

Understanding Microbial Communities - Developing the Potential

Thursday 4<sup>th</sup> December 2014

Isaac Newton Institute, Cambridge , UK



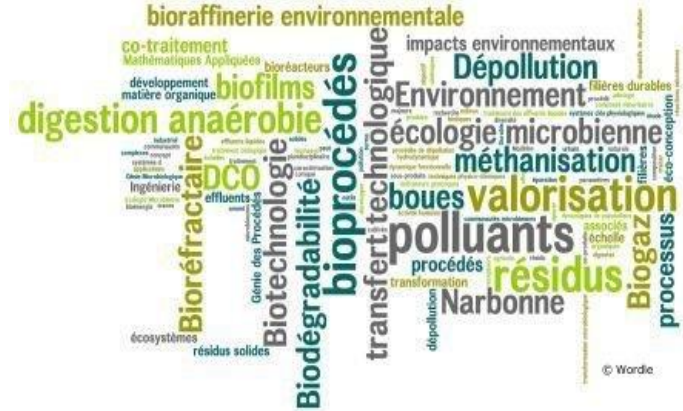
# Innovation and Technology Transfer in Anaerobic Digestion



**Jean-Philippe Steyer**

Laboratoire de Biotechnologie de l'Environnement  
INRA Narbonne – France

# Laboratoire de Biotechnologie de l'Environnement (INRA-LBE Narbonne)



<http://www.montpellier.inra.fr/narbonne>

## A long history

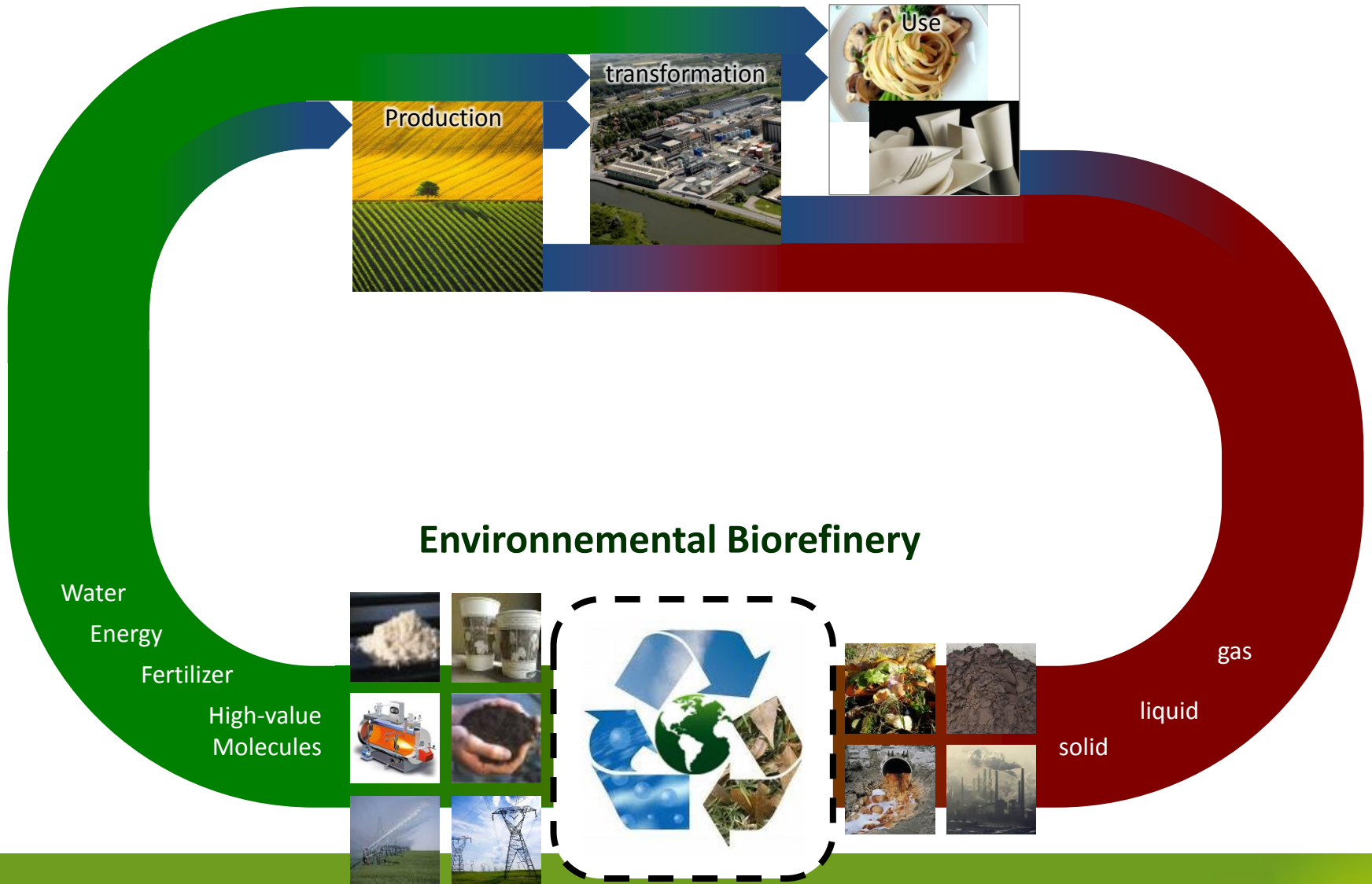


Le 25 octobre 1936

de M. Blum

Député de Narbonne

Président du  
conseil

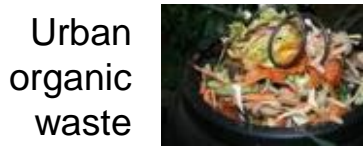
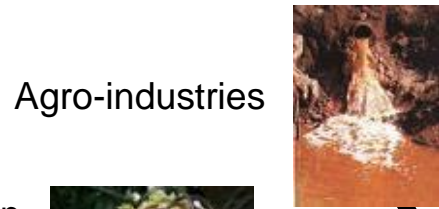


## Environnemental Biorefinery

## Environmental Biorefinery

### Multiple inputs and territory

### Commodities for bioeconomy



*Sanitary and environmental constraints (chemical and microbial contaminants)*

CH<sub>4</sub> and/or H<sub>2</sub>



Heat  
Electricity  
Biofuel  
Natural gas

Platform Molecules



Acetate, butyrate, propionate, lactate, ethanol,...

Fertilizers



N, P, K,  
Organic matter

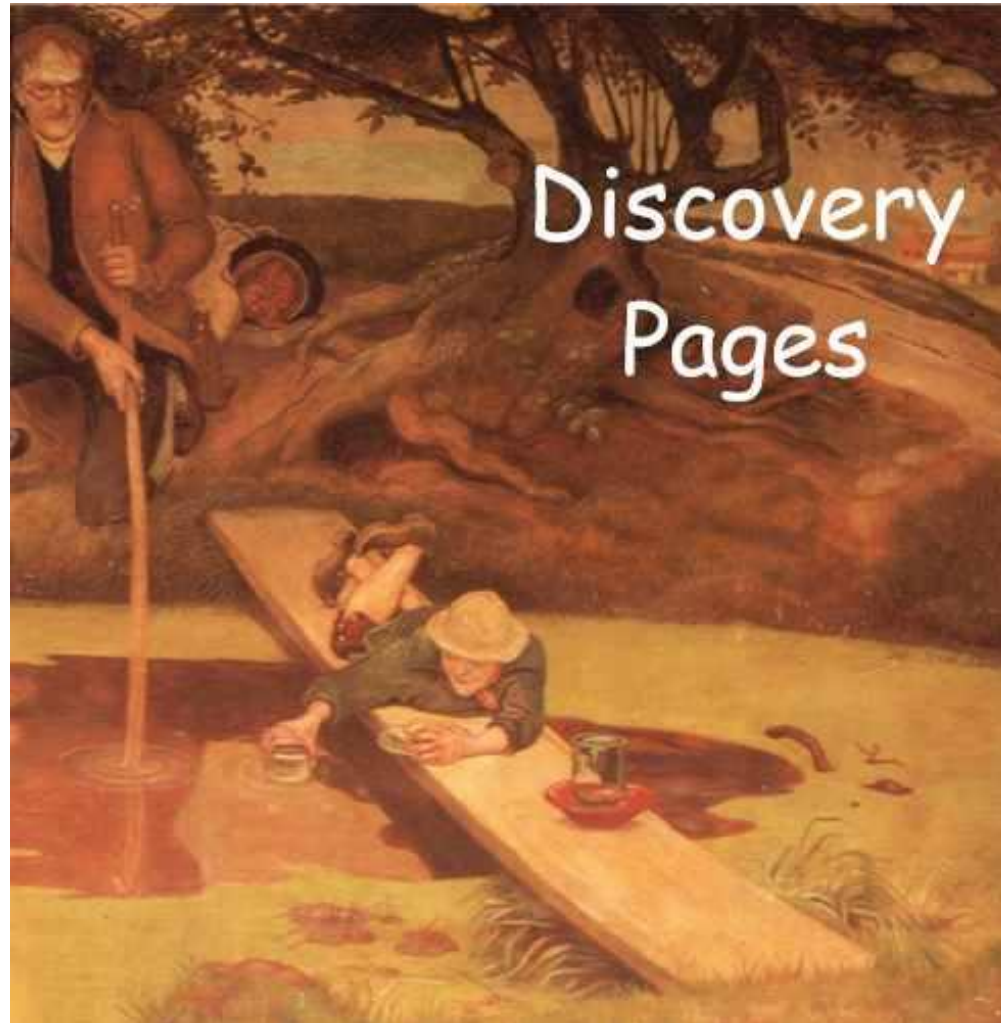
H<sub>2</sub>O



Reuse, irrigation

# Anaerobic digestion

An old story for today and tomorrow

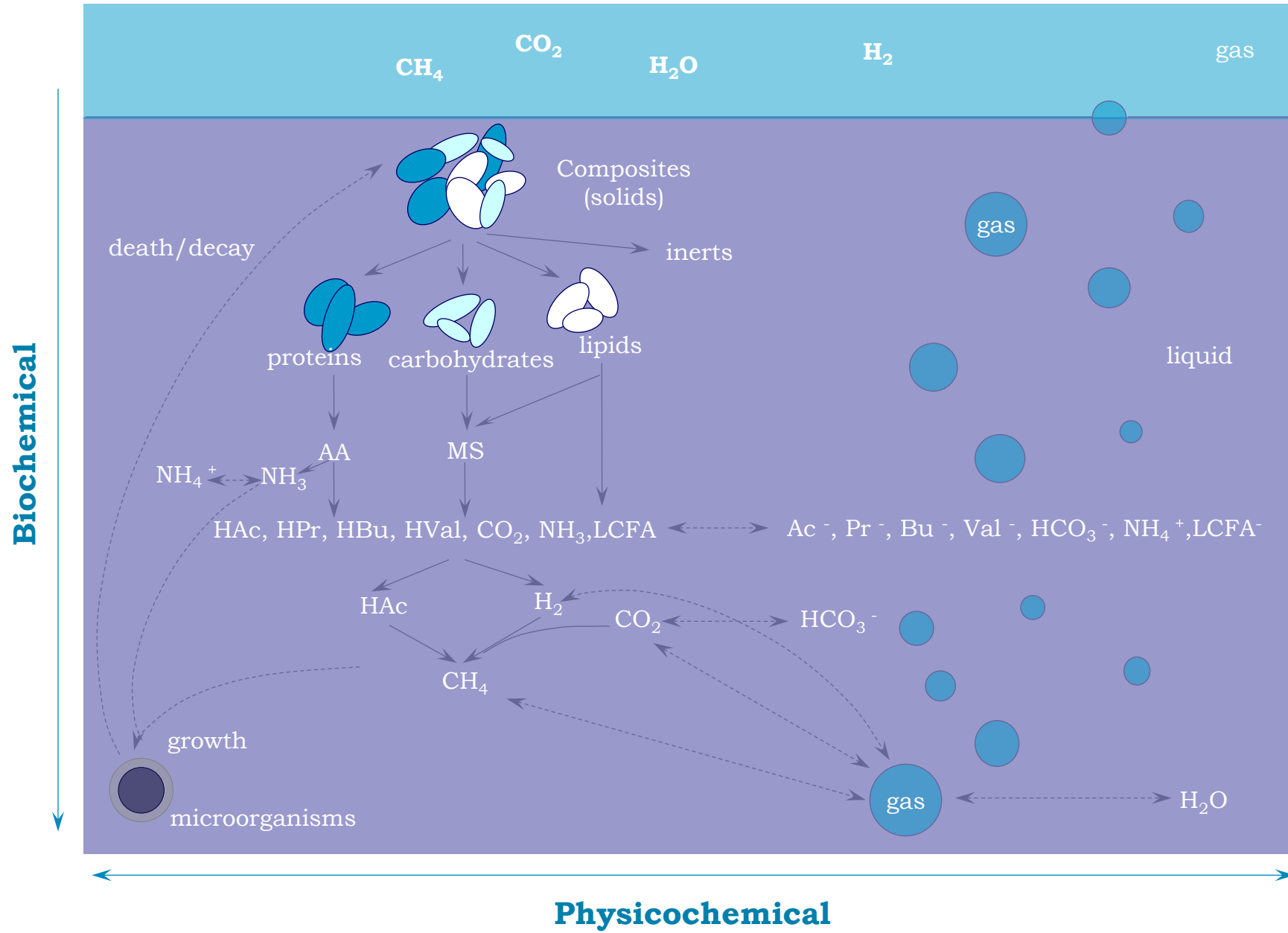


# Anaerobic digestion

**A natural ecosystem !**

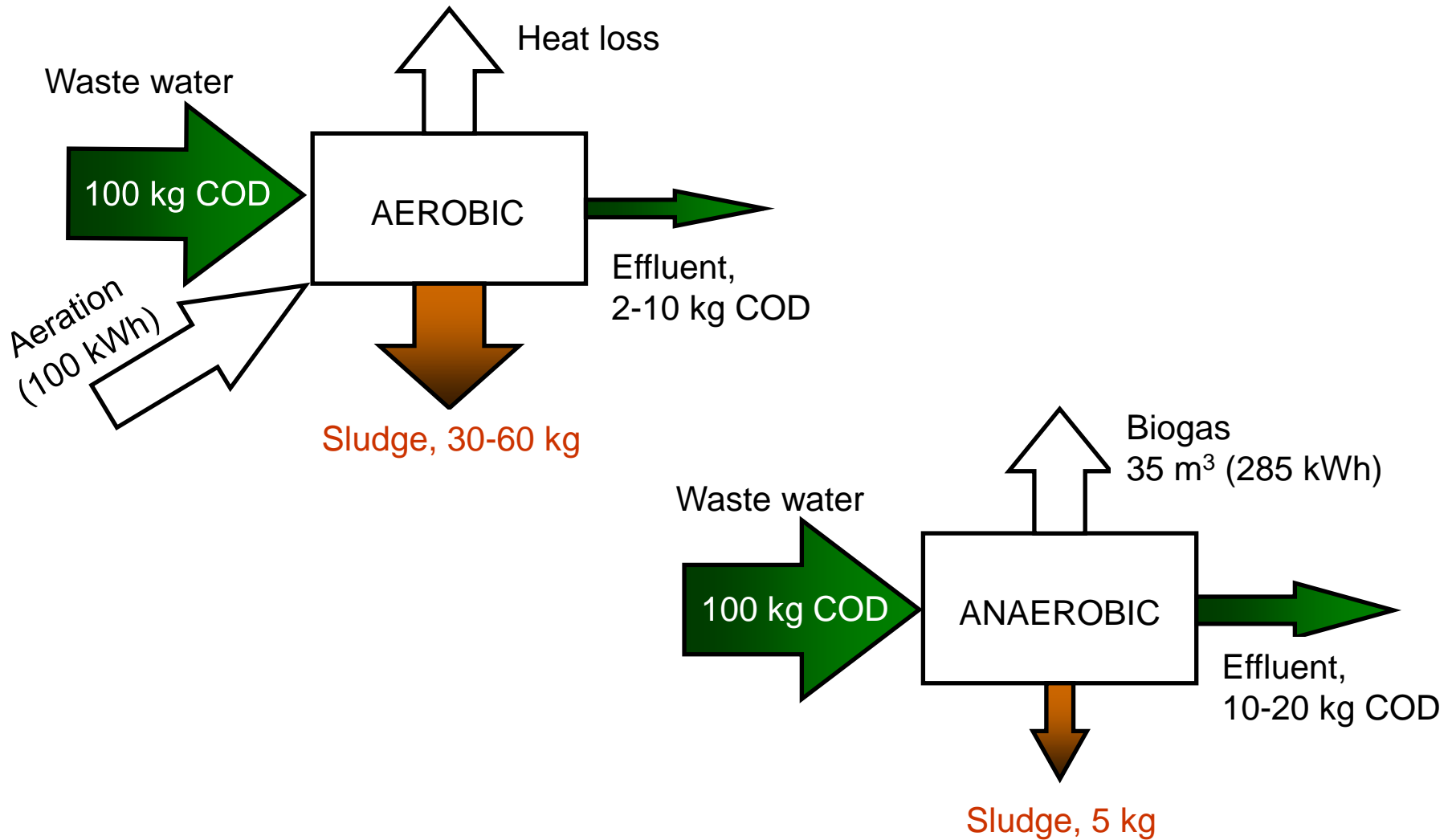


# Conversion processes in AD process

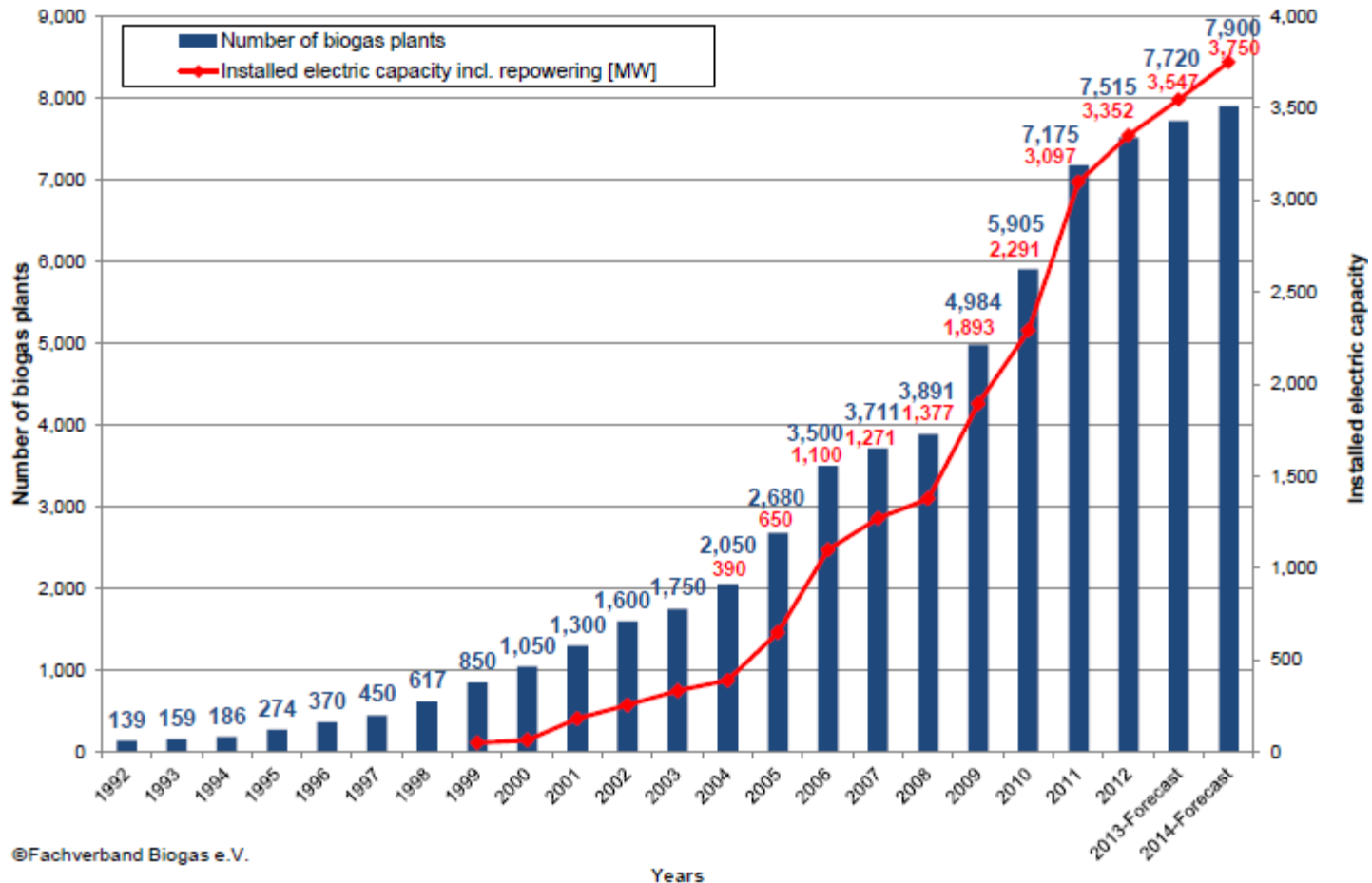




# Why anaerobic treatment ?



# AD in Germany (at the farm level)



# AD in France

**SOCIÉTÉ CENTRALE D'APPROVISIONNEMENT  
DES AGRICULTEURS DE FRANCE**  
PROCÉDÉS DUCELLIER ET ISMAN

8, Rue d'Athènes      PARIS      TEL. TR 01-54



Une technique nouvelle  
à la portée  
de tous les Agriculteurs

**INSTALLATIONS DE GAZ DE FUMIER  
EN CUVES A PAROIS MINCES**  
RENDEMENT ÉLEVÉ - AMORTISSEMENT RAPIDE  
SÉCURITÉ TOTALE DE FONCTIONNEMENT

*Ades expérimentées et celles de nos Agents sont à votre service  
Profitez-en  
Tous renseignements et devis gratuits sur simple demande*



Cuisinière  
**GAZELLE**  
à Gaz de Fumier

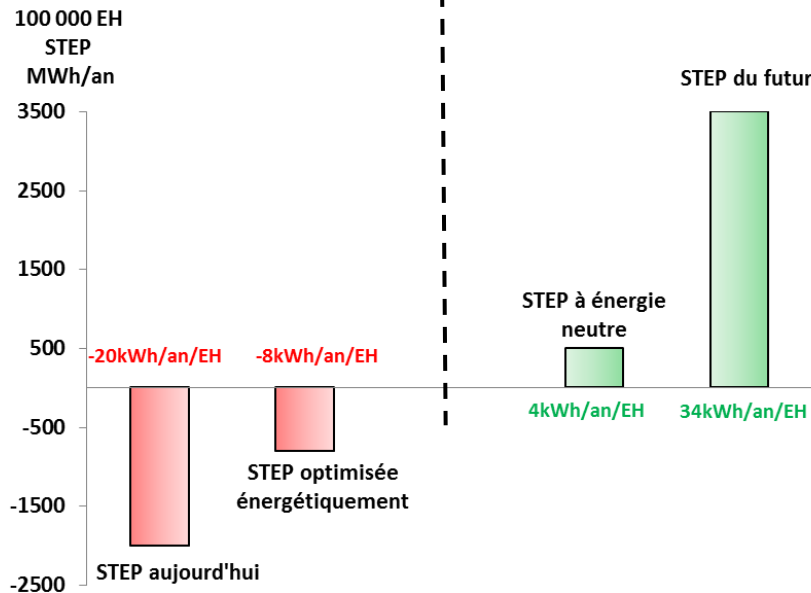
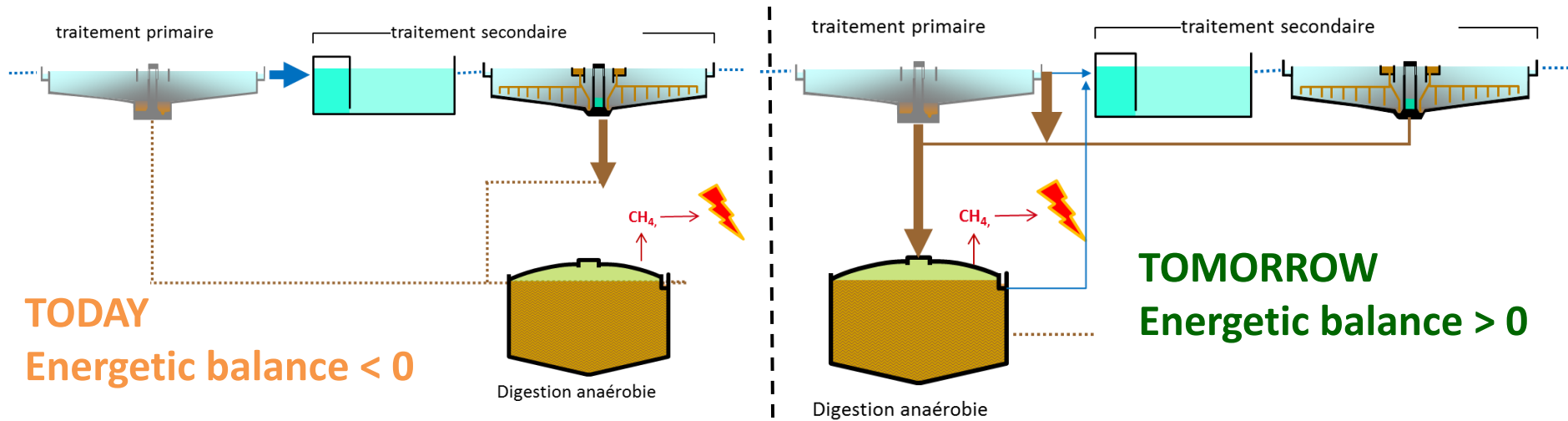
ETABLISSEMENTS  
**P. GENEVÉE**  
ST-OUEN VENDÔME  
(LOIR-et-CHER)

digesteur agricole et cuisinière alimentée en gaz de fumier<sup>17</sup> (1952)



# AD in France

## The next generation of WWTP – Towards WRRF

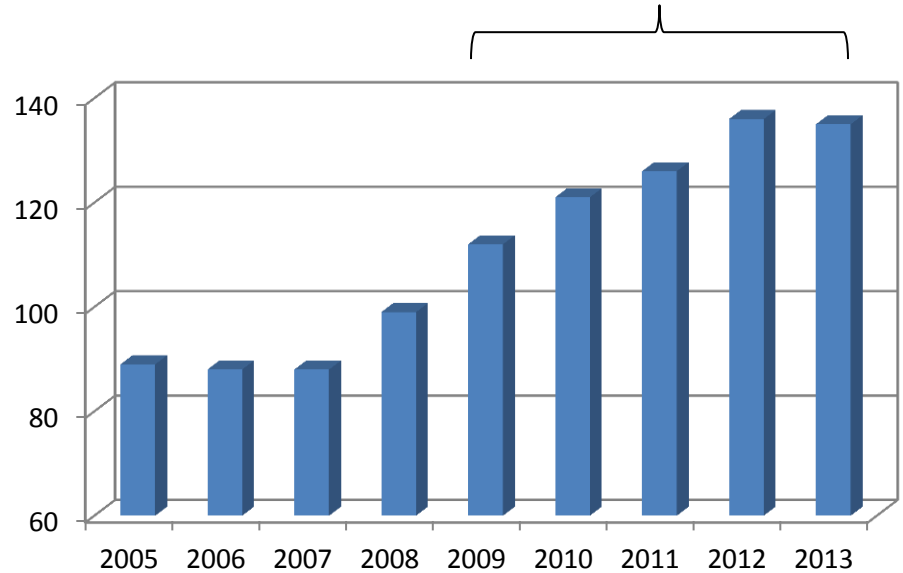


## The people

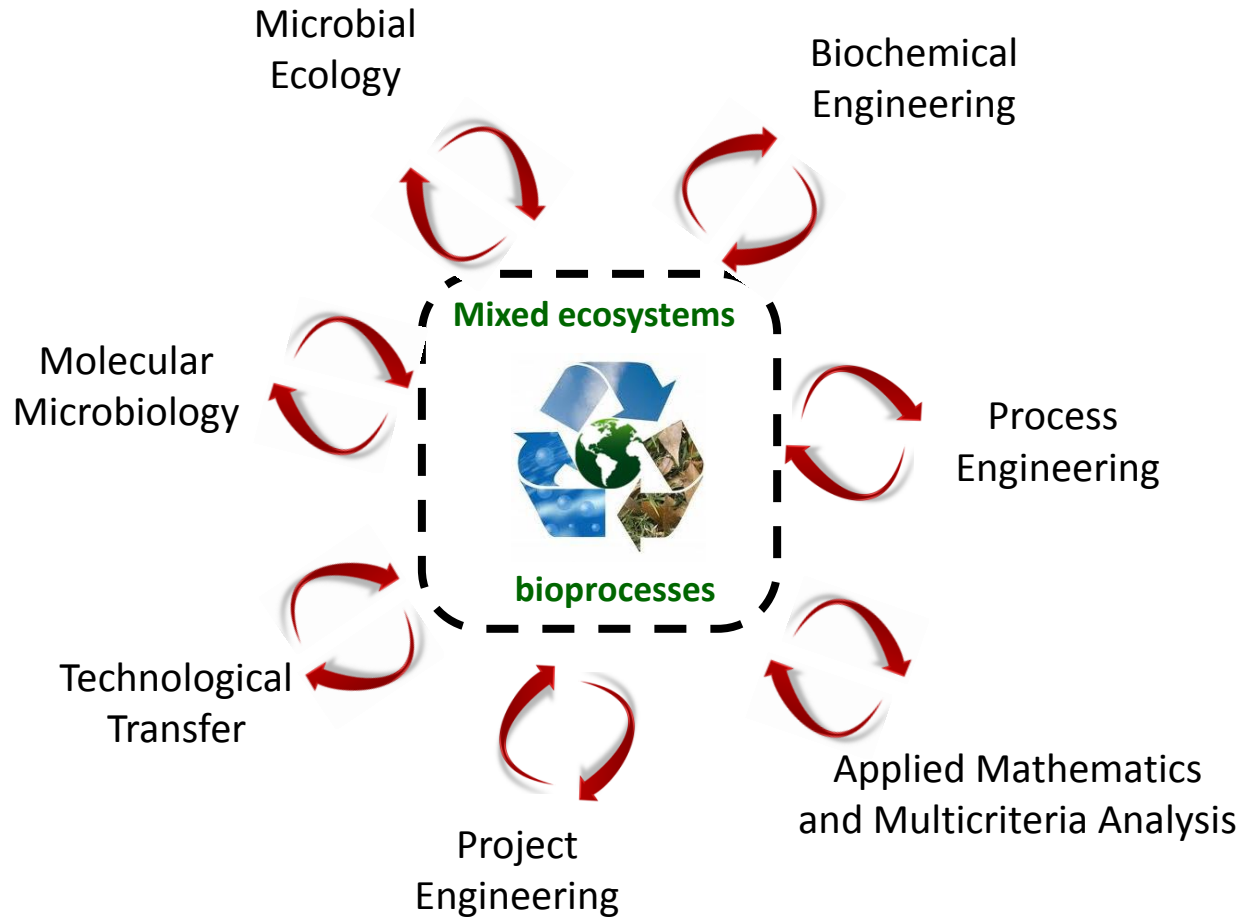


- 15 researchers (with permanent positions)
- 38 permanent positions in total
- On average 80 full-time equivalents

**28 different nationalities  
(but nobody from UK !)**



## Our scientific backgrounds



## The processes

- ✓ 400+ BMP and BHP tests / year
- ✓ 60+ digesters (1 liter to 1 m<sup>3</sup>) in operation
- ✓ Pretreatments (°C, US, O<sub>3</sub>, mechanical,...)





## Scientific production

- ✓ Over the last 4 years, 264 papers in **96 different journals**
- ✓ **3.9 papers/researcher.year - 2.8 papers/PhD**
- ✓ **80% of our papers are co-authored** (35 countries)

WEB OF SCIENCE™ THOMSON REUTERS™

Search My Tools Search History Marked List

Results: ...  
(from Web of Science Core Collection)

You searched for: TOPIC: (anaerobic digestion) ...More

Create Alert

Organizations-Enhanced Refine Exclude Cancel Sort these by: Record Count

The first 100 Organizations-Enhanced (by record count) are shown. For advanced refine options, use Analyze results.

<input type="checkbox"/> INSTITUT NATIONAL DE LA RECHERCHE AGRONOMIQUE INRA (313)	<input type="checkbox"/> UNIVERSITY OF JYVASKYLA (65)	<input type="checkbox"/> UNIVERSITY OF MANITOBA (45)
<input type="checkbox"/> WAGENINGEN UNIVERSITY RESEARCH CENTER (215)	<input type="checkbox"/> UNIVERSITY OF SOUTHAMPTON (63)	<input type="checkbox"/> UNIVERSITY OF MANCHESTER (44)

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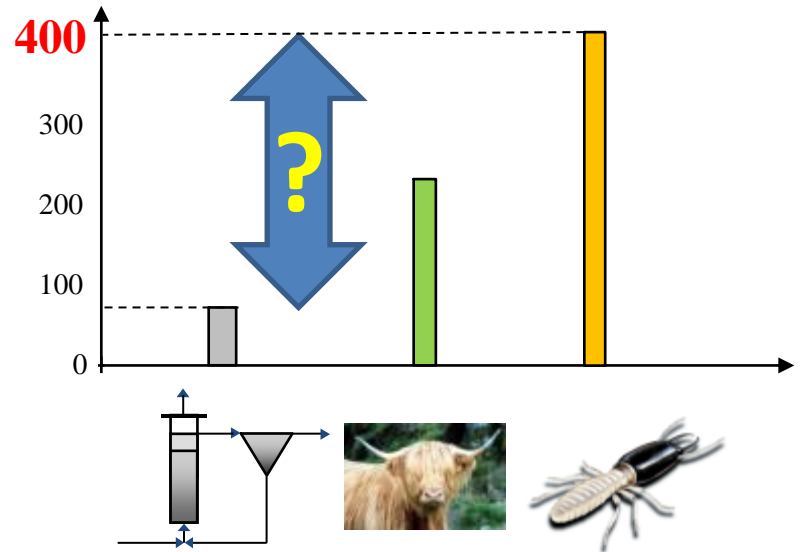
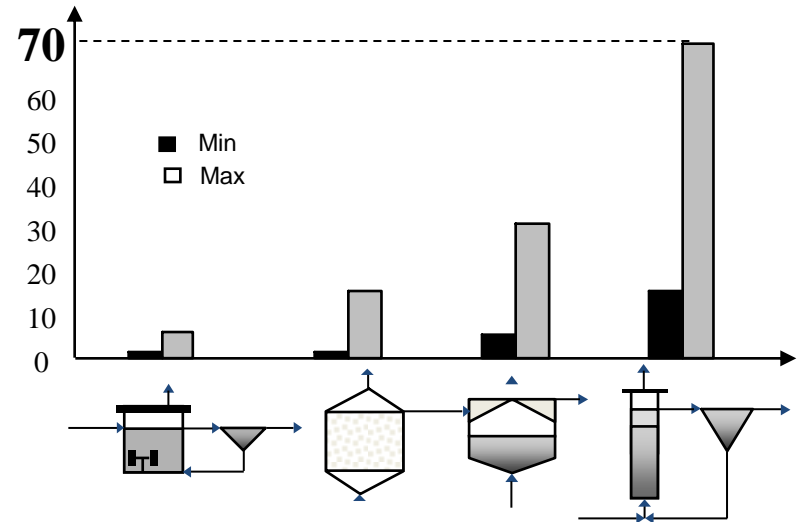
**A quick snapshot about our research:**

**Innovative process design inspired by Nature**

# Innovative process design inspired by Nature



Organic load ( $\text{kg}_{\text{COD}}/\text{m}^3 \cdot \text{d}$ )

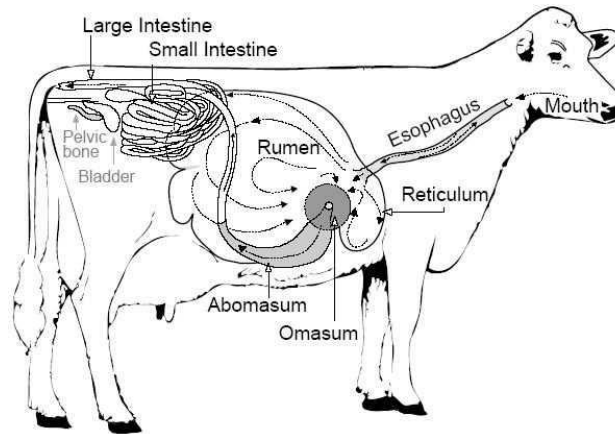


# Innovative process design inspired by Nature

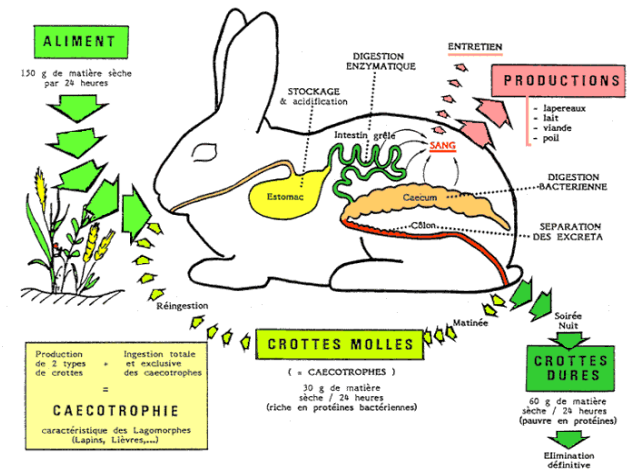
## Effect of microbiology ?



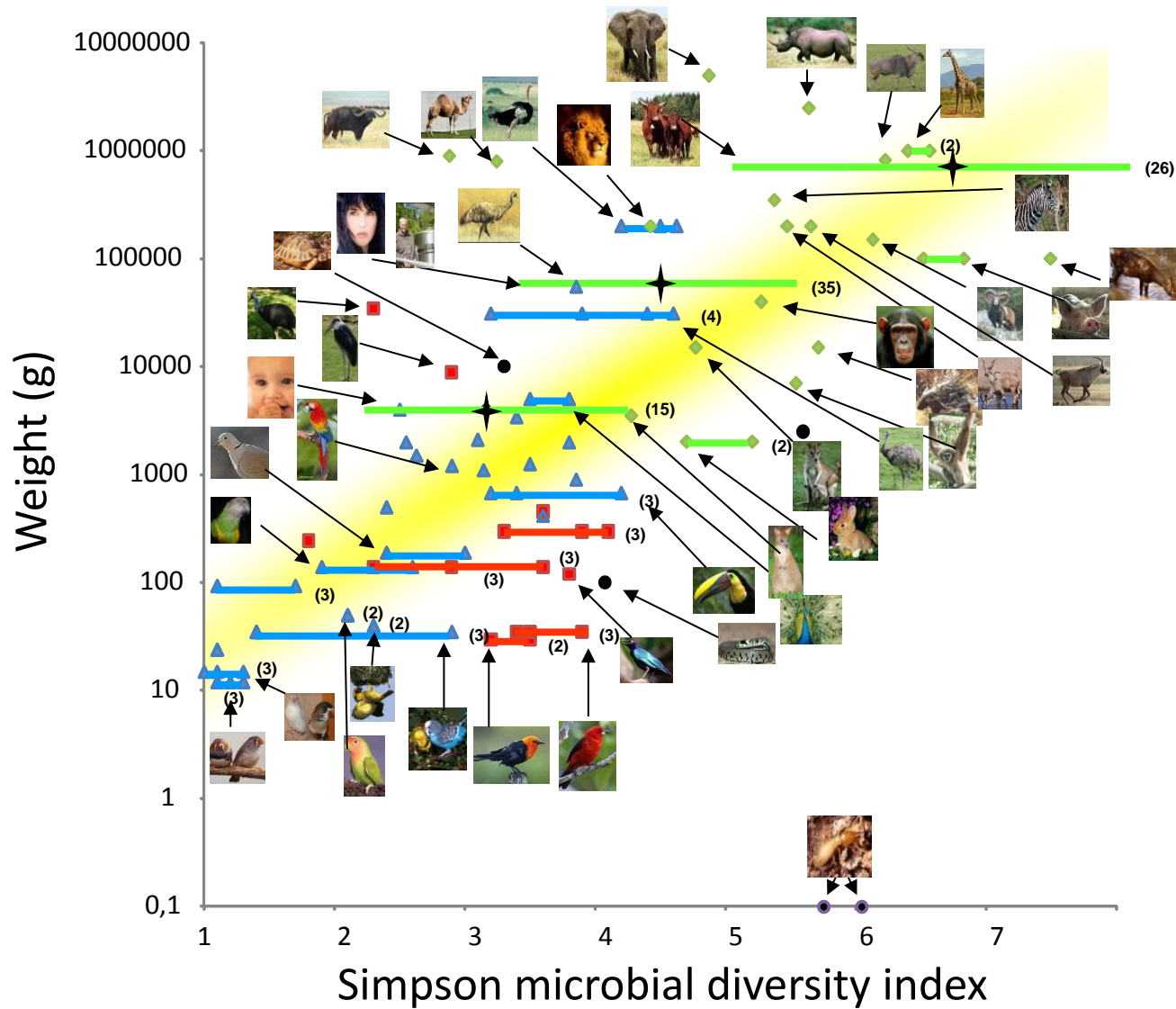
## Effect of process design ?



## Effect of operating conditions ?



# Innovative process design inspired by Nature

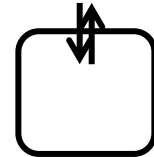


# Innovative process design inspired by Nature

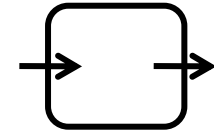
## From the analysis of 190 digestive tracts



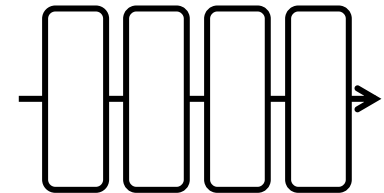
Batch reactor



Continuous stirred tank reactor (CSTR)



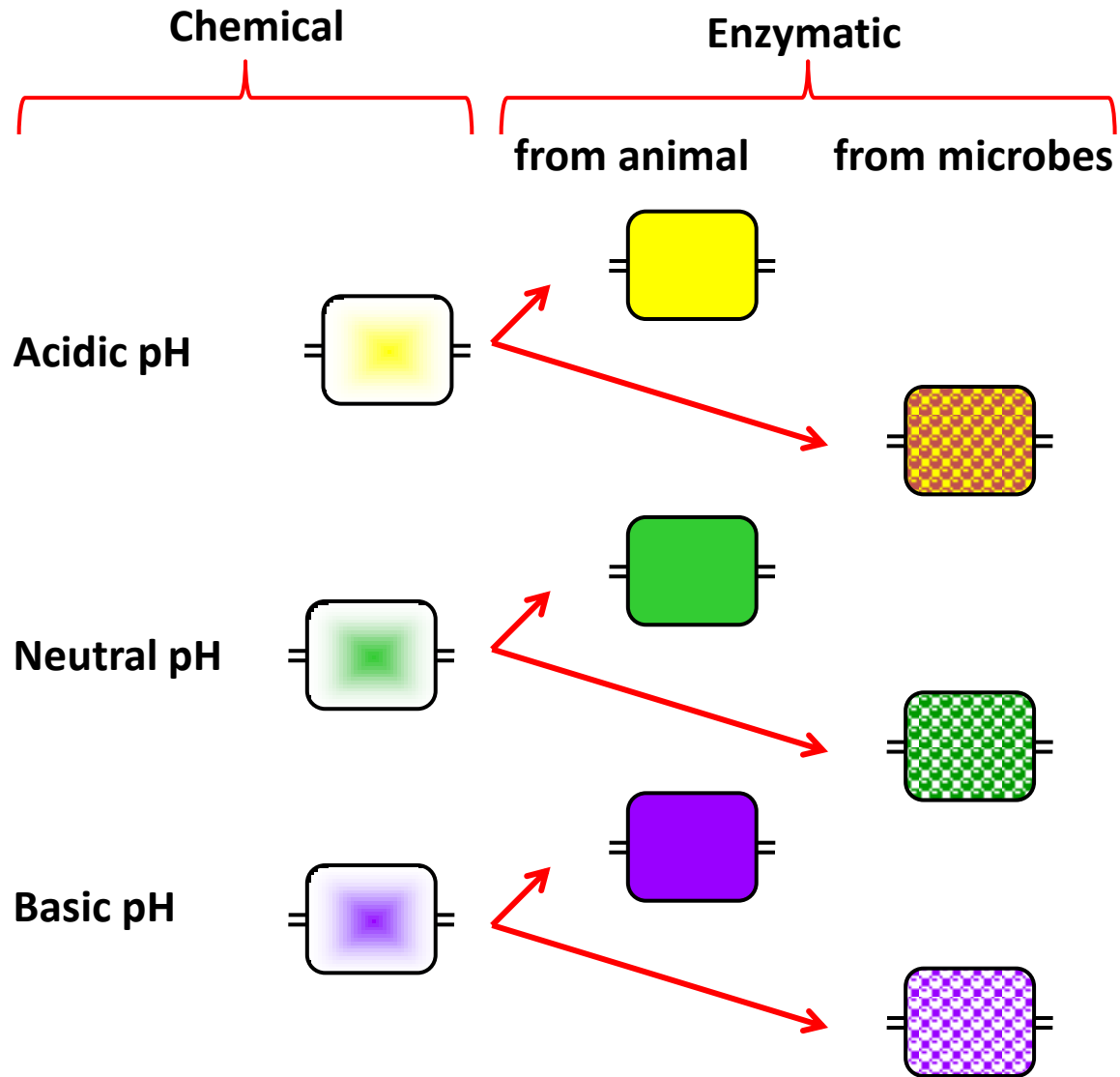
CSTRs in série



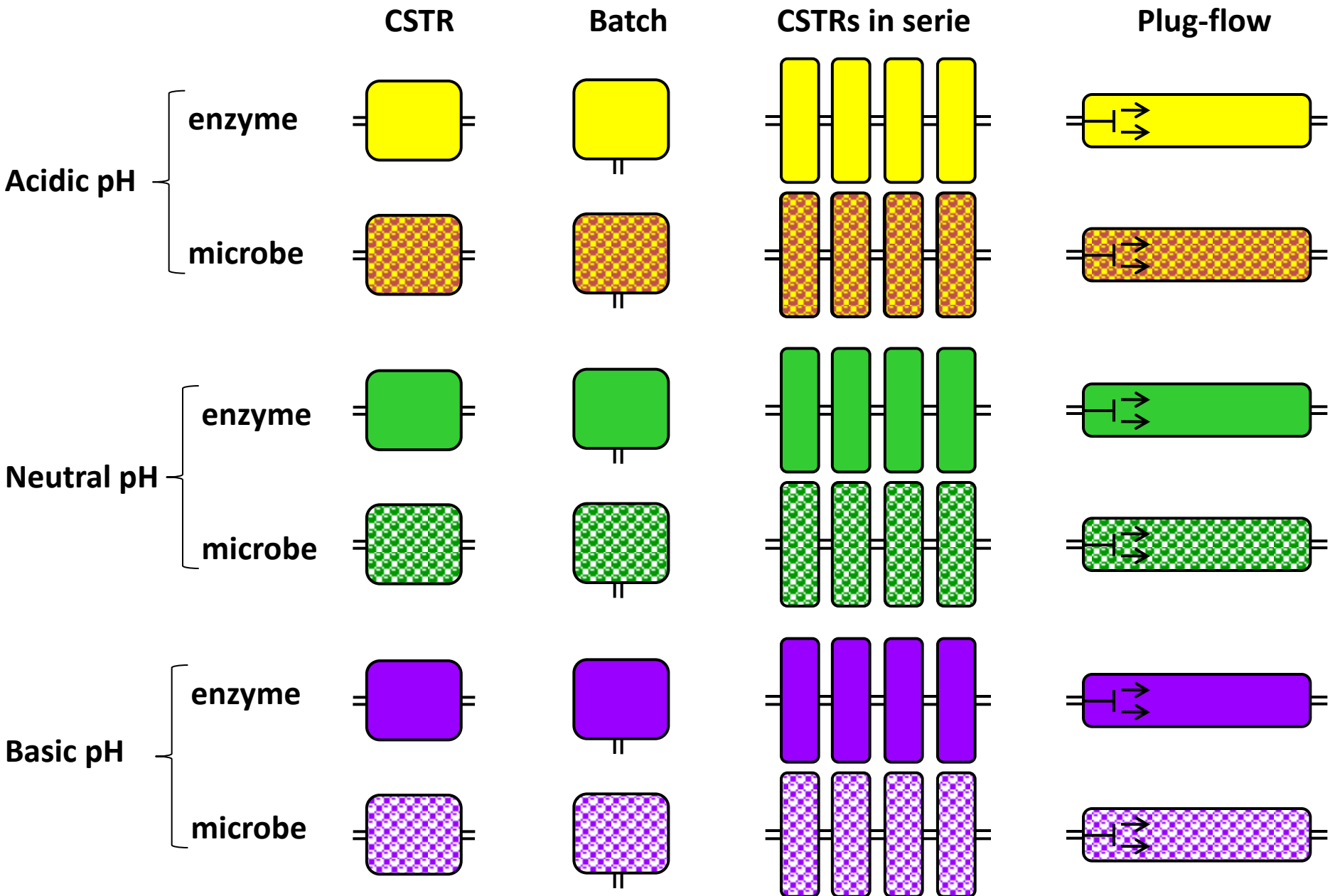
Plug-flow reactor



# Types of hydrolysis within the reactors

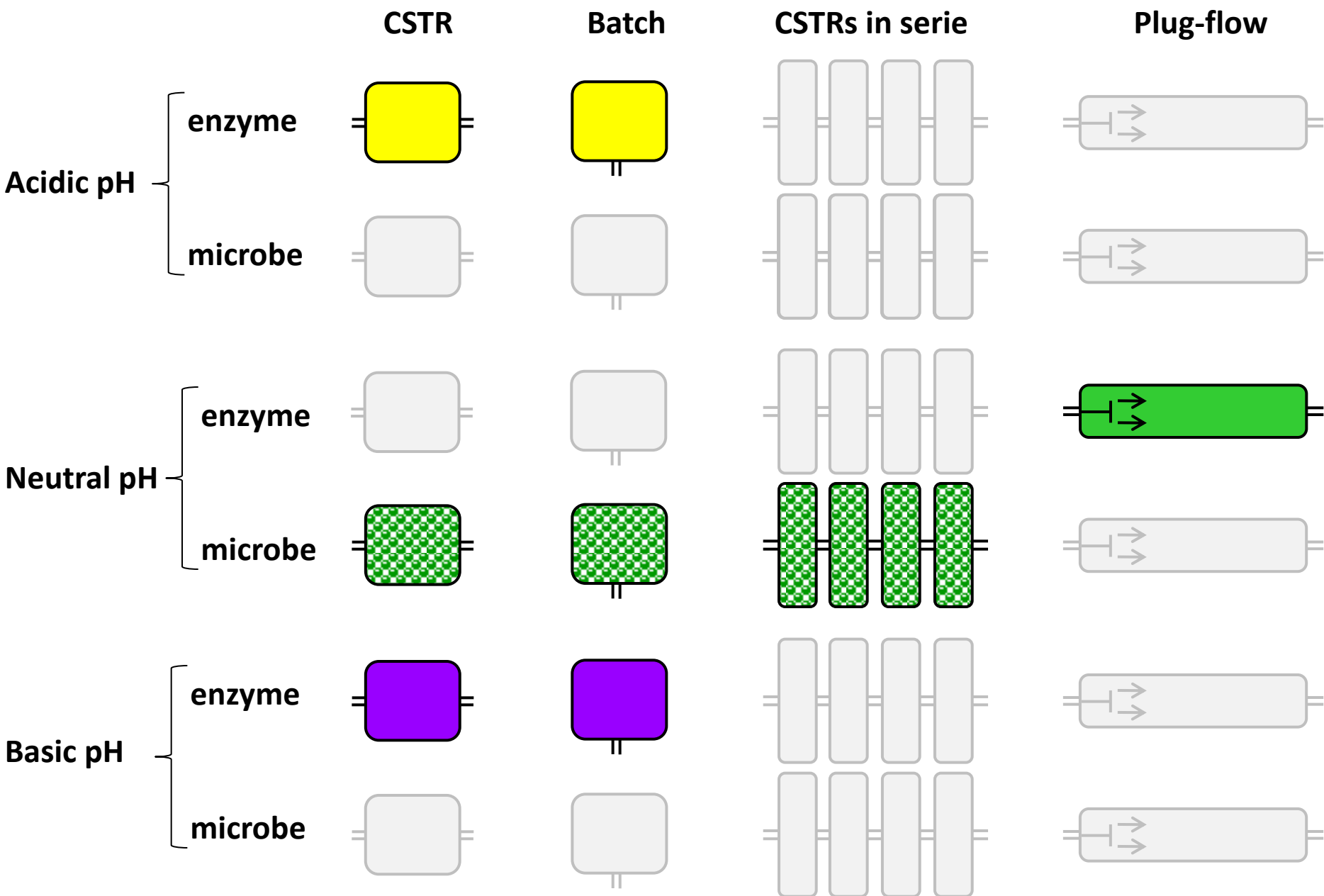


# Innovative process design inspired by Nature

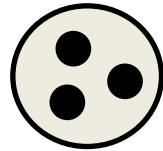




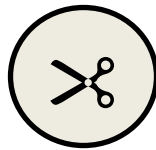
# Innovative process design inspired by Nature



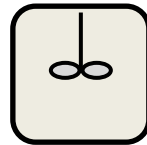
# Types of mechanic action found in organisms



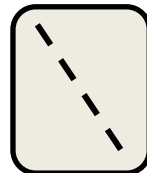
grinding



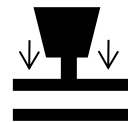
cutting



mixing

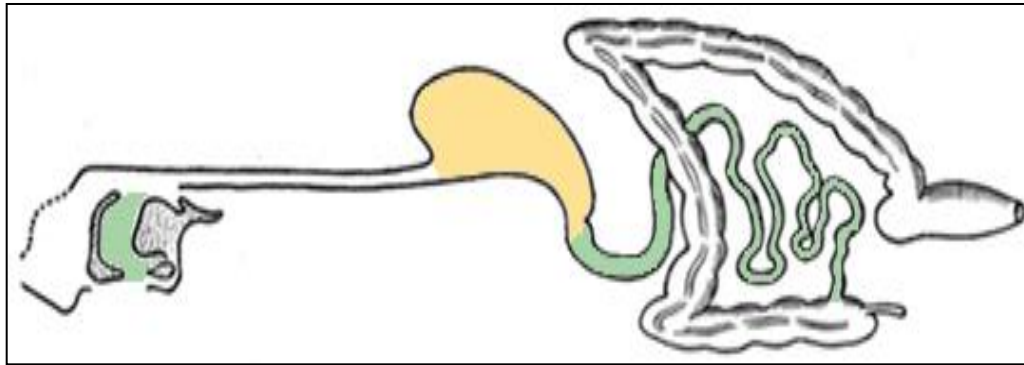
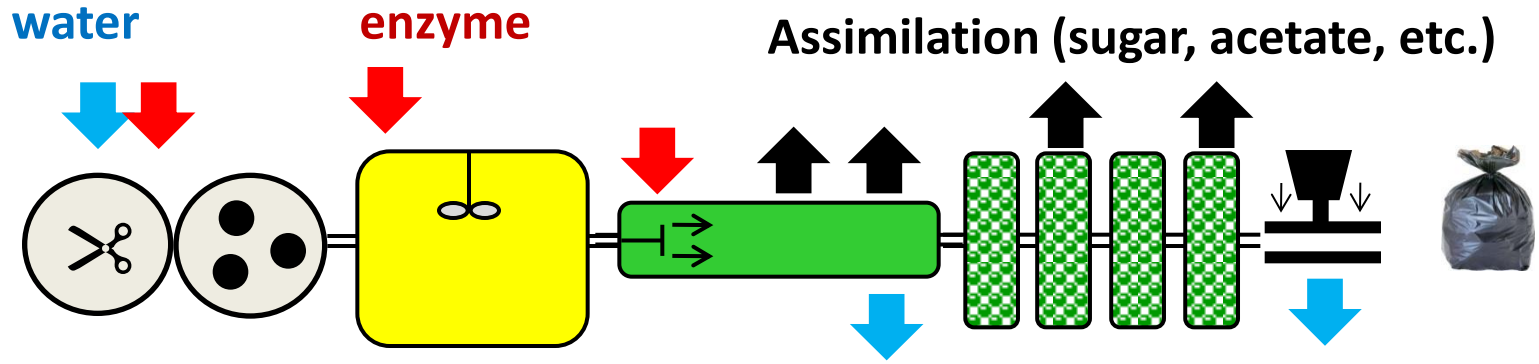


Particle size separation  
Particle/water separation

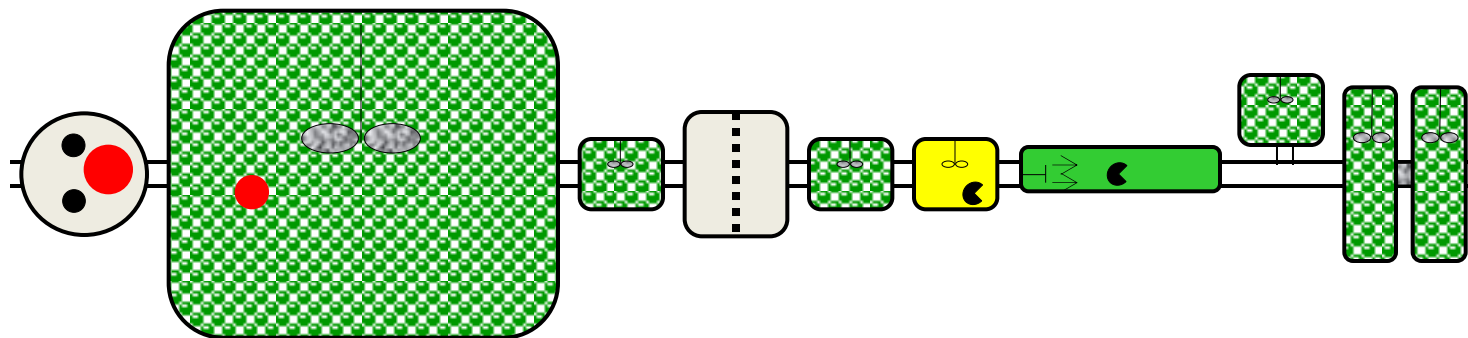


Pressing (dewatering)

# From the process to the organism



# Recycling : the cow's testimony

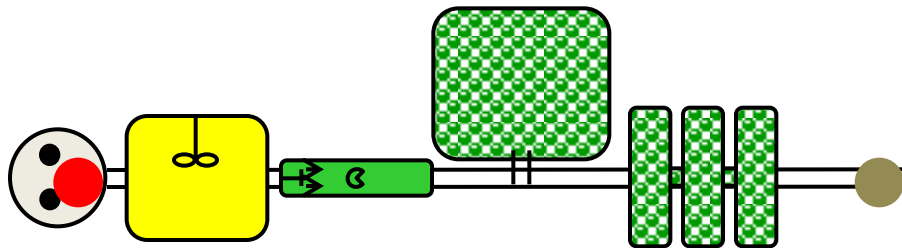


Size particle separation

Re-grinding of the large particles



# Recycling : the rabbit's testimony

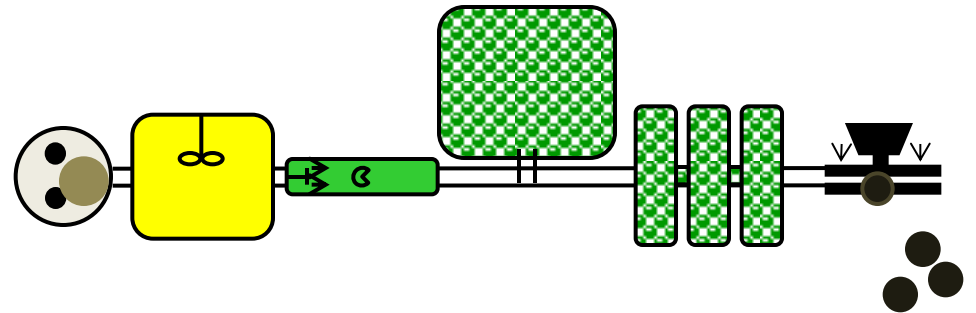


First digestion

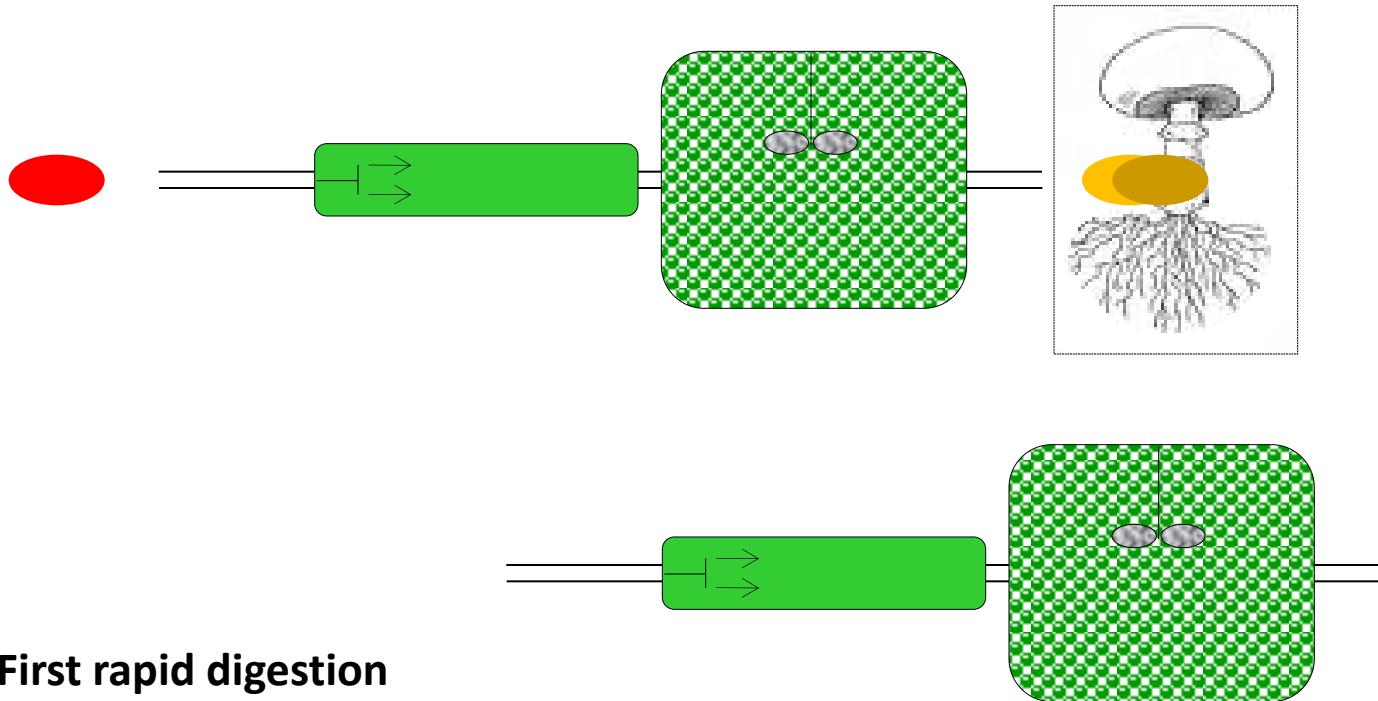
Production of special feces (caecotrophe)

Feces eating

Second digestion



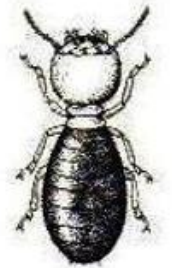
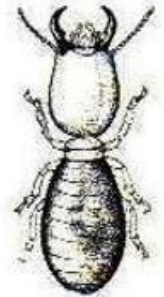
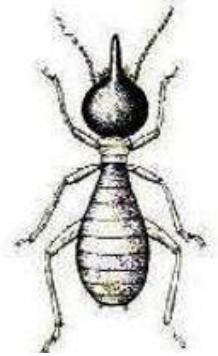
# The termite's testimony



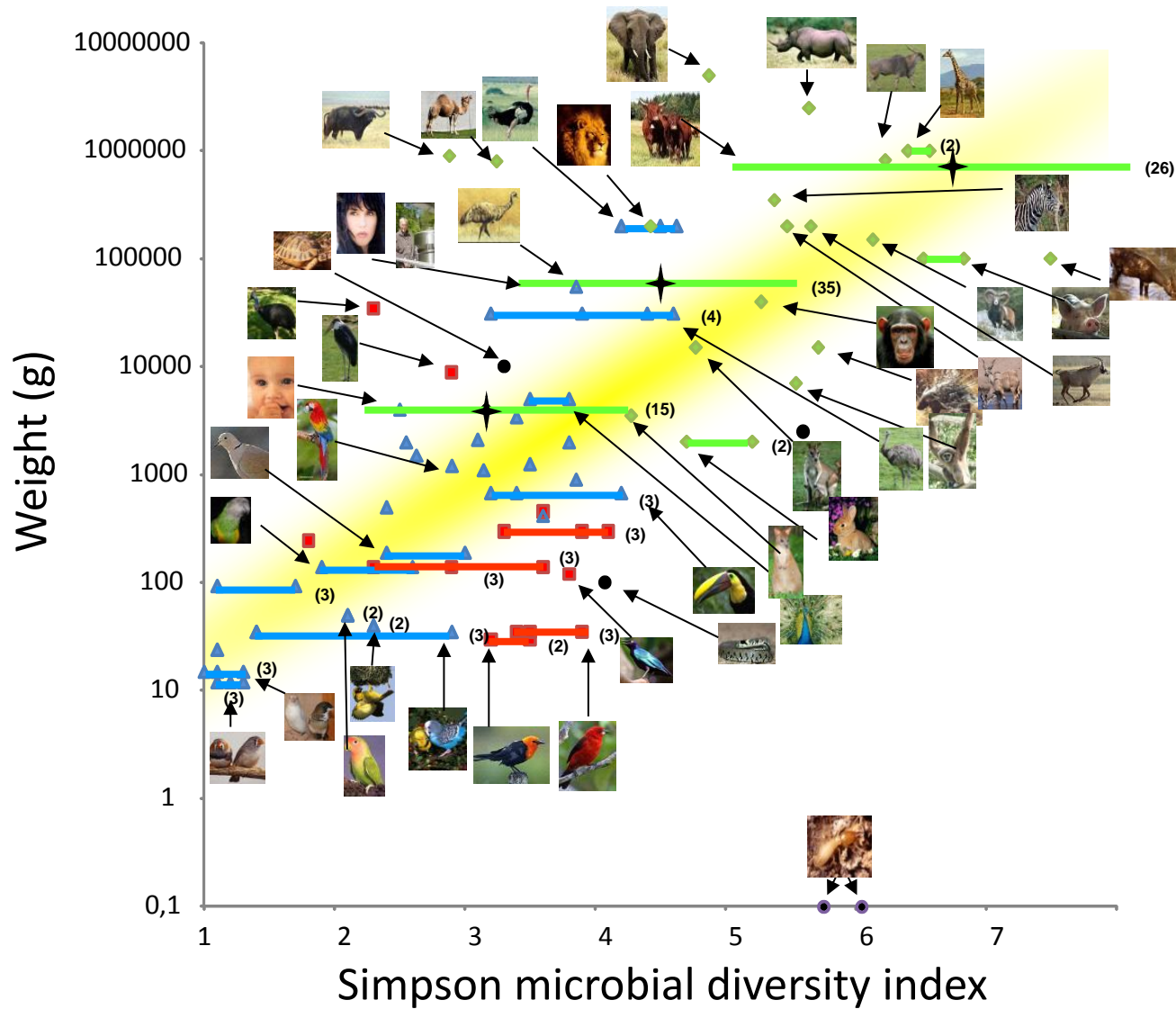
First rapid digestion

Degradation in an external fungal reactor

Fungal reactor eating



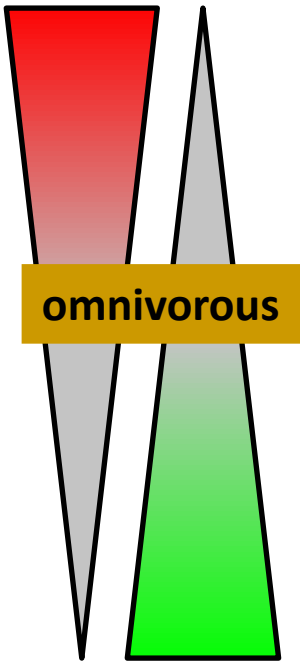
# Innovative process design inspired by Nature



# Innovative process design inspired by Nature

Readily Biodegradable Substrates

**carnivorous**



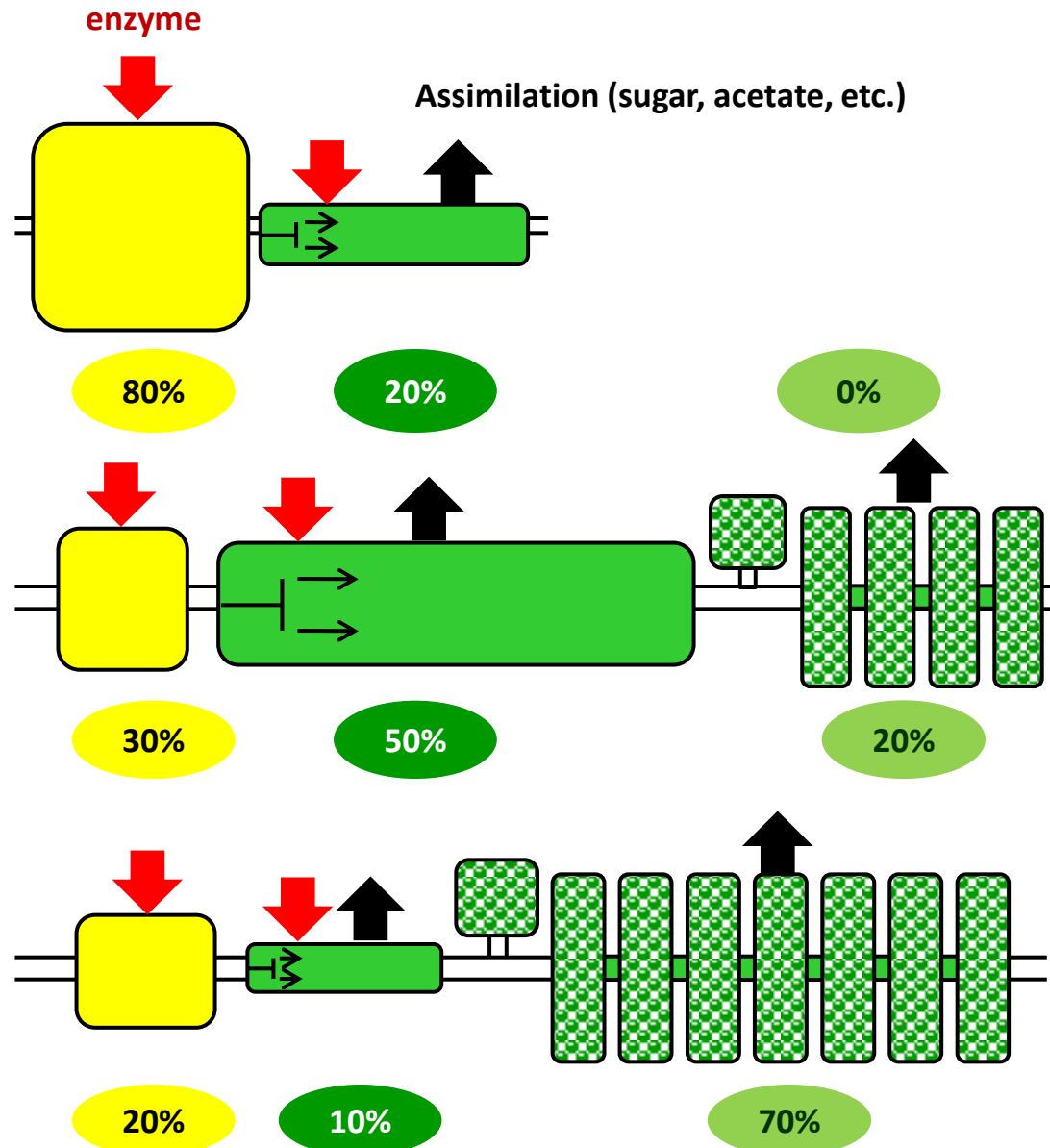
**omnivorous**



**herbivorous**



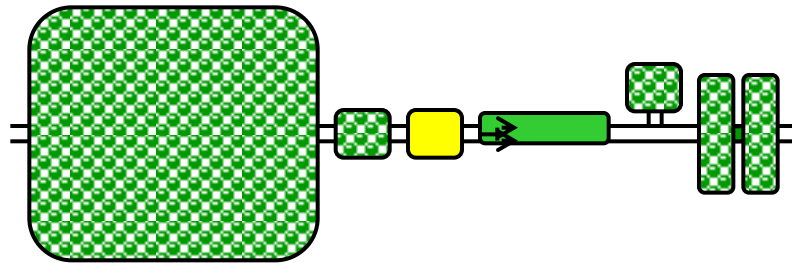
Slowly Biodegradable Substrates



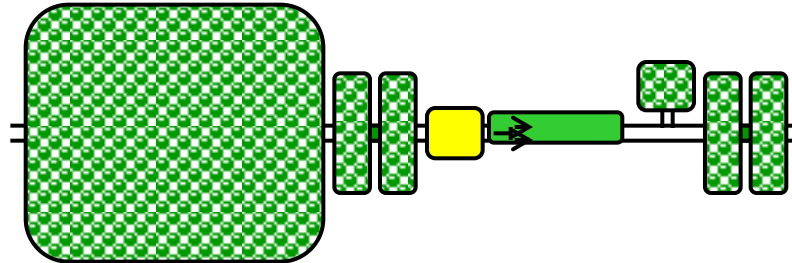


# The 'herbivorous' configuration part I

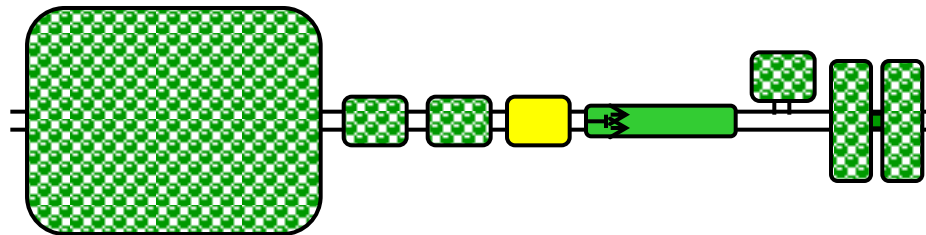
Lama



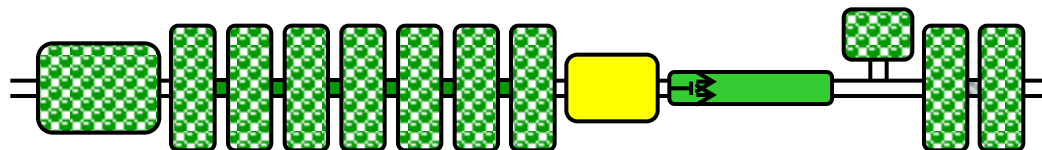
Hoazin



Cow



Kangaroo

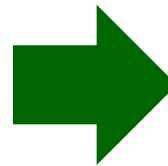
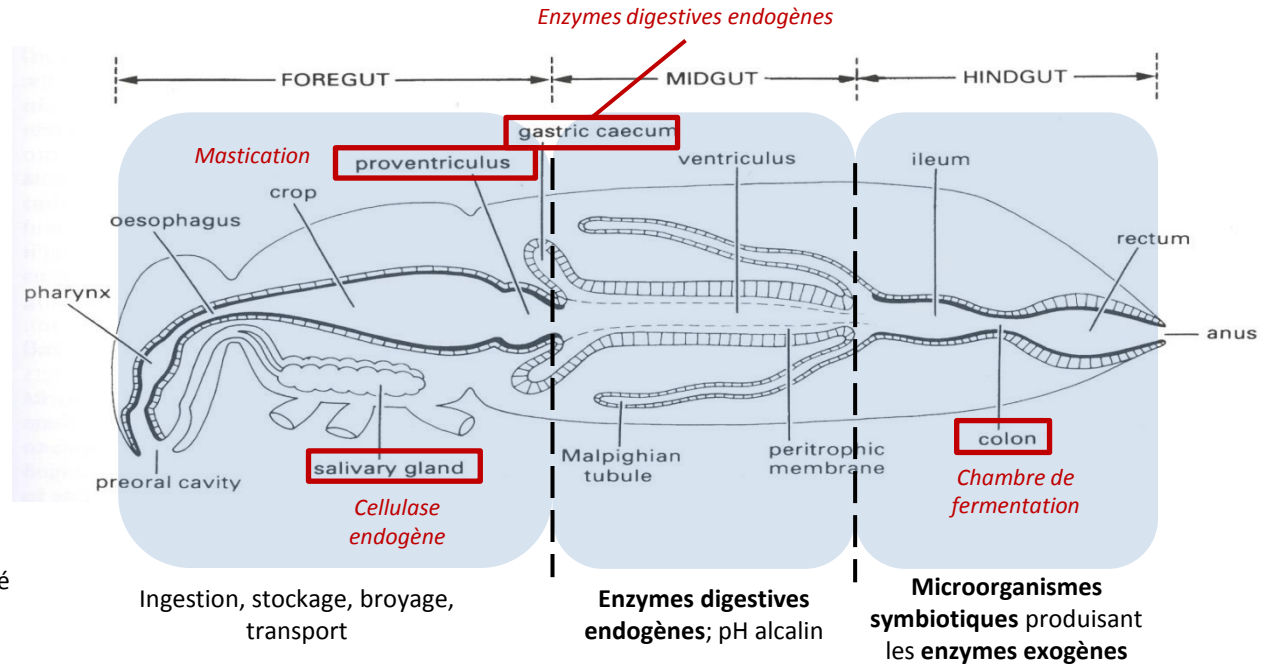


# Innovative process design inspired by Nature

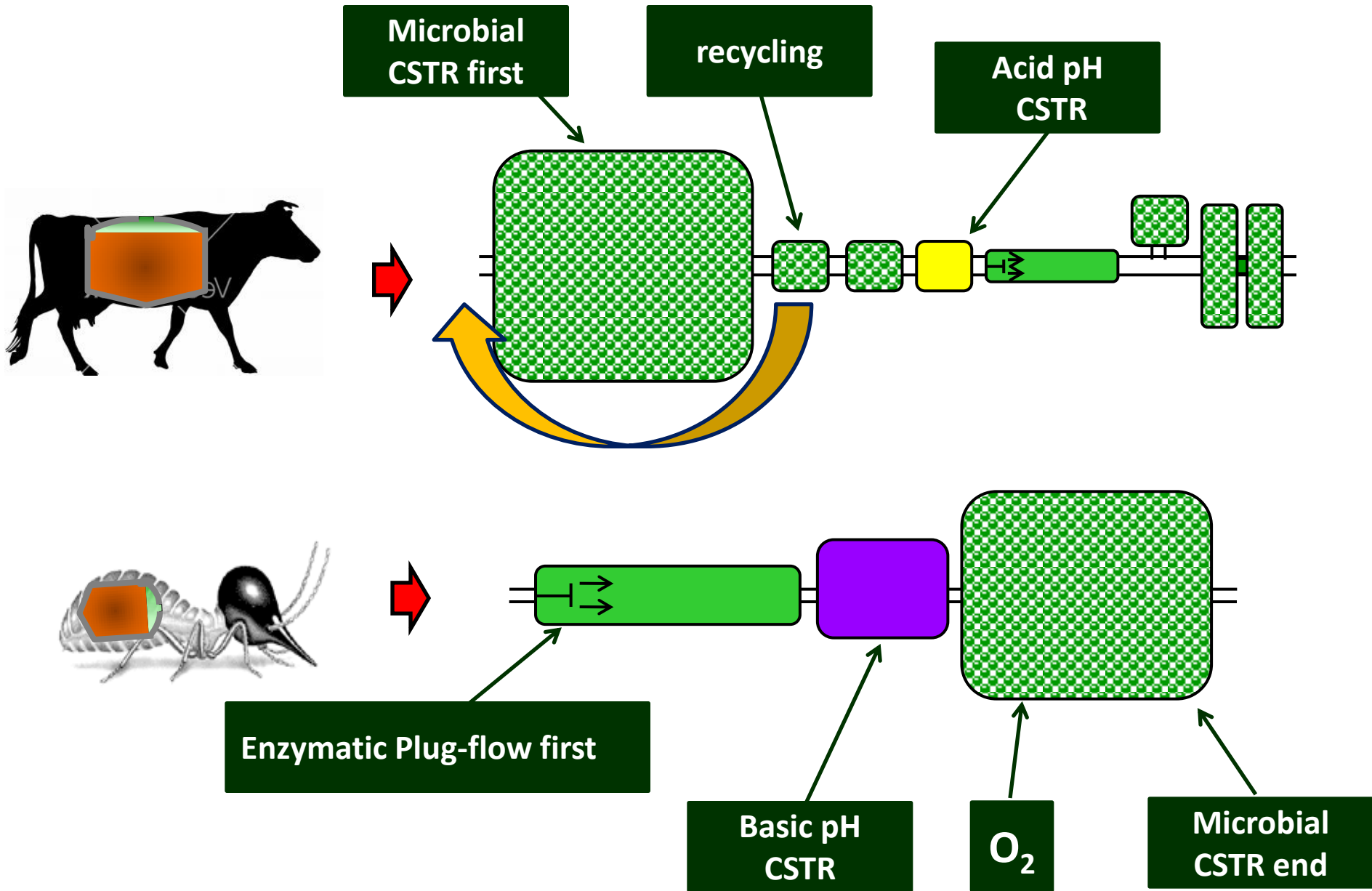
## Our current research



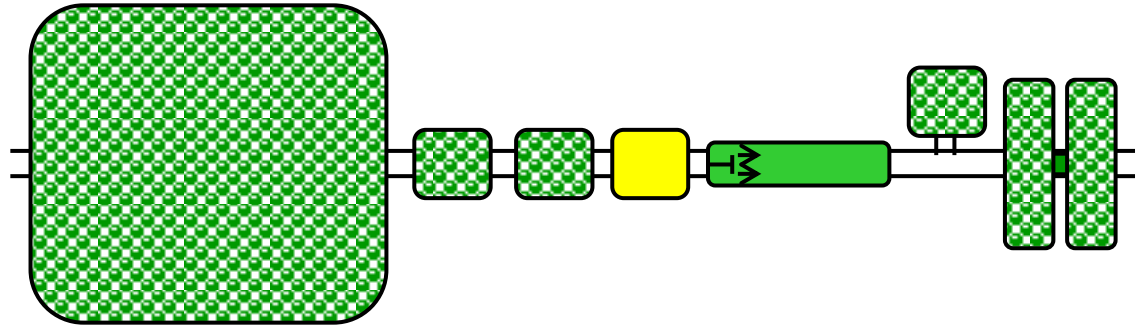
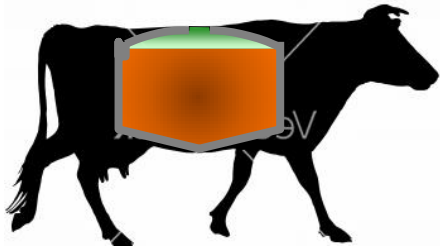
**Mandibles:**  
mastication -> accesibilité



# Our current research



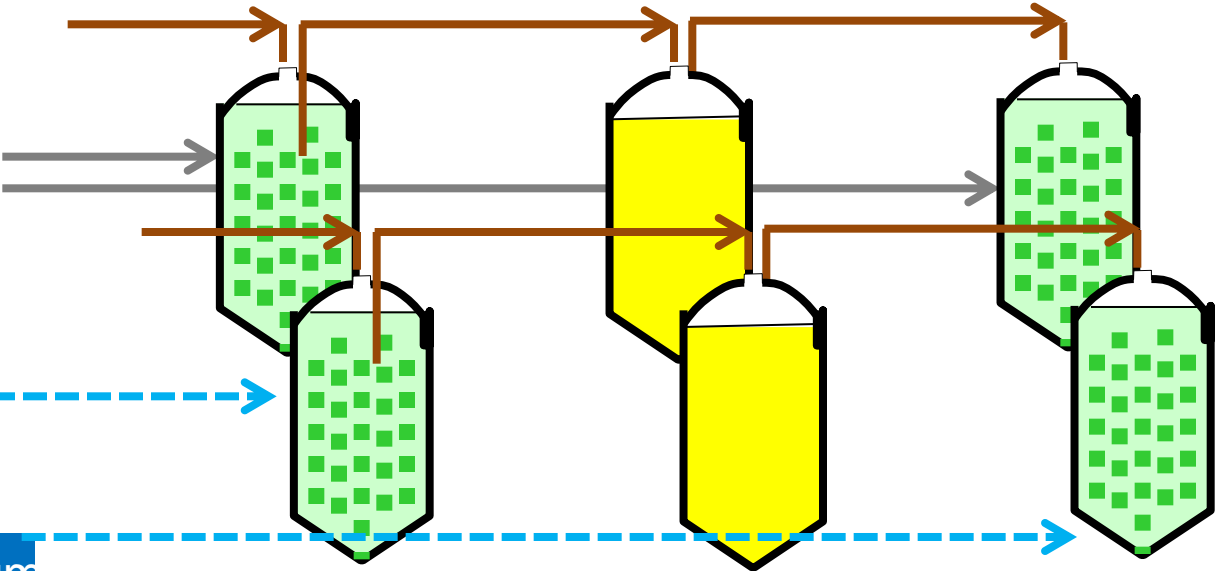
# Cow mimicking reactor parameters



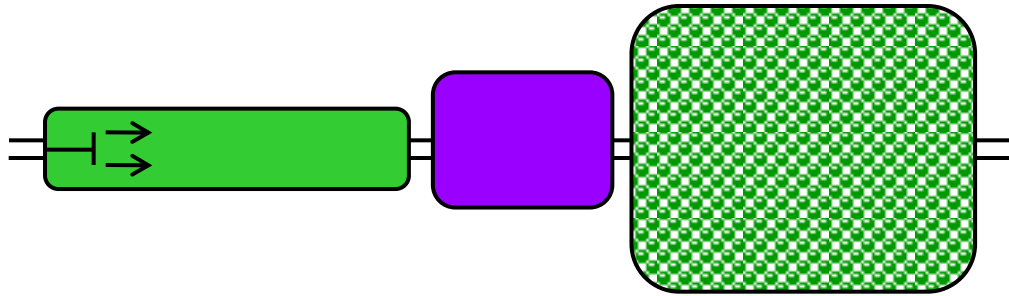
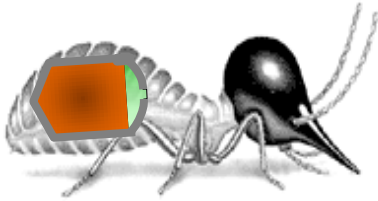
Inoculum wastewater sludge

Rumen as inoculum

Feces as inoculum

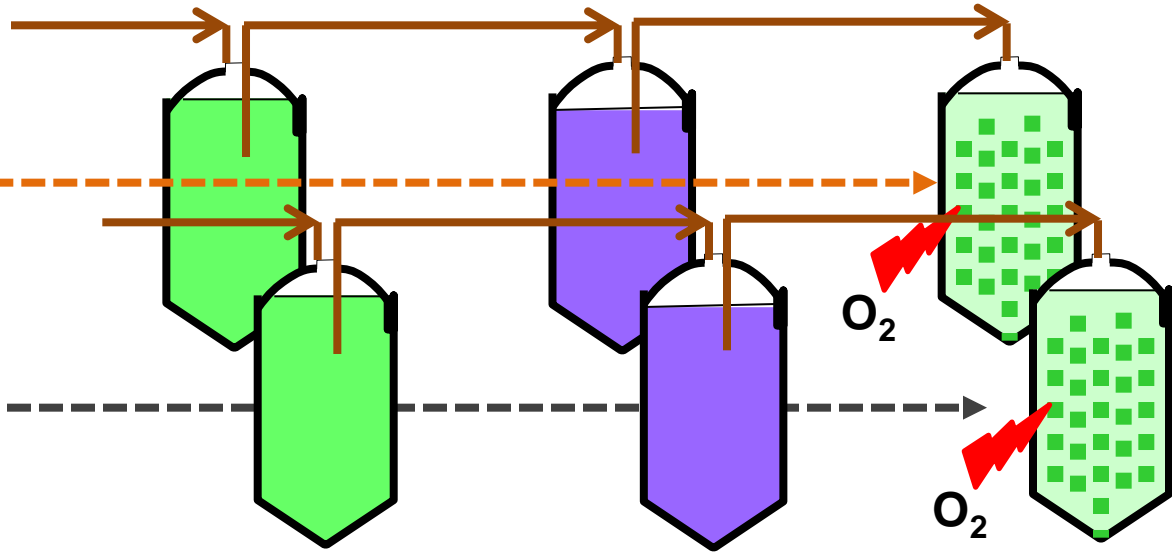


# Termite mimicking reactor parameters





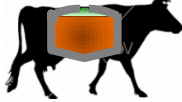

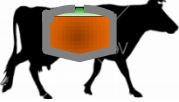
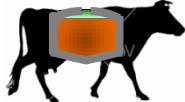






Inoculum digested  
wastewater sludge

Termite as inoculum



# Summary of the preliminary results

Type of process	Origin of microbe	Methane NmL/g <sub>MVS</sub>	Treatment efficiency
Industrial 	Activated sludge 	150-350	30-40%
Lab scale references 	Activated sludge 	189 (cow ref) 154 (termite ref)	36% (cow ref) 31% (termite ref)
Cow mimicking 	Activated Sludge 	343	62%
Cow mimicking 	Cow (rumen and Feces) 	362	61%
Termite mimicking 	Activated sludge 	209	39%
Termite mimicking 	Termite 	in progress	in progress

## The Bio<sup>2</sup>E platform for innovation and industrial transfer

LBE technological competencies	TRL								
	1	2	3	4	5	6	7	8	9
Anaerobic digestion (effluents, solid residues, biomass)	➔	➔	➔	➔	➔	➔	➔	➔	➔
Biological waste-water (pre)treatment	➔	➔	➔	➔	➔	➔	➔	➔	➔
Fermentation (Bio-hydrogene, Bio-hythane)	➔	➔	➔	➔	➔	➔	➔		
Platform molecules & downstream	➔	➔	➔	➔	➔	➔	➔		
Microbial resources management	➔	➔	➔	➔					
Bioelectrochemistry	➔	➔	➔	➔	➔	➔	➔		
Micro-algae valorisation	➔	➔	➔	➔	➔	➔			
Sanitary risk evaluation & control	➔	➔	➔	➔					
Modelling, Instrumentation & control	➔	➔	➔	➔	➔	➔	➔	➔	➔
Life Cycle Analysis & Eco-design	➔	➔	➔	➔	➔	➔	➔	➔	➔

TRL: Technology Readiness Level

# Innovation and Industrial Transfer



- ✓ 8 patents, 11 know-how licencings
- ✓ 6 PhDs paid by companies
- ✓ POLLUTEC-ADEME Innovation Award in 2007, 2009, 2010, 2012, 2013
- ✓ Hosting of industrial partners (Mean « retention time » : 7 years)
- ✓ 54 jobs currently in activity in industry



# Valorization and Industrial Transfer

## The PROVEO process

From lab scale...



... to pilot scale...



... and industrial application



**3 lab scale PROVEO digesters (10 L)**

Optimisation of operating conditions and basis for design



**Pilot scale PROVEO process (1 m<sup>3</sup>)**  
Study of the scale-up



**Industrial PROVEO process (50 m<sup>3</sup>)**  
For dairy effluents



# Valorisation of a patent: the “Naskeo Environnement” company (2005)



40 people in 2014, 9 M€ budget, 10 % of the digesters sold in France, R&D in Narbonne

## A spin-off of the LBE



### Technological offers



#### From the « catalogue »

- Analysis and characterisation of pollution, biodegradability, microbial biodiversity (PCR-SSCP),...

#### Dedicated studies

- Feasibility at lab or pilot scales
- Monitoring of microorganisms in their environment
- Consulting for industrial plants
- ...



### Tertiary offers

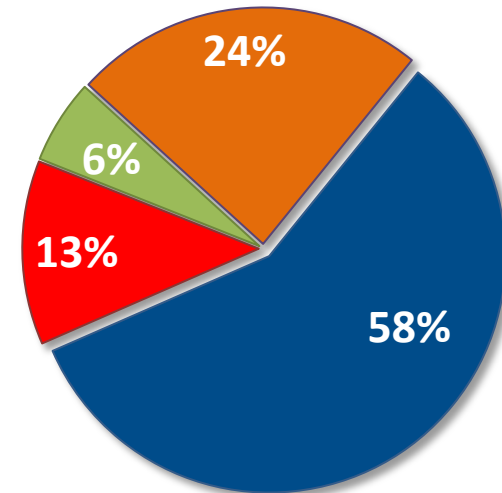
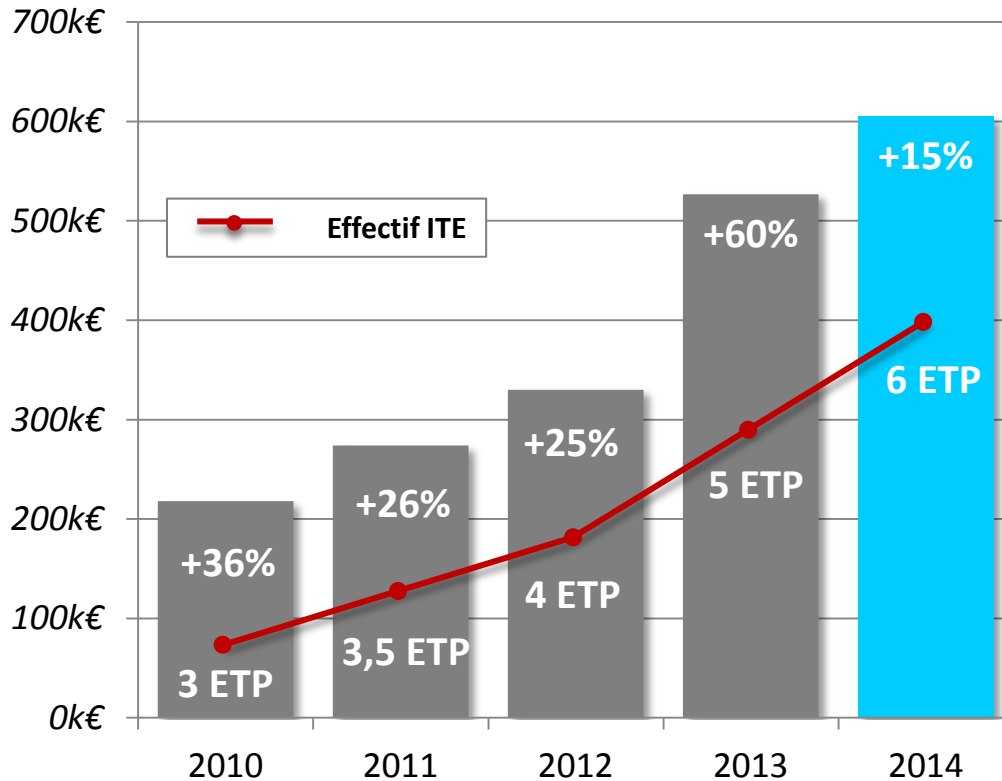


#### Teaching, training

- Teaching of technical staffs
- Organization of dedicated training days
- Bibliographic reviews
- Project management

# INRA Transfert Environnement (IT-e)

## A spin-off of the LBE



- Bioprocédés
- Microbiologie
- Projets
- Colloques

**INRA TRANSFERT ENVIRONNEMENT**  
**NOUVELLES PRESTATIONS EN**  
**MICROBIOLOGIE MOLECULAIRE**

*L'analyse microbiologique de vos échantillons environnementaux*  
**Air, Eaux, Sites et Sols pollués, Surfaces, Effluents, Résidus, Bioprocédés, Agro-alimentaire**

**Collecter et conserver**  
 (banque d'ADN et ARN)  
 La microflore d'échantillons très variés : Air, bégas, eaux, sols pollués, boues, déchets, composts, biofilms, matériaux de construction et de décoration ...

**Identifier par séquençage haut-débit**, les microorganismes présents

**Extraire et amplifier** l'ADN et l'ARN de matrices différentes

**Comparer** les échantillons sur la base de la diversité bactérienne, eucaryote et archéale par un outil d'empreinte moléculaire (CE-SSCP) et par séquençage haut débit

**Mesurer** la diversité microbienne d'un échantillon par des calculs d'indices de diversité et de richesse

**Mesurer par PCR quantitative en temps réel**, les concentrations en micro-organismes totaux : bactéries, eucaryotes, archées...

**Mesurer par PCR et RT-PCR quantitative en temps réel**, les concentrations de groupes microbiens spécifiques, bioindicateurs, gènes de fonction (Legionella, Salmonella, E. coli, Staphylococcus, Clostridium perfringens, Aklk...)

**Caractériser** par bioinformatique les microorganismes identifiés (données sur l'origine, la potentialité de pathogénicité...)


**Observer** les échantillons par microscope optique, épifluorescence, biofilms en stéréomicroscopie...

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Contacts : marina.moletta-denaat@supagro.inra.fr / 04 68 46 64 32 ou romain.oreason@supagro.inra.fr / 04 68 46 64 30  
 www.montpellier.inra.fr/ite/

## Use of infrared spectrometry to predict methane potential (BMP) from solid waste





Process Biochemistry 45 (2010) 431–440

Contents lists available at ScienceDirect

Process Biochemistry

ELSEVIER journal homepage: www.elsevier.com/locate/procbio

Review

Alternative methods for determining anaerobic biodegradability: A review

M. Lesteur<sup>a,\*</sup>, V. Bellon-Maurel<sup>b</sup>, C. Gonzalez<sup>c</sup>, E. Latrille<sup>a</sup>, J.M. Roger<sup>b</sup>, G. Junqua<sup>c</sup>, J.P. Steyer<sup>a,\*</sup>

<sup>a</sup>INRA, UR1050 Laboratoire de Biotechnologie de l'Environnement, Avenue des Etangs, Narbonne F-11100, France  
<sup>b</sup>Commissariat National Supérieur des Universités, UR 1050, 34033 Montpellier Cedex 3, France  
<sup>c</sup>Laboratoire Génie de l'Environnement Industriel, Ecole des Mines d'Alès, 6 avenue de Clavières, 30319 Alès Cedex, France

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Bioresource Technology 102 (2011) 2280–2288

Contents lists available at ScienceDirect

Bioresource Technology


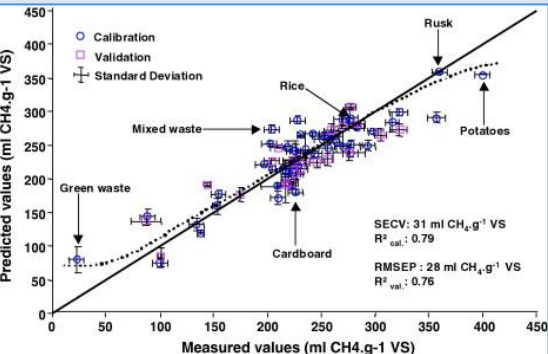

ELSEVIER journal homepage: www.elsevier.com/locate/biortech

First step towards a fast analytical method for the determination of Biochemical Methane Potential of solid wastes by near infrared spectroscopy

M. Lesteur<sup>a,b,c</sup>, E. Latrille<sup>a</sup>, V. Bellon Maurel<sup>b</sup>, J.M. Roger<sup>b</sup>, C. Gonzalez<sup>c</sup>, G. Junqua<sup>c</sup>, J.P. Steyer<sup>a,\*</sup>

<sup>a</sup>INRA, UR1050 Laboratoire de Biotechnologie de l'Environnement, Avenue des Etangs, Narbonne F-11100, France  
<sup>b</sup>Commissariat National Supérieur des Universités, UR 1050, 34033 Montpellier Cedex 3, France  
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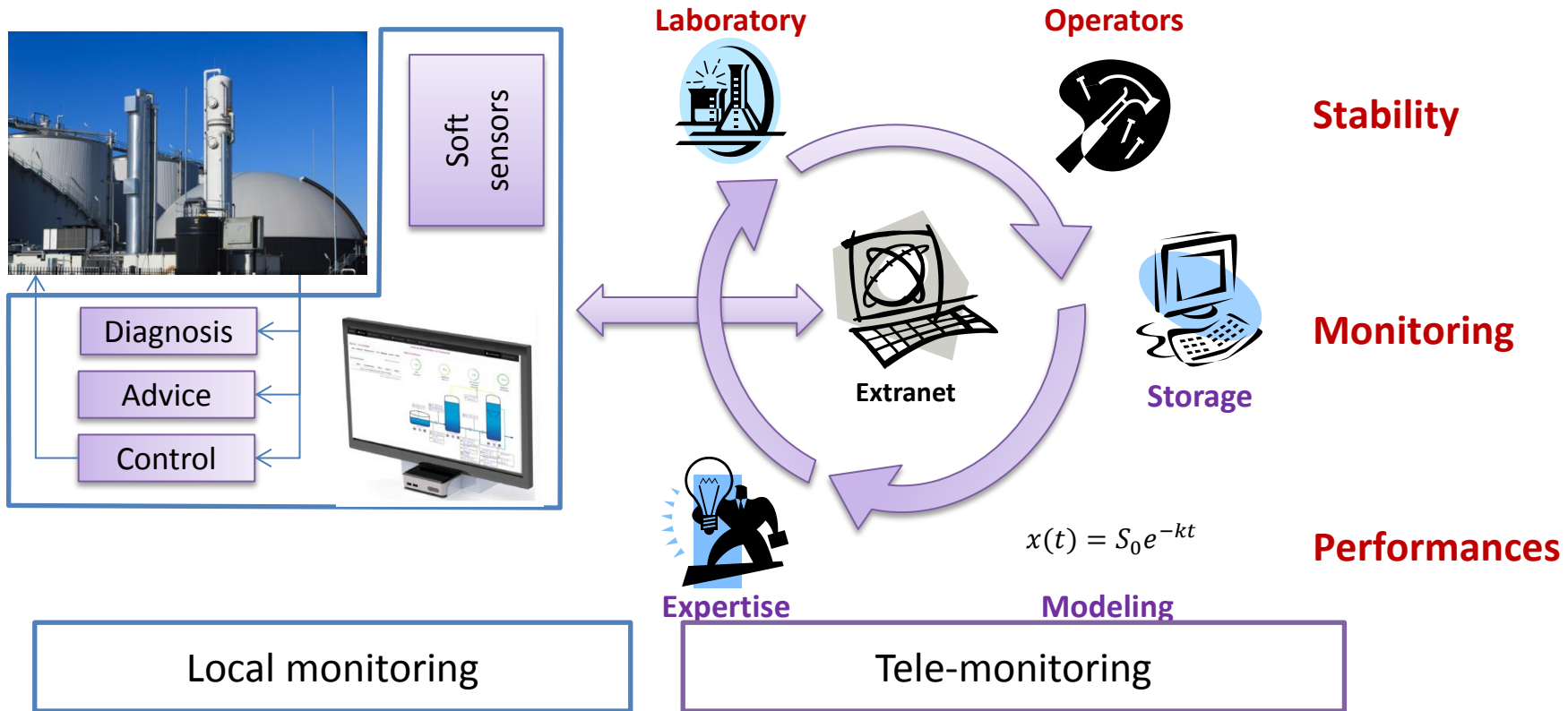
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# To conclude

## My personal view of innovation

- ✓ Imagine and think differently
- ✓ Dare to go for it
- ✓ Don't be afraid to be disappointed



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# Thank you very much for your attention

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**Laboratoire de Biotechnologie de l'Environnement**

Accueil

**Edito**

Le Laboratoire de Biotechnologie de l'Environnement (LBE) situé à Narbonne est une unité propre de recherche de l'Institut National de la Recherche Agronomique (INRA). Concentré d'innovation, le LBE mène des recherches centrées sur le concept de la bioraffinerie environnementale.

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