmental impact evaluation
  - 1 aspect of sustainable development
- Development of other tools
  - LCC = Life cycle cost
  - SLCA = Social LCA



LCSA = Life Cycle Sustainability Assessment

To conclude …
Thanks to the « 3 teams » !

Université de Liège

LGC CHEMICAL ENGINEERING

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  - Yvon bert PAMBOU (PhD student)
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Dank u voor uw aandacht !

Vragen ?

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