
AEROPERF


Raw Material Extraction
Material Processing
Part Manufacturing
Assembly
Product Use
End of Life
LIFE CYCLE
ASSESSMENT

From sludge drying to LCA: 20 years of activities at ULiège

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Products, Environment, and Processes (PEPs)
Chemical Engineering
Université de Liège
www.chemeng.uliege.be

From ULiège to Chemical Engineering research unit

LIÈGE université

CHEMICAL ENGINEERING

ULiège

- 11 faculties

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

Human and Social Sciences

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

Faculty of Applied Sciences

- 4 departments managing 12 masters in engineering
  - Aerospace
  - Architectural
  - Biomedical
  - Chemical
  - Civil
  - Computer science
  - Data science
  - Electrical
  - Electromechanical
  - Geological and mining
  - Mechanical
  - Physical

+ Master in computer science
+ Master in data science

Faculty of Applied Sciences

- 4 research units
  - Aerospace and Mechanical Engineering
  - ArGEnCO = Architectural, Geological, Environmental and Civil Engineering
  - Electrical Engineering and Computer Science
  - Chemical Engineering

https//www.chemeng.uliege.be

Chemical Engineering

- Integrated knowledge-based methodological approach with many application areas

Chemical Engineering

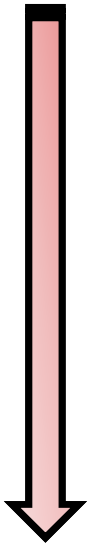
- About 70 personnes for 66 FTE
  - 9 academic (including 2 lecturers at 5%)
  - 3 permanent scientists (FNRS/ULiège)
  - 1 research logistician
  - 14 senior researchers or postdocs
  - 30 to 35 temporary scientists (about 30 PhD students)
  - 2 administrative staff
  - 2 industrial engineers - 3 technicians

Chemical Engineering

- Structuration in 3 groups
  - CRYO - Cryotechnology
    - Pr J.-L. Bozet
  - NCE - Nanomaterials, Catalysis, Electrochemistry
    - Pr B. Heinrichs, Pr N. Job, Dr S. Lambert, Dr C. Gommes
  - PEPs – Products, Environment, Processes
    - Dr M.-N. Dumont, Pr A. Léonard, Pr. A Pfennig, Pr D. Toye, Pr. G. Léonard

Chemical Engineering

- 5 main application areas
  - Energy
  - Environment
  - Health
  - Resource and recycling
  - Space

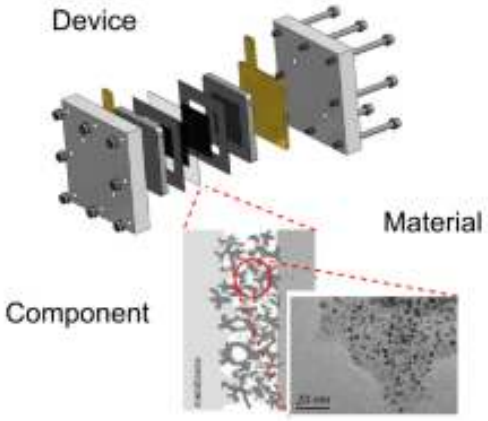


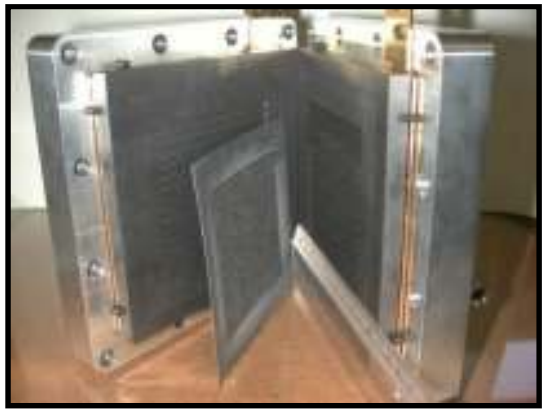
Transversal topic

Materials

Energy

- Storage and energy conversion
  - Electrochemistry: from materials to systems
    - batteries, fuel cells, …





Energy

- CCUS – Carbon Capture, Use and Storage
  - Post-combustion CO_2 capture by absorption
    - Experimental study of solvent degradation
    - Modelling and optimisation of the capture process
    - natural gas extraction, biomass or fossil fuel combustion

Degradation test rig for amine solvents

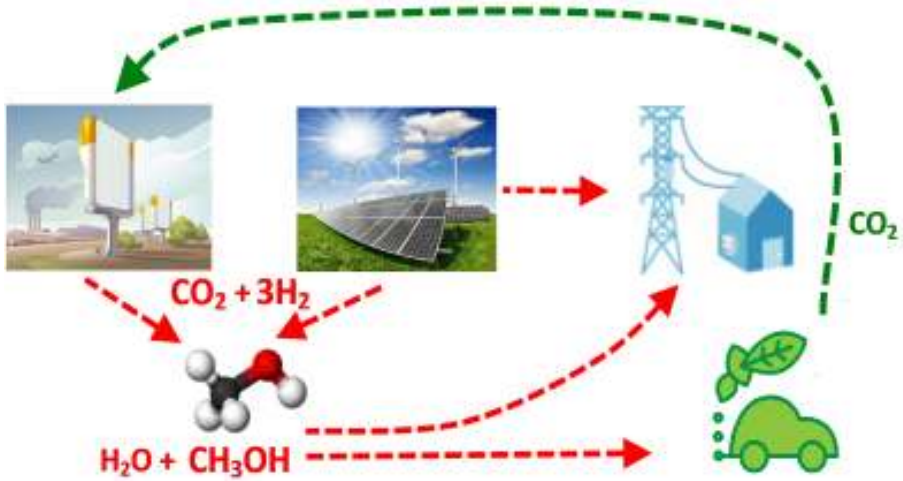
Léonard et al., 2015. DOI: 10.1002/cjce.22094.

Degraded amine solvent samples

Léonard et al., 2014. DOI:10.1021/ie5036572.

Energy

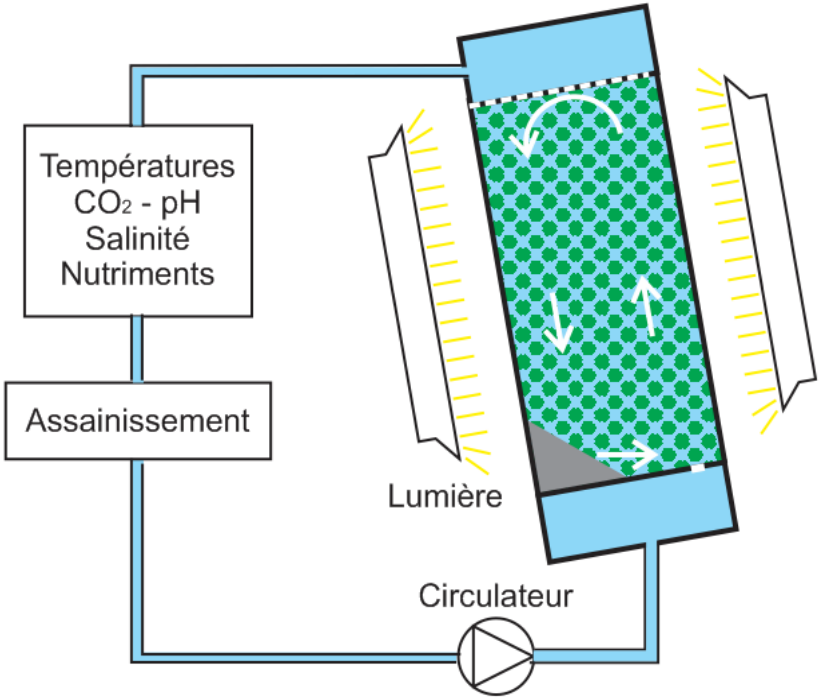
- CCUS – Carbon Capture, Use and Storage
  - Power-to-fuel
    - CO_2 capture, water electrolysis, synthesis of energy carriers (fuels)
    - Long-term energy storage
    - Better integration of intermittent renewable resources



Léonard et al., 2015. Electricity storage with liquid fuels in a zone powered by 100% variable renewables, IEEE 978-1-4673-6692-2.

Energy

- CCUS – Carbon Capture, Use and Storage
  - Microalgae culture
    - Design of photobioreactors

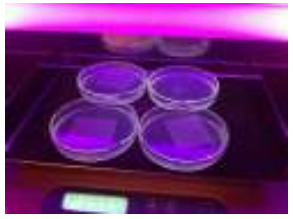


Modelling and scale up of photobioreactors based on the coupled characterisation of :

- Hydrodynamics of liquid and solid phases;
- Light distribution
- Biological activity

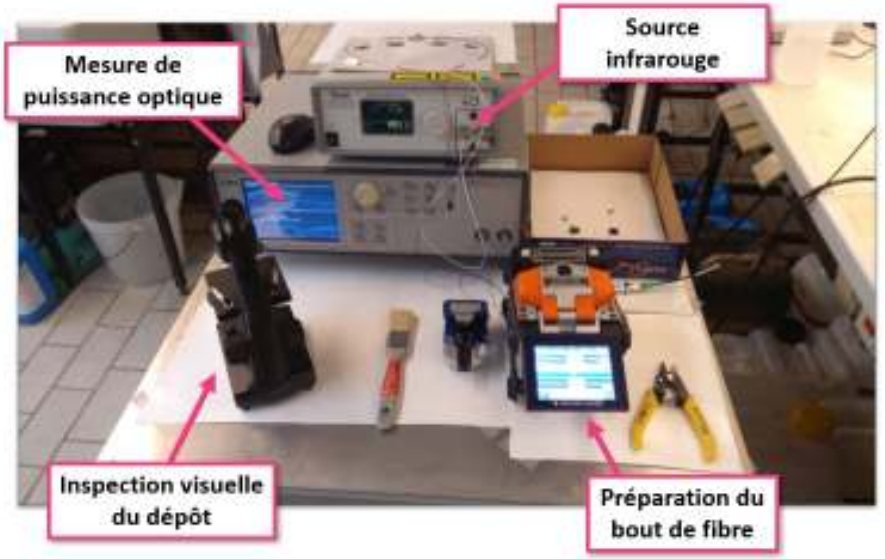
Environment

- Treatment of micropollutants in water
  - Ozonation and TiO_2 photocatalytic treatment
  - Photocatalyst development, characterisation, shaping
  - Scale up of processes



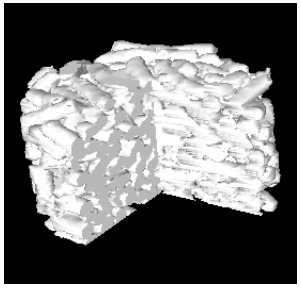
Environment

- Disinfection and decontamination of bathing water
  - Advanced photocatalytic oxidation
  - Low energy process
- Development of sensors for the continuous monitoring of organic pollutants in water



Environment

- Optimisation of sludge management
  - Conditioning, dewatering, drying



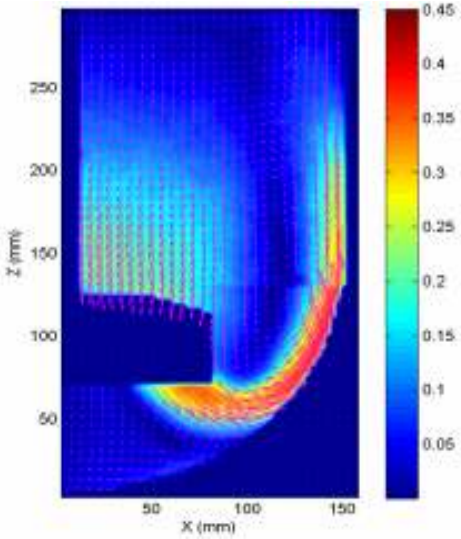
Environment

- Phosphorus recovery
  - Development of a mobile pilot unit
    - Leaching, liquid liquid extraction, precipitation
  - LCA of processes

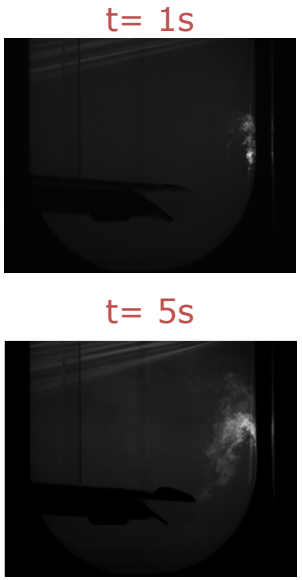
Health

- Hydrodynamics in (bio)reactors
  - Stem cell multiplication
  - Vaccine production

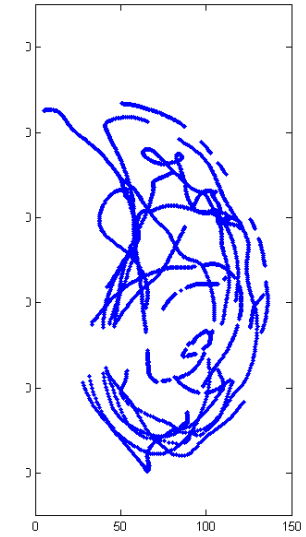
30 litre plexiglas cold mock-up



Flow field measured by 2D and 3D - PIV



Mixing time analysis – Concentration fields measured by PLIF

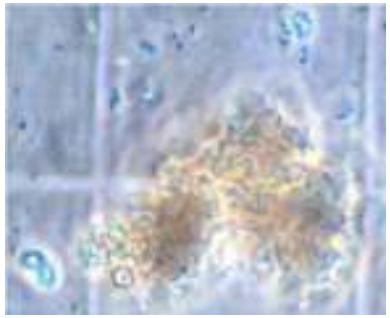


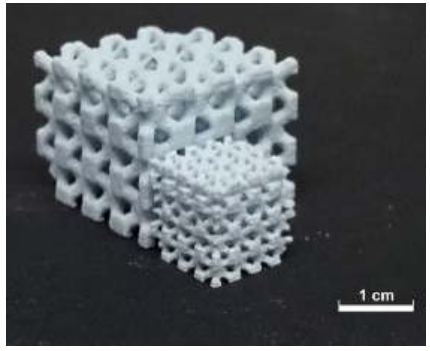
Path of a fluid element – Optical trajectography measurements

Health

- Development and characterization of inorganic-polymer composites for the delivery of pharmaceutical compounds
- Encapsulation of proteins for bone reconstruction

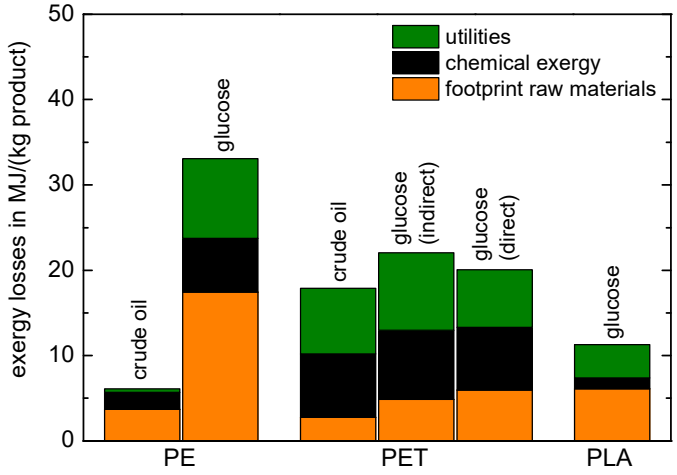
Biomatériaux fonctionnalisés

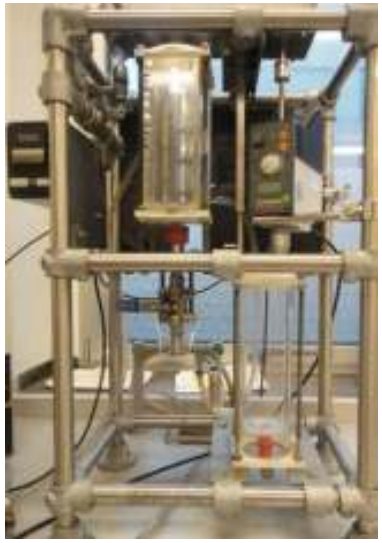




Resource - Recycling

- Biobased processes + Recycling processes
  - Separation of molecules via leaching and reactive extraction
    - Rare earths
    - Phosphorus
    - Metabolites (fermentation)





Resource - Recycling

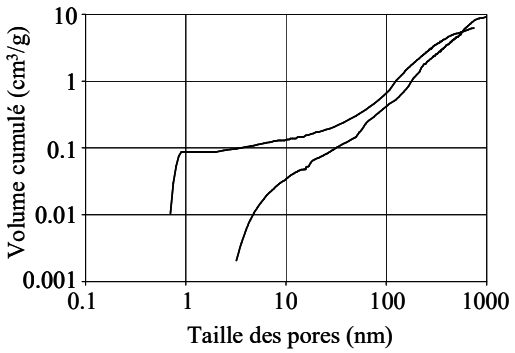
- Life cycle assessment
  - Environmental footprint of a product/process
  - Support for process ecodesign
  - Training
  - Environmental Product Declarations (EPDs)
  - Several domains
    - Recycling of construction materials
    - Bio-based products
    - CO_2 capture
    - Transport
    - ...

Space

- Potentially hazardous test site with six cryogenic test beds
  - ESA projects
  - Consultancy

CARPOR platform

- Materials characterisation platform
  - High energy X-ray tomograph
  - X-ray microtomographs
  - Mercury porosimetry
  - Nitrogen adsorption-desorption
  - TG-DSC



Scientific career

Career …

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 Associate professor at ULg: Chemical processes and Sustainable development, development of existing LCA activities

2011 Head of the Dpt of Chemical Engineering (until end 2015)

2013 Professor

2016 Director of the Research Unit 'Chemical Engineering'
Chair Woman of Drying Working Party of the European Federation of Chemical Engineering
Member of the 'Femmes et Sciences' committee (President between 2018 and 2020)

2017 Full Professor
Member of the Board of the B-IWA (Belgian Branch of the International Water Association)

2018 Member of the Board of VALBIOM ASBL
President of the 'Femmes et Sciences' committee (until September 2020)

2020 Member of the Board of GREENWIN

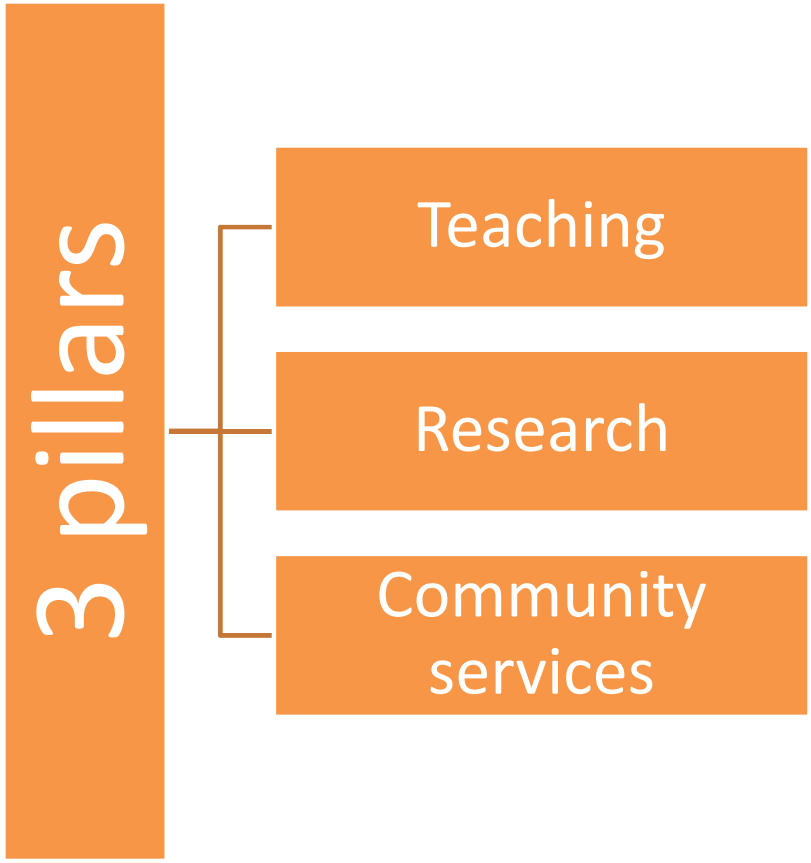
Career …

Drying/Sludge

Drying/sludge | **LCA**

Drying/sludge & **LCA**

3 pillars for an academic



Teaching …

- Travail de fin d'études
- Séminaires de sécurité industrielle, 15h Th, 2j T. t.
- Procédés de chimie industrielle, structure de l'industrie chimique, 30h Th, 1j T. t.
- Life cycle assessment - Ecodesign, 10h Th, 30h Pr
- Question avancée de génie chimique : épuration des eaux et traitement des boues, 20h Th, 15h Pr, 1j T. t.,
- Gestion durable des combustibles : approvisionnement, synthèse et utilisation, 50h Th
- Procédés de chimie industrielle : structure de l'industrie chimique et approche bilantaire
- Introduction à l'évaluation environnementale, 9h Th, 9h AUTR,
- Génie de l'environnement, 30h Th
- Integrated project, 10h Th, 270h Proj., 1j T. t.
- Technologies industrielles, 45h Th

Community services …

- Director of the research unit
- President of the jury of the master in chemical engineering
- Participation to several boards and committees
- Conferences for several audiences (participation + organization)
- Member of PhD thesis
- Expertises for several research agencies
- Promotion of studies
- Presence in the media
- …

3 main research topics

- Drying of deformable materials
  - Both experimental and modeling approaches
  - Long expertise in **sludge** drying
    - **Sludge management → whole treatment chain**
  - 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
  - Used for product-oriented-engineering approach
- Environmental management: **Life Cycle Assessment studies**, eco-design, environmental product declarations

Publications: https://orbi.ulg.ac.be/browse?type=authorulg&rpp=20&value=L%C3%A9onard%2C+Ang%C3%A9lique+p003296

Focus on research activities

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CHEMICAL ENGINEERING

Focus on research activities

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

    → (micro)-tomography + image analysis

Convective drying of deformable materials

- Which materials ?
  - **Initial focus on wastewater sludges**
  - Extension to resorcinol-formaldehyde xerogels as model material
  - Recent collaborations
    - Geotechnical materials: limestone, clay, cement and concrete (Coll. Geo³ - R. Charlier/F. Collin)
    - Soils (Coll. A. Degré – Mini-ARC) + PhD thesis Sarah Smets (August 2018)
  - + food products
    - Through visiting researchers
    - Recent collaboration with Mexico (potatoes)
- Both experimental data and modeling approach

Focus on research activities

About sludge management …

Sludge ?

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

Oupeye - 446 500 PE

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 + **P 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
- Sludge drying = complex unit operation
  - Depends on **sludge properties and history**
    - 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

Sludge = nutrient source

Relevant bio-based waste streams - in Europe

[kton P/year]	Total	Recycled	Potential
Sewage sludge	**297**	115	182
Biodegradable solid waste	130	38	92
Meat & bone meal	128	6	122
Total	**427-555**	**153-160**	**274-396**
Manure recycling =	**1 736**		
Mineral fertiliser use =	***1 448***		

Van Dijk & Oenema: Overview of phosphorus flows in wastes in Europe", 2013, Fertilisers Europe seminar, 6 Feb. 2013.
Updated Van Dijk et al. 2015 "

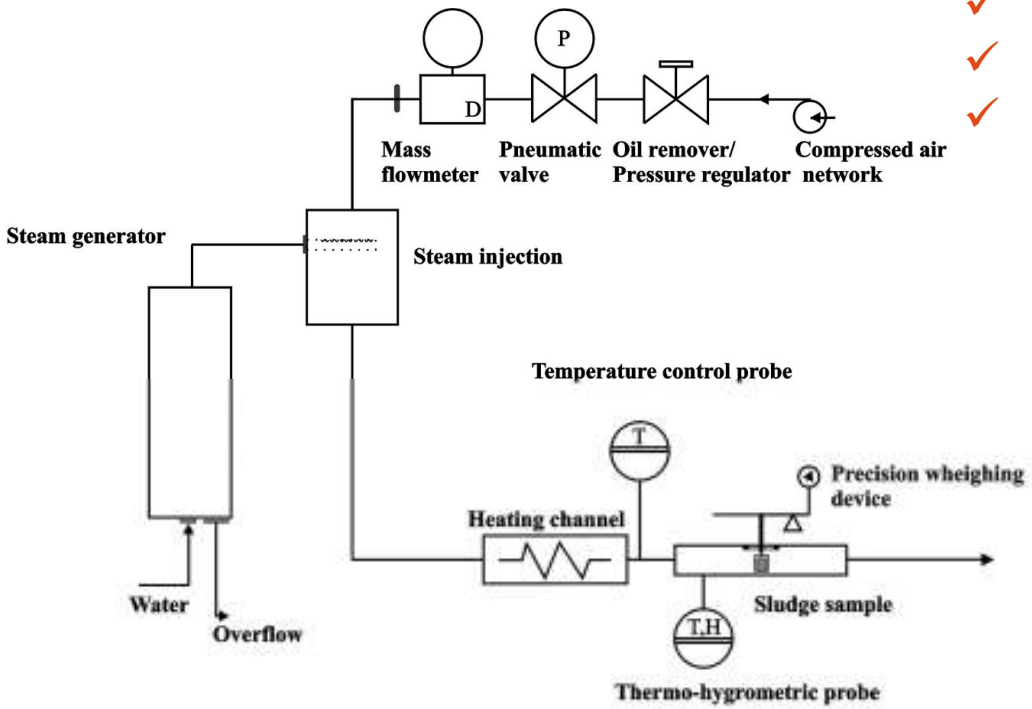
Sewage (sludge) is the second most **relevant** renewable waste stream for P recovery & recycling in Europe!

Focus on research activities

Equipments …

Equipment available

- Micro-dryer

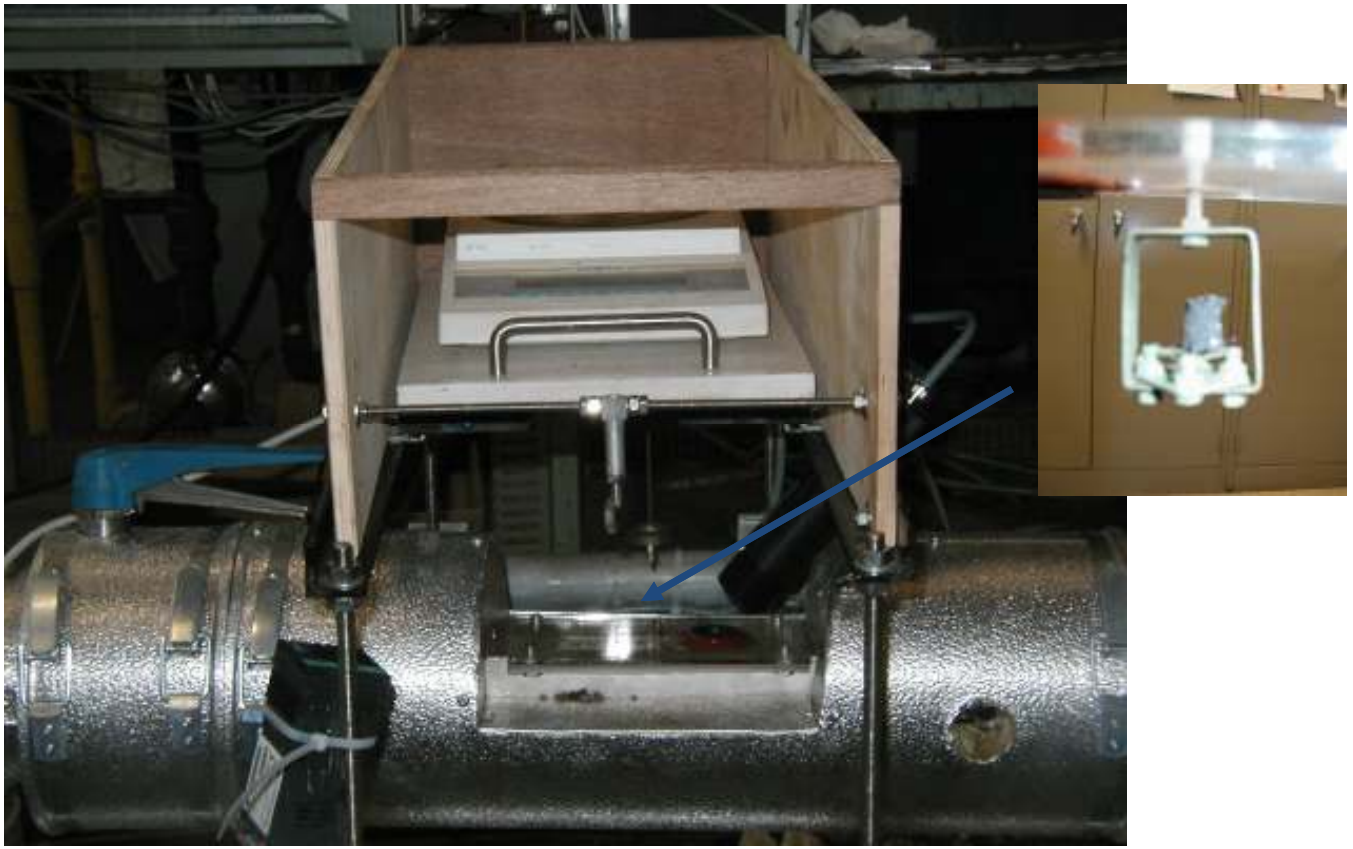


- ✓ Convective drying
- ✓ Individual sample: 1 – 5 g
- ✓ Control of 3 operating conditions
  - ✓ Temperature
  - ✓ Velocity
  - ✓ Humidity

Equipment available

- Micro-dryer

✓ Continuous follow-up of sample mass



Equipment available

- Pilot-scale dryer

- Extrusion

Sevar pilot scale dryer

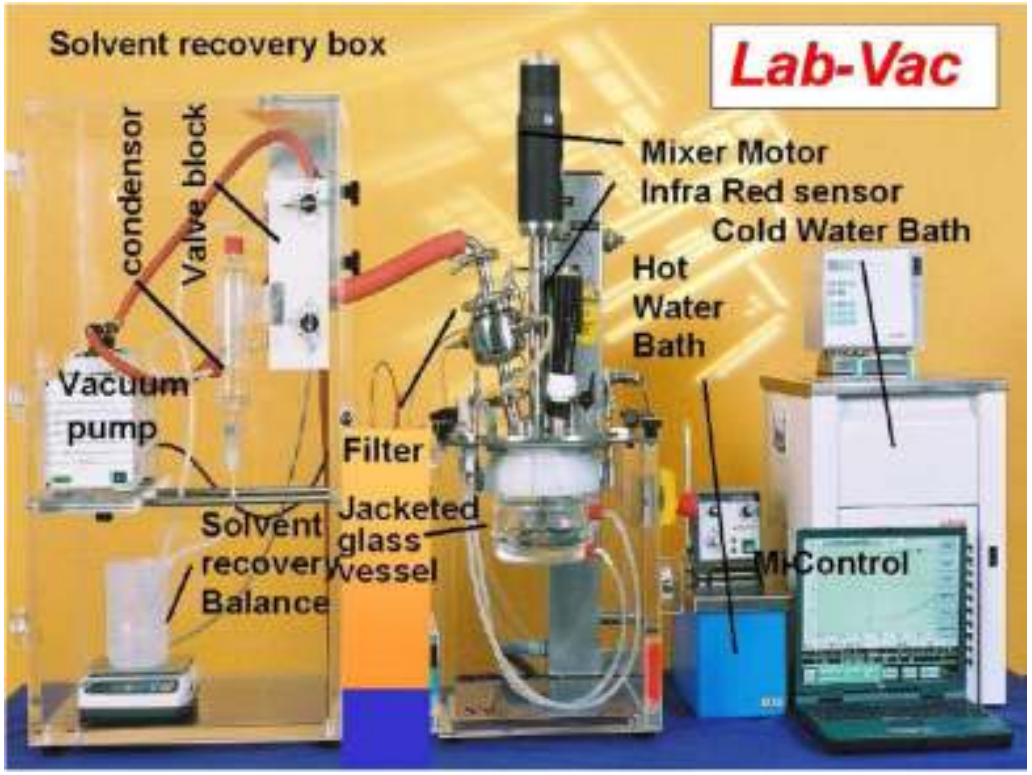
- Fixed bed (cross flow)
- Capacity
  - 1 to 3 kg
  - Up to 200 kg water/m²h

Equipment available

- Superheated steam dryer

Equipment available

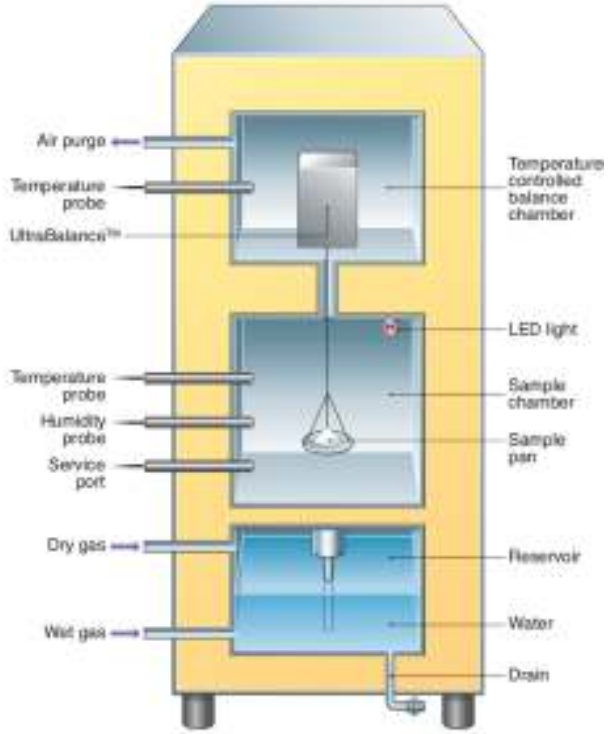
- Vacuum agitated contact dryer

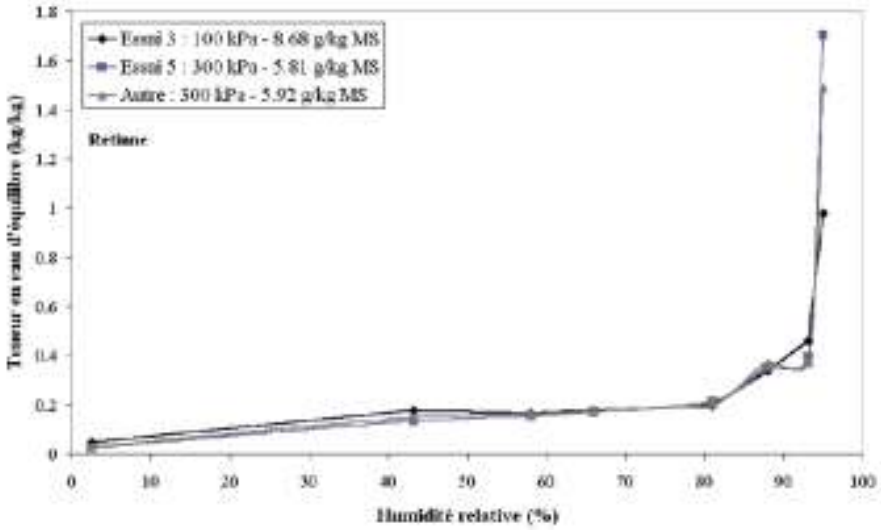


- Thermosensitive products

Equipment available

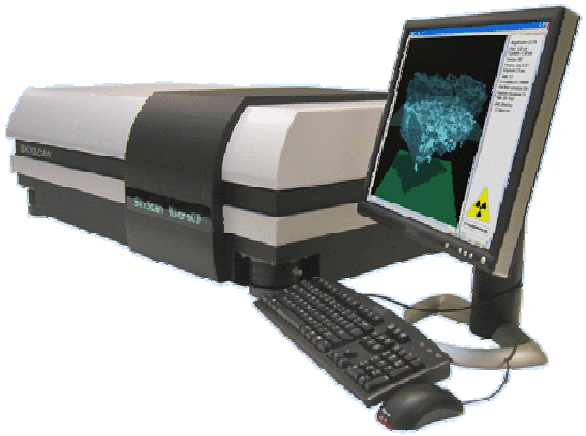
- Dynamic vapour sorption





Equipment available

- Microtomograph



Purchase year: 2006

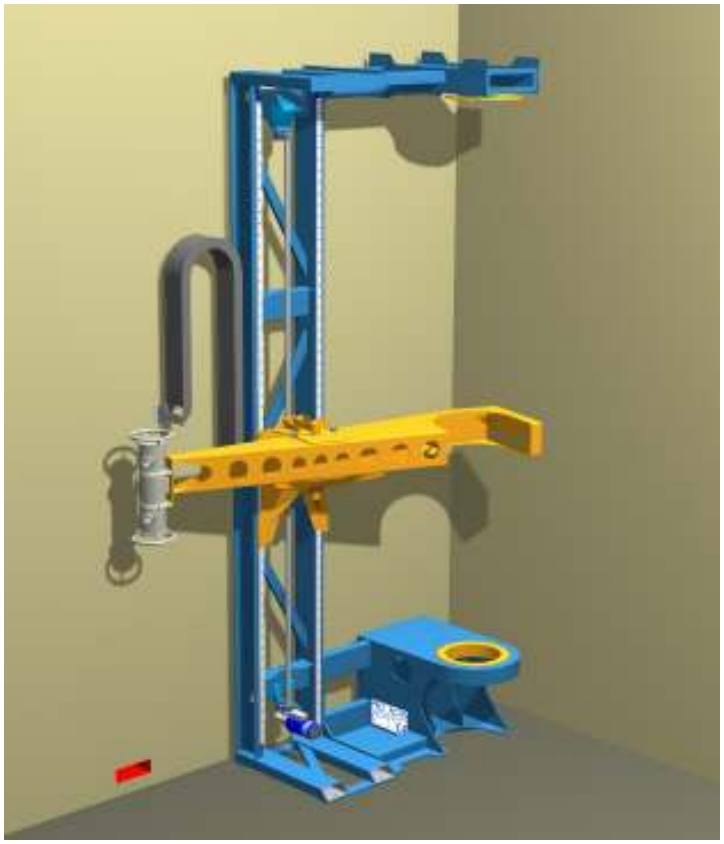
- **Source: 100 kV - 250 mA - Cone beam**
- **Detector: 4000 x 2300 pixels**

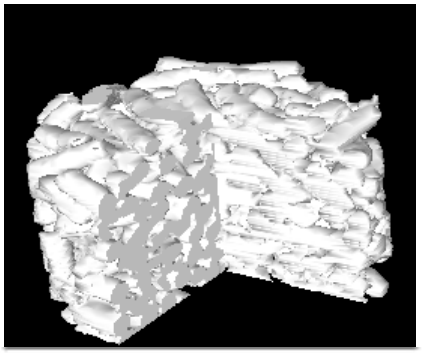
  12-bit CCD Camera
- **Pixel size: from 34 to ≈ 2-3 µm**
- **Max sample size: ∅: 35 mm (68 mm with camera offset)**

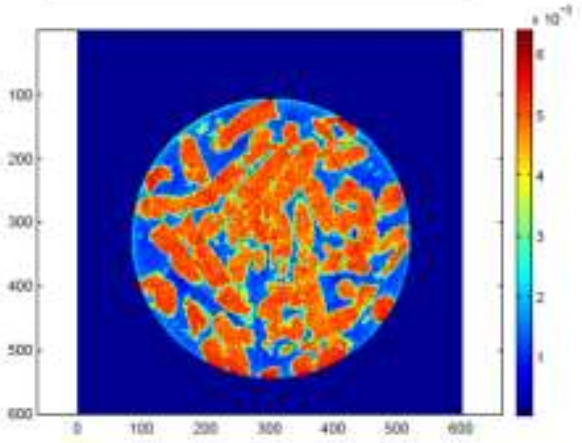
  h: 35 mm (70 mm with camera offset)

Equipment available

- High energy ‘macro’ tomograph (D. Toye)







Equipment available

- Belt filter

Purchase year: 2018
EQUIP FRS-FNRS

Equipment available

- Decanter-centrifuge

Purchase year: 2018
EQUIP FRS-FNRS +
faculty project

Focus on research activities

Some results in relation with sludge …

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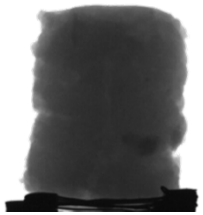
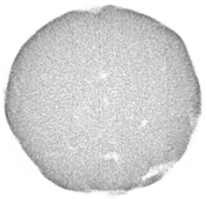
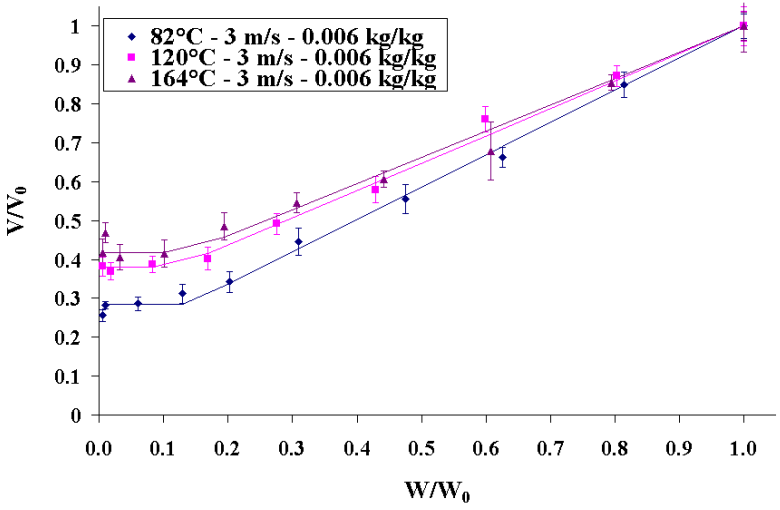
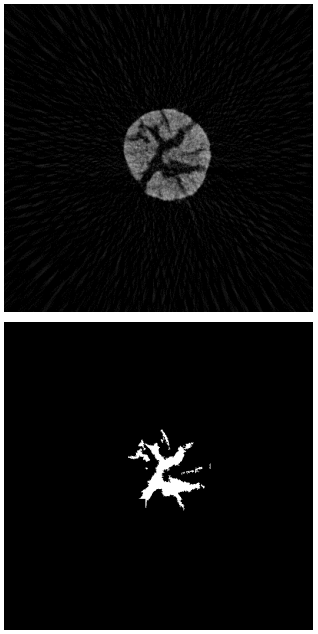
Follow-up of structural changes

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

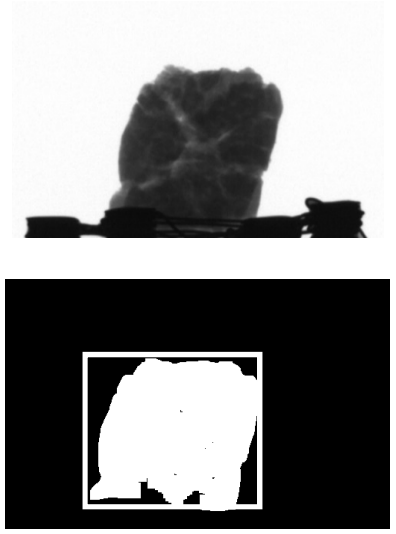








Cracks

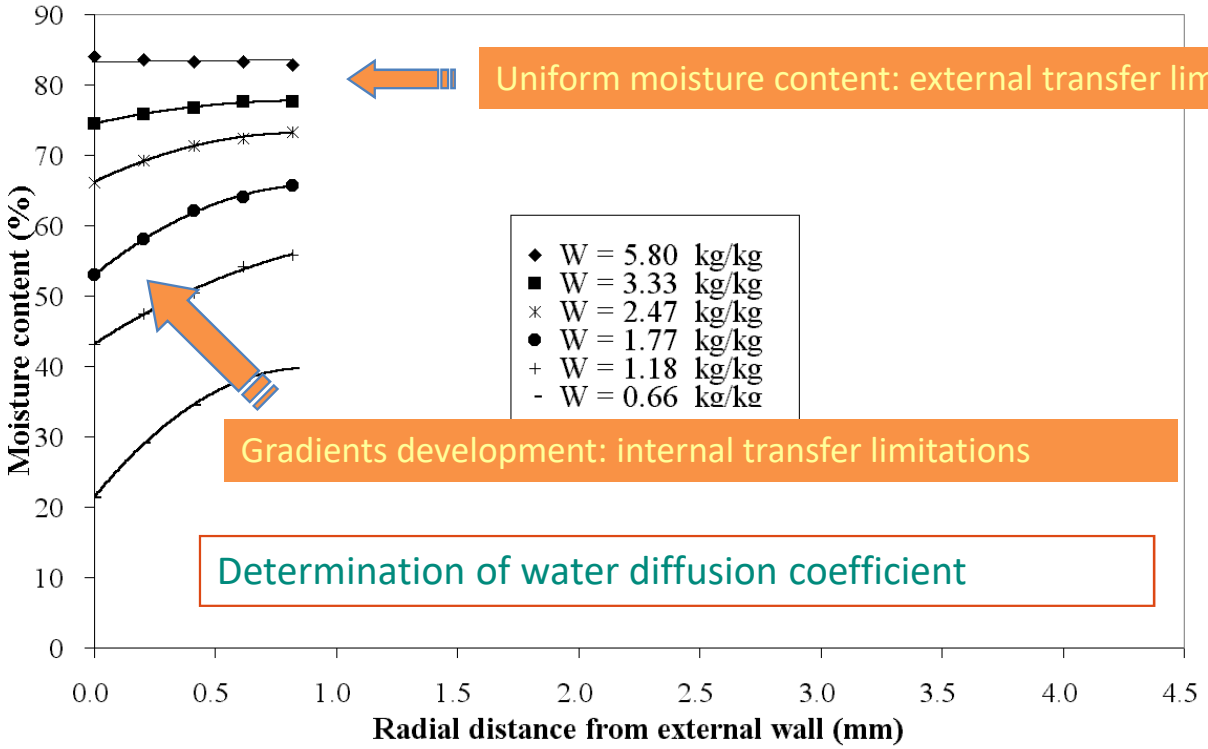


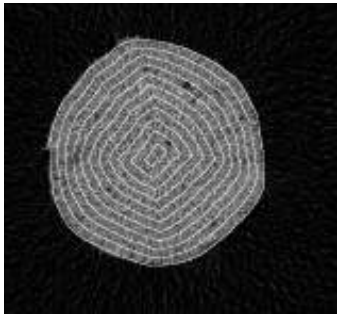
Height

X-ray microtomograph
Micro dryer scale

Follow-up of internal moisture profiles

- Understanding of mass transfer + model validation



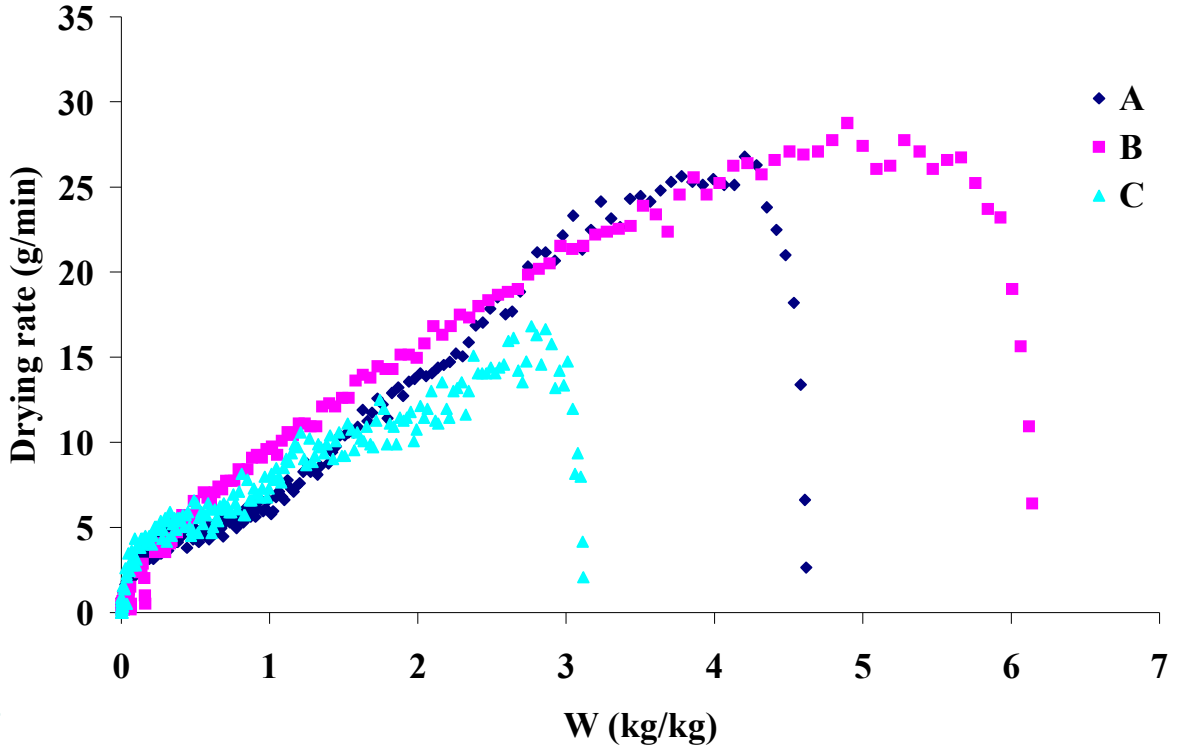


X-ray microtomograph
Micro dryer scale

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

Impact of sludge origin

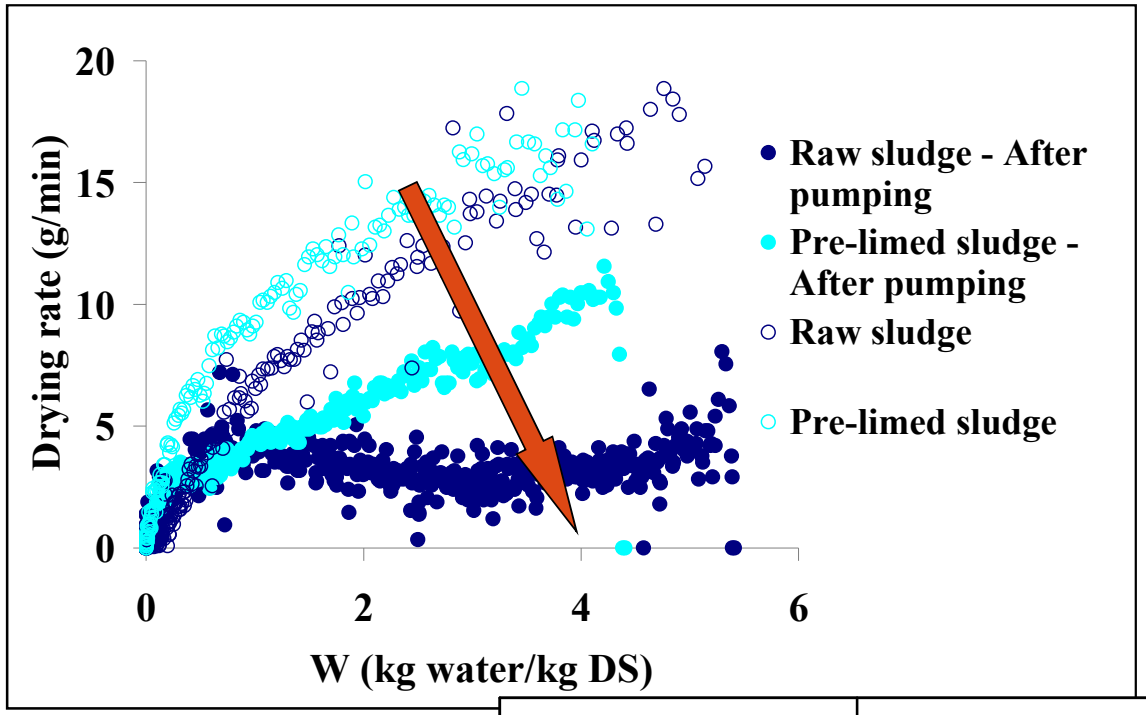
- Max drying rate: ratio up to 3:1



Pilot scale dryer

Impact of sludge pumping

- Influence of pumping on drying kinetics

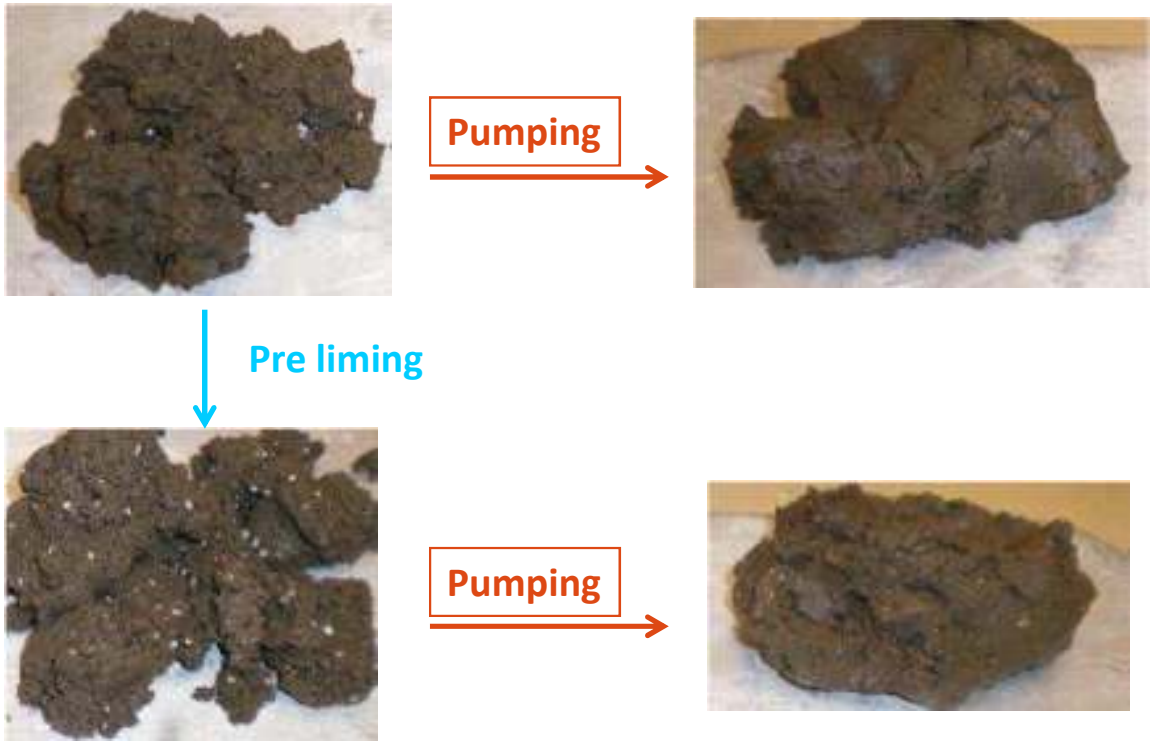


Pilot scale dryer

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

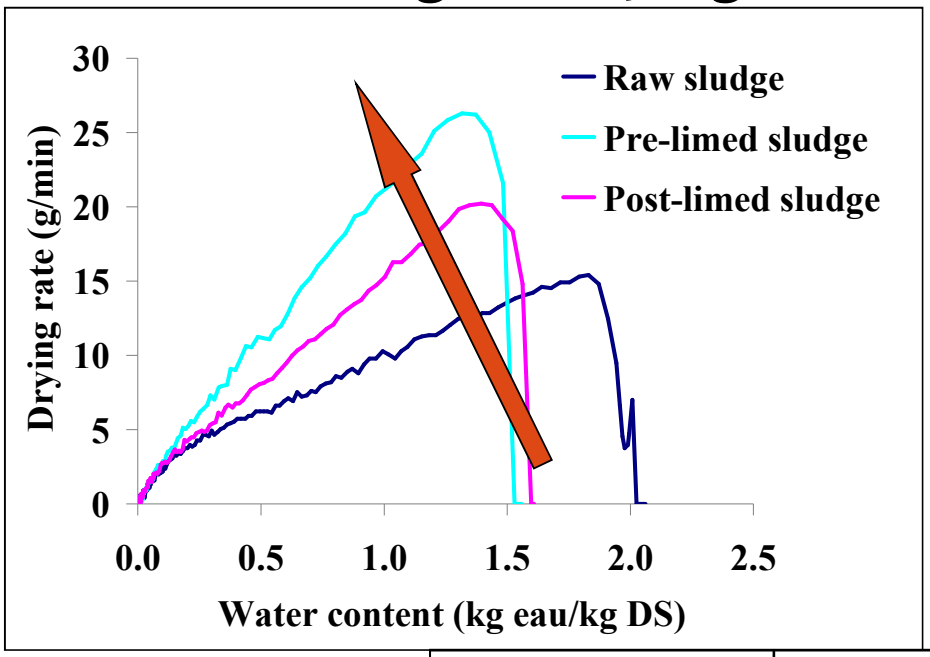
Impact of sludge pumping

- Importance of textural properties



Impact of sludge liming

- Influence of liming on drying kinetics

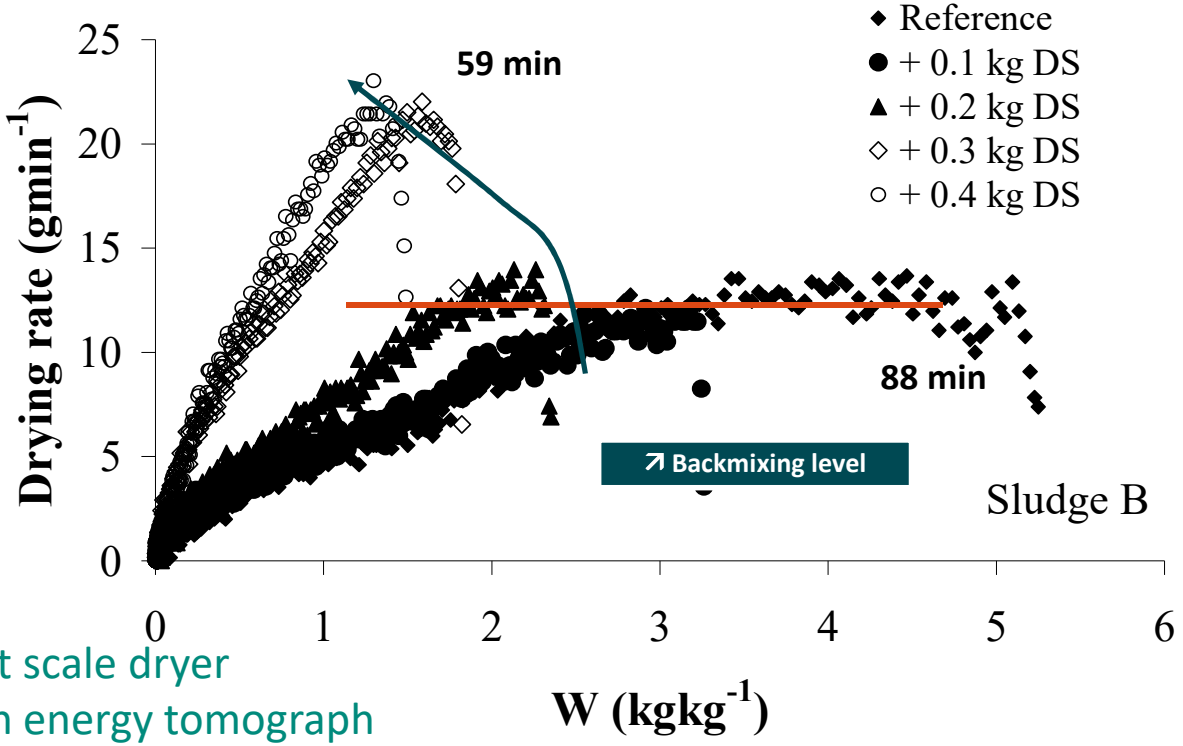


Pilot scale dryer

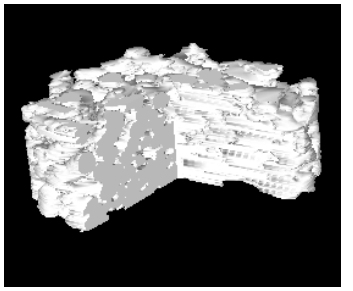
	Specific evaporation capacity (kg/m²h)
Raw sludge	24.3
Post-liming	28.9
Pre-liming	37.0

Impact of back-mixing

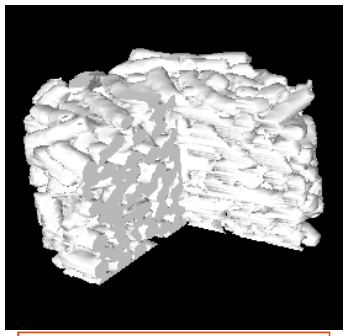
- Recirculation of dried product → way to correct 'bad texture'



Pilot scale dryer
High energy tomograph



1000 g – 16% DS
Raw sludge



1400 g – 40% DS
+ 400 g DS

Phosphorus recovery

COMMUNIQUÉ DE PRESSE

L'ULiège met au point un démonstrateur de récupération du phosphore à partir de nos eaux usées

En Europe, on n'a pas de phosphore… mais on a des projets pour le récupérer !

26 avril 2021

About drying

European Conference on Sludge Management

Focus on research activities

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
- « Cradle to cradle » → circular economy
- « Cradle to gate »

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

LCA: a standardized methodology

Goal & Scope

Primary data ↔ Partners
Generic data : Ecoinvent 3.6 (CH) (EI)

ecoinvent SimaPro

Life Cyle

Functional Unit (FU)
Boudaries

TOTEM

Inventary

	Flow	Quantities
Inputs	Water	m^3
	Styren	kg
	Electricity	KJ
	etc.	kg
Outputs	CO_2 (air)	kg
	Hydrocarbons (air)	kg
	HCl (water)	kg
	Waste water (water)	kg
	Mercury (soil)	kg
	Cadmium (soil)	kg
	etc.	kg

Impacts

- **Climate change**
- **Resource exhaustion**
- **Energy consumption**
- Eutrophication
- Human toxicity
- Acidification
- Ozone layer depletion
- **Waste**
- …

IPCC

Method

CML IA v3.06
(EN 15804)

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: strengths

- No transfer of impact
  - between life cycle stages
  - between impact categories

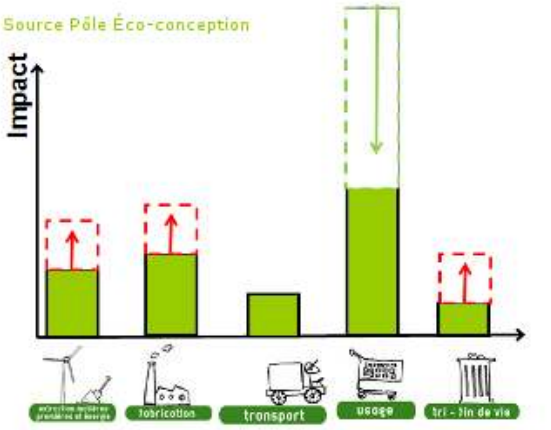


Illustration du transfert d'impact
d'une étape du cycle de vie à d'autres étapes.

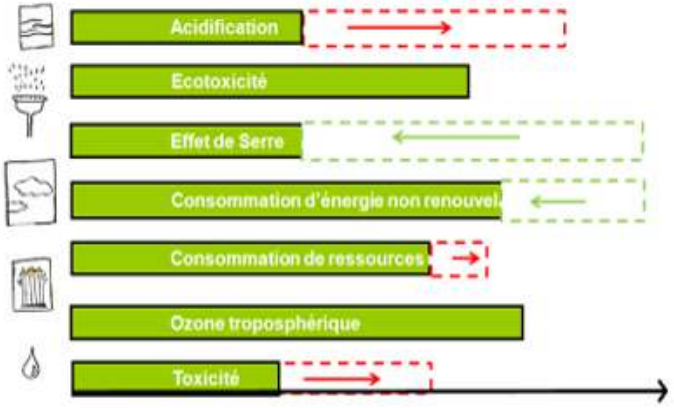


Illustration du transfert d'impacts
à d'autres impacts environnementaux

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

External

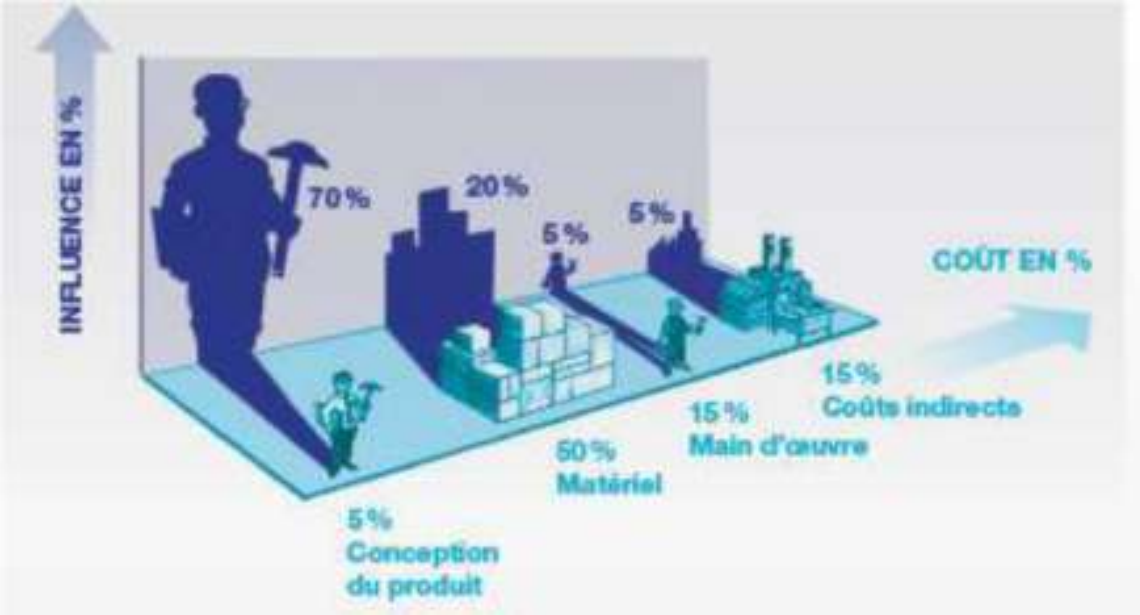
Marketing

Policy

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

LCA = way to « ecodesign » new processes

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



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

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

Different types of activities

- Academic research + consultancy
  - Evaluation of the environmental impact of processes
  - Support to process ecodesign
  - **Redaction of environmental product declarations ('EPD')**
    - **LCA + products category rules (PCR) = type III environmental labelling**
  - Development of databases
  - Development of new indicators
- Teaching and coaching
- Participation to several regional, federal and European projects
- LCA FNRS contact group creation
- …

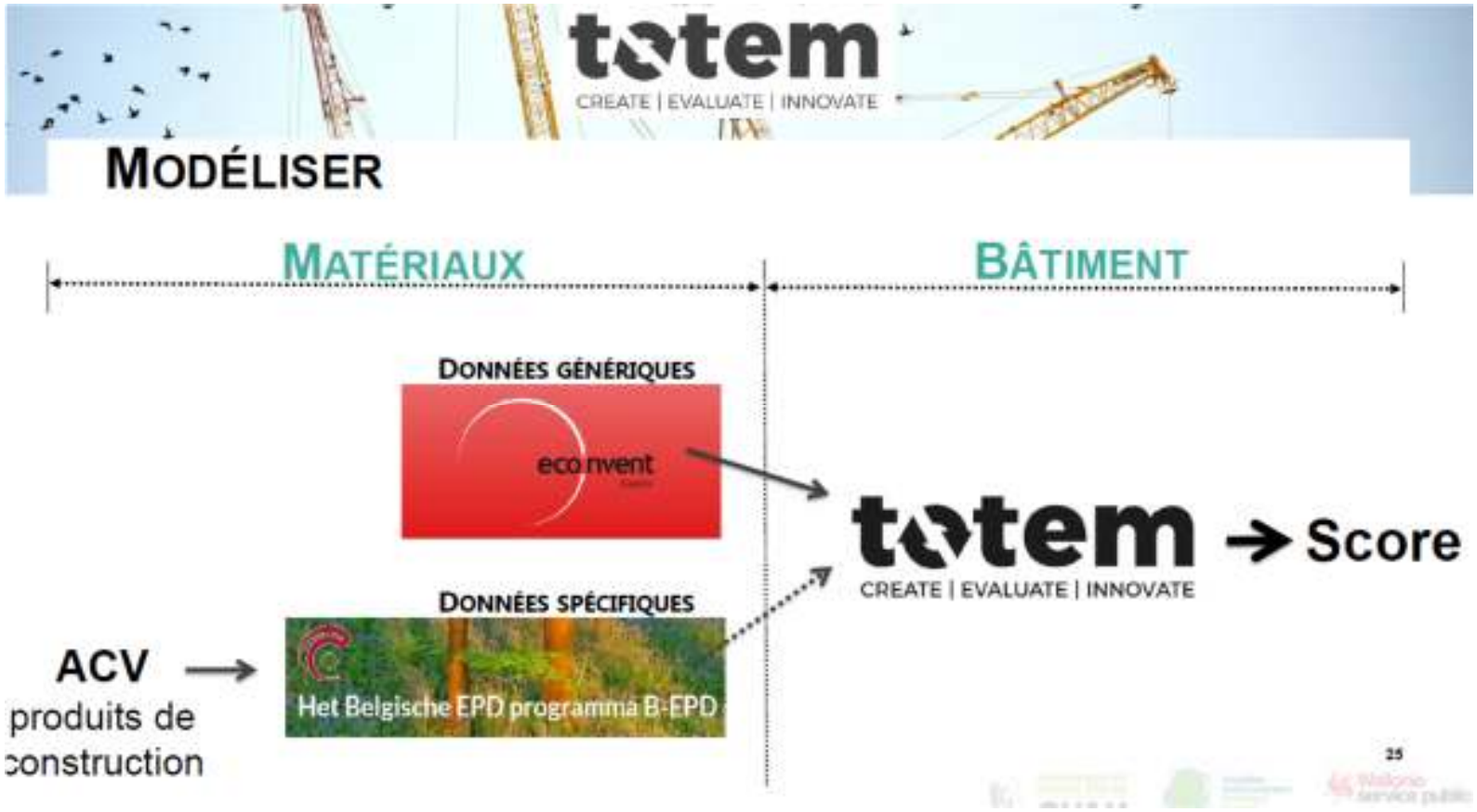
A large number of topics

- Comparison of waste management scenarios
- Comparison of packaging options
- Study of biofuels production
- Study of agro-food by-products valorization ways
- Impact of water management (whole anthropic water cycle)
- CO_2 mapping (sector agreements)
- Study of several fuel cells configurations
- Ecodesign of anti-fingerprint coatings
- Ecodesign of wastewater treatment
- Ecodesign of demolition waste recycling ways
- Impact of intermodal transport
- EPDs of phosphoric acid and derived fertilizers
- …

TOTEM … LCA and EPD

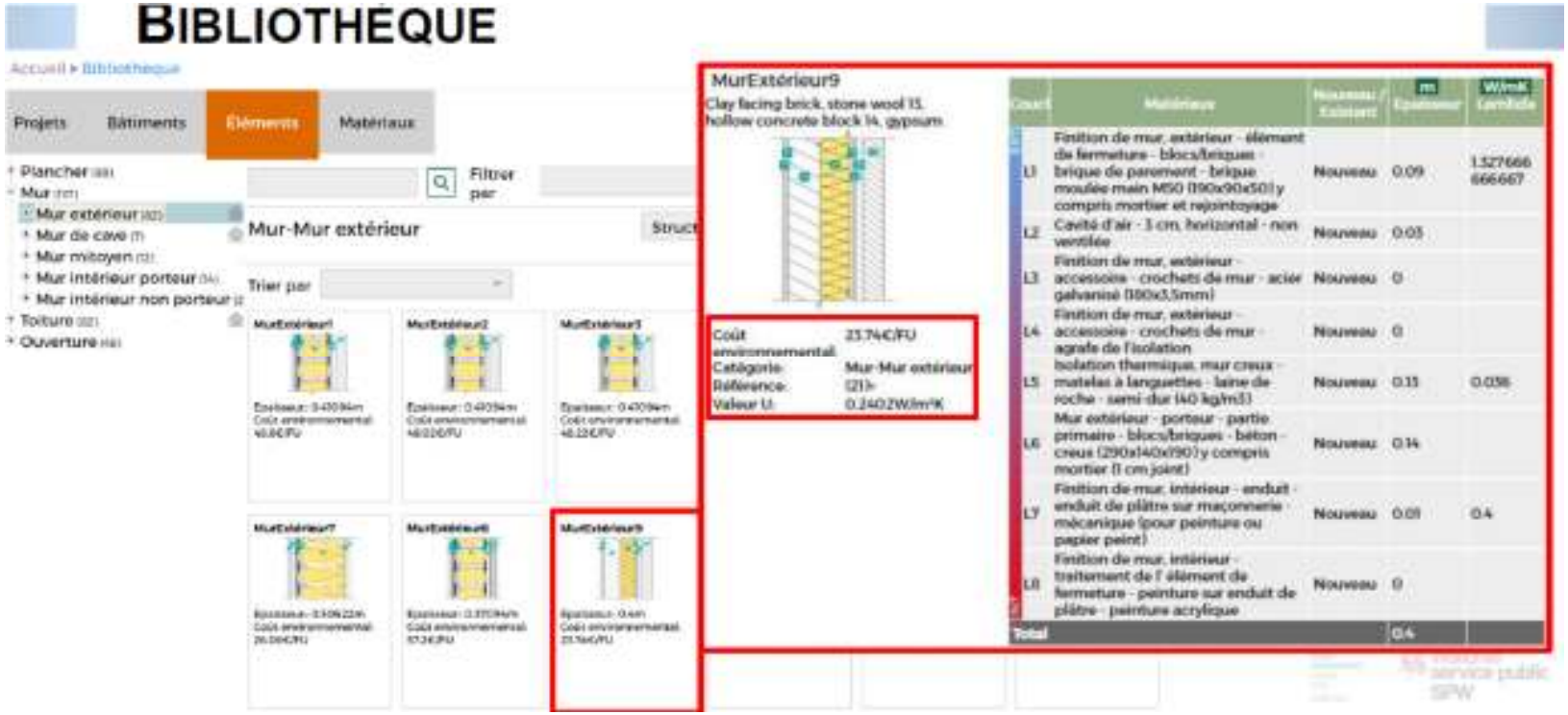
- Initiative supported by the 3 regions in Belgium
- TOTEM = Tool to Optimize the Total Environmental impact of Materials

TOTEM … LCA and EPD



TOTEM … LCA and EPD

TOTEM … LCA and EPD



TOTEM … LCA and EPD

NEW: From July 2021 → PEF weighting method in points !

Focus on research activities

Some LCA achievements …

ISOHEMP

- Participation to LCIP project: Life Cycle in Practice
- LCA on their blocs → EPD

		Production		
		A1 Matières premières	A2 Transport	A3 Fabrication
	PRG total (kg CO2 équiv./UF)	6.11E+00	6.16E+00	-3.21E+01
	PRG fossile (kg CO2 éq./UF)	5.80E+01	6.16E+00	-1.85E+01
	PRG biogénique (kg CO2 éq./UF)	-5.19E+01	2.53E-03	-1.36E+01
	PRG-luluc (kg CO2 éq./UF)	3.16E-02	4.88E-05	8.37E-04

KNAUF INSULATION

- PhD thesis: Ecose® binder
- Ecodesign → master thesis focusing on packaging
- EPD on insulating products

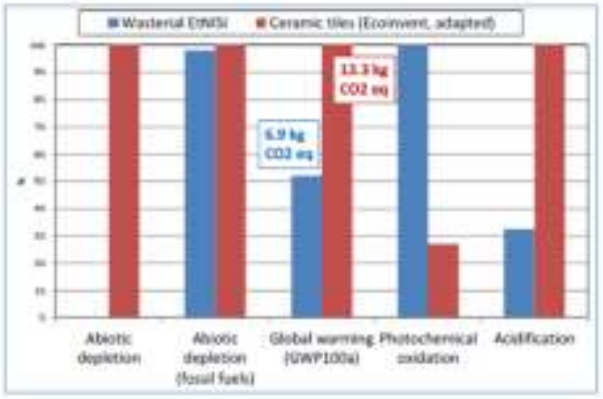
Knauf Insulation
Laine de verre ECOSE Technology®
Naturoll 035 145 mm

FICHE DE DECLARATION ENVIRONNEMENTALE ET SANITAIRE DE PRODUIT

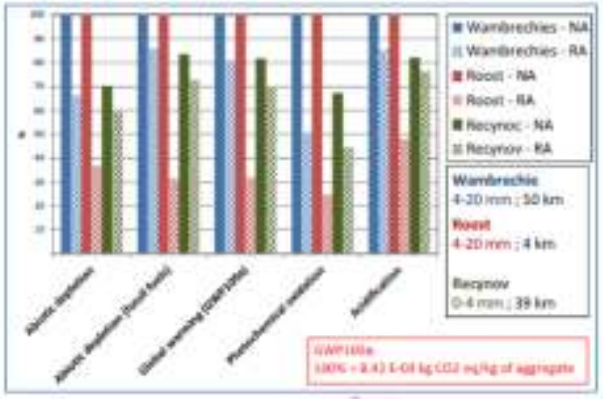
En conformité avec la norme NF EN ISO 14025 et NF EN 15804+A1 et son complément national NF EN 15804/CN

N° d'inscription : 3-432:2021
12 Août 2021

LEROY MERLIN (Valdem project)



SimaPro ecoinvent CML



- **Demolition** of Leroy Merlin store of Douai (59, FR)
- **Recycling** of the "waste" (recycled aggregates, RA)
- → **Substitution** of natural aggregates (NA)

excavation on-site transport crushing

0-4 mm
Wasterial
→ resin slabs - EtNISI

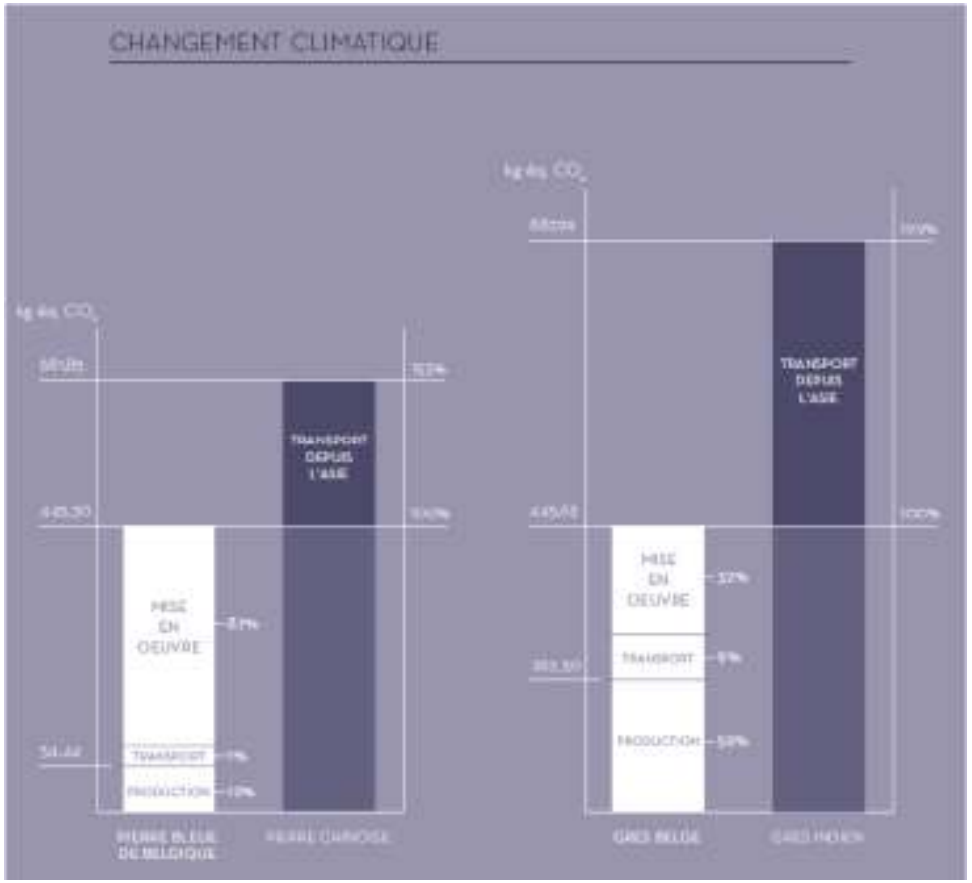
4-20 mm
Concrete
Eqiom
→ new Leroy Melin store (Tourcoing) concrete slab

Transport

4-20 mm: transport to Eqiom concrete plants (2)
- Wambrechies, 50 km
  → Leroy Merlin Tourcoing
- Roost-Warendin, 4 km
  → other projects

0-4 mm: transport to Recynov sorting site, Santes, 39 km
- → EtNISI Wasterial (+ other "recycled sand" uses)

Pierres et marbres de Wallonie



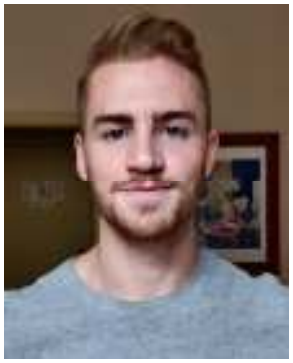
Focus on research activities

Projects and team …

On going or accepted projects

- Greenwin “COSMOCEM” – Alternative materials for cement production
- Greenwin “ATISOL” – Design of a new vapour and air barrier membrane
- Greenwin “MONOCRETE” - Thick single-layer coating based on alternative binders and recycled aggregates
- Greenwin “BITUMCLEAN” - Recycling of bituminous roof coverings by prior extraction of tars (PAH)
- Greenwin “ECOPUR” - Ecological Medical Support Surfaces for the future
- Greenwin “CORSSI” - Speed bumps made from recycled composites
- Greenwin “ELITHE” - Enzyme development by synthetic biology
- Greenwin “MINERAL LOOP” - Industrial CO_2 capture and sequestration by carbonation of mineral waste
- Win2Wal “Aeroperf” - Effect of particle microstructure on the efficacy of inhalation powders
- Interreg “Phos4You” – Recovery of P in wastewater and sludges
- Interreg “CIRMAP” – 3D printing of concrete
- PDR FRS-FNRS – Sludge rheology (PhD thesis)
- FRIA – Low cost process for sludge stabilization (PhD thesis)

The team …






Last but not least

Girls in STEM …

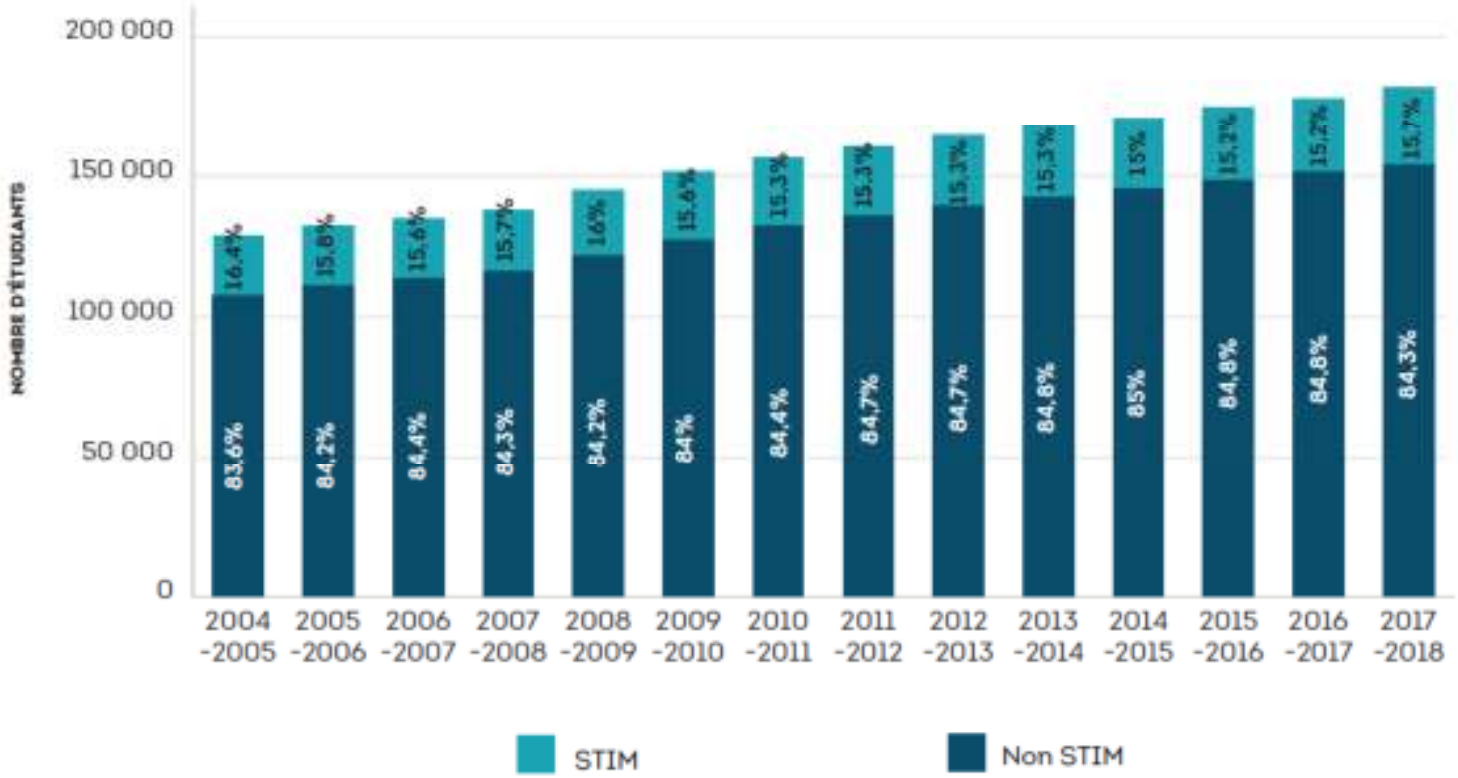
LIÈGE université

CHEMICAL ENGINEERING

Gender issues in STEM studies…

ARES
StatSup'Info
N° 1 JUIN 2021

GRAPHIQUE 2 · Proportion d'étudiants STIM et non-STIM en FWB entre 2004-2005 et 2017-2018



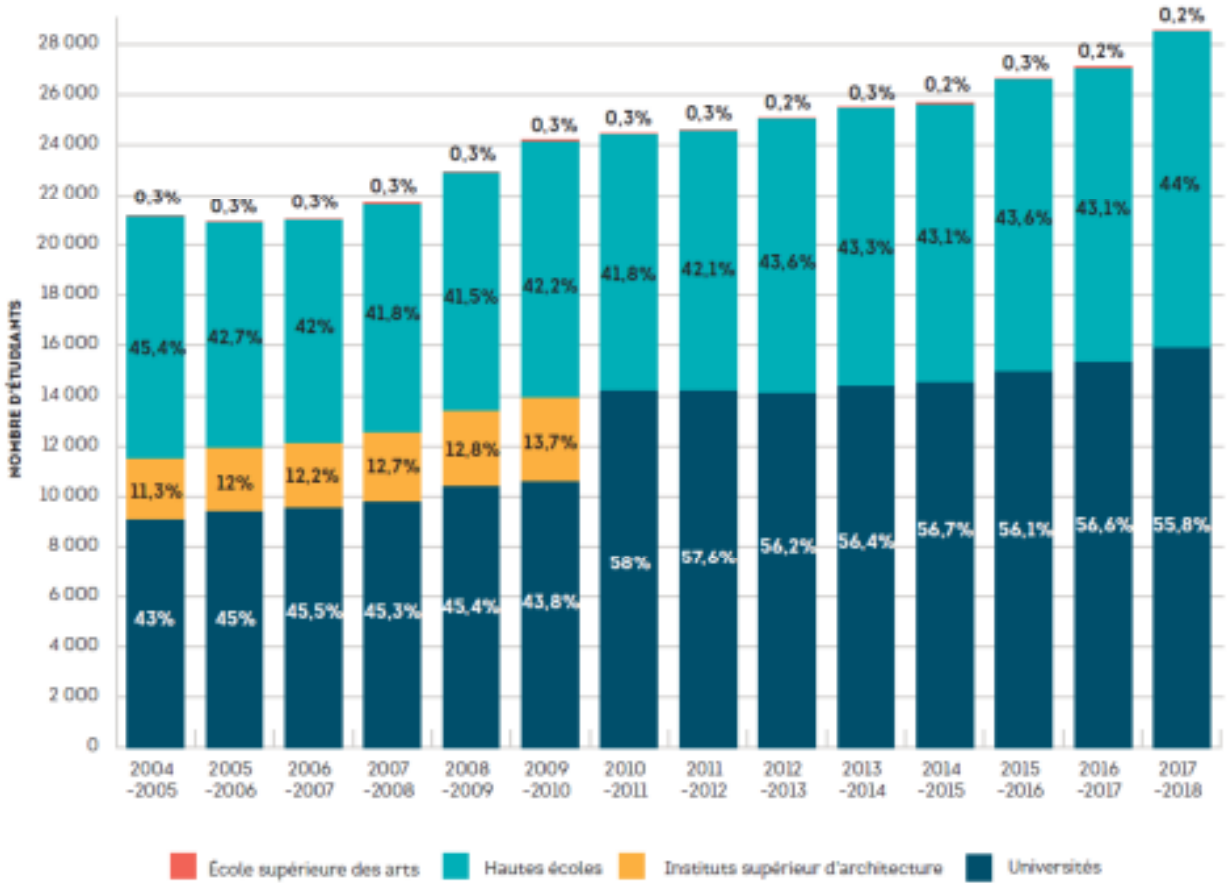
Gender issues in STEM studies…

ARES

N° 1
JUIN 2021

STATSUP'INFO

GRAPHIQUE 3 · Évolution du nombre d'étudiants en STIM en FWB selon le type d'établissement d'enseignement supérieur



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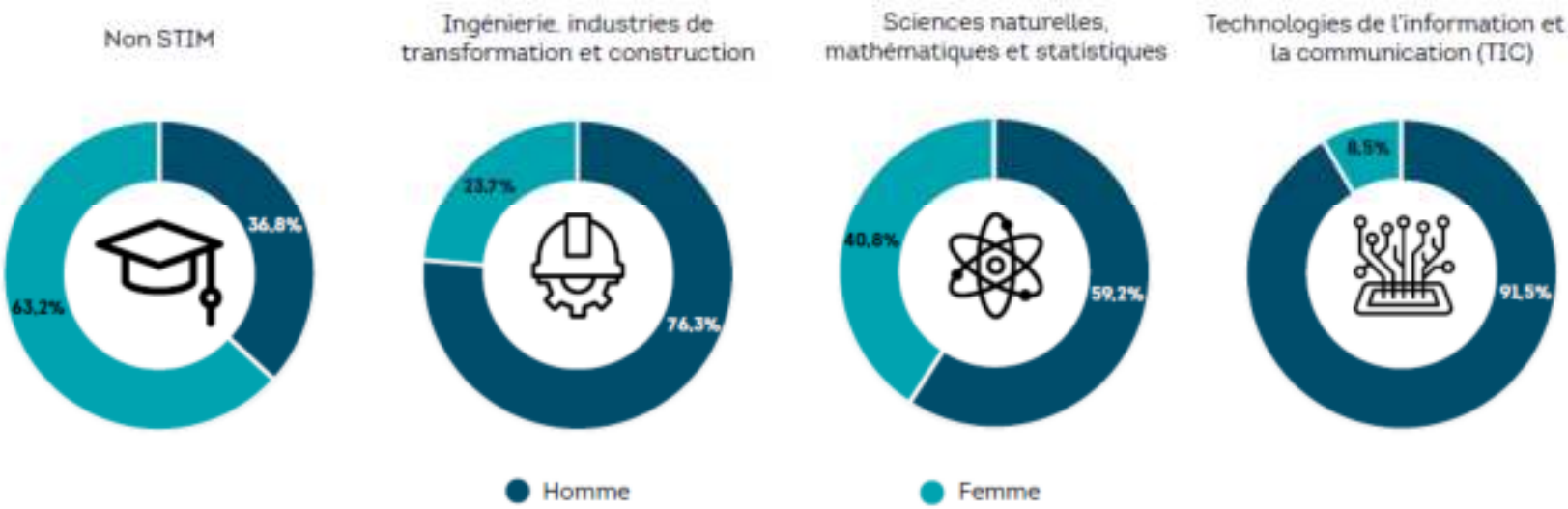
Gender issues in STEM studies…

ARES
N° 1
JUIN 2021
STATSUP'INFO

GRAPHIQUE 4 · Proportion d'étudiants par sexe et par domaine CITE en 2017-2018



Gender issues in STEM studies…

https://www.ares-ac.be/fr/agenda/497-11-02-19-rencontre-regards-croises-sur-les-carrieres-au-feminin-dans-les-stim-bruxelles-bluepoint-brussels

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