AgroParisTech
Institute of technology for life, food and environmental sciences

CHAIRE Agro Biotechnologies Industrielles

INRA SCIENCE & IMPACT

Membrane-assisted extractive fermentation for the production of biobased molecules: towards bioprocess intensification

Marwen Moussa, Claire Saulou-Bérion, Violaine Athès , Andreia Teixera, Henry-Eric Spinnler

Joint Unit "Food Process Engineering and Microbiology", INRA-AgroParisTech, Grignon, France

Chair of Industrial Agro-Biotechnology– AgroParisTech, Reims, France

AgroParisTech – general facts

Institut national agronomique Paris-Grignon — 1826

ENGREF — 1824

ensia — 1893

AgroParisTech is the result of the merging of 3 Graduate Institutes in Science and Engineering dating back to the 19th century

AgroParisTech

Institute of technology for life, food and environmental sciences

Founded on January 1st 2007

www.agroparistech.fr

8 campuses

Our 8 campuses nationwide

Key Figures :

- 2 000 students including 450 PhD students
- 230 academic staff
- 300 researchers
- 39 research laboratories

AgroParisTech is deeply involved in Research with its 5 departments :

- Agronomy, Forestry, Water and Environment
- Life Science and Health
- **Science and engineering for Food and Bioproducts**
- Modelling: Mathematics, Informatics and Physics
- Social Sciences, Economics and Management

Research Unit: Food Process Engineering and Microbiology

→ **Research and teaching missions related to the engineering of agricultural, food and biological product transformations**

→ **Joint Research Unit between INRA & AgroParisTech**

4 multidisciplinary research teams
5 support platforms

bioproducts, food, microorganisms and processes
BioMiP

cheese microbial ecosystems
EcoMic

food digestion perception
ADP

modeling of food and biological complex systems
MALICES

Support platform: Administrative coordination, maintenance.

Engineering and instrumentation platform

Analyses platform

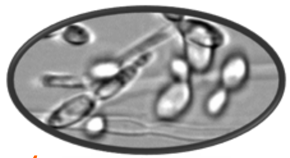
Software platform

Transfer

Integrated Approach

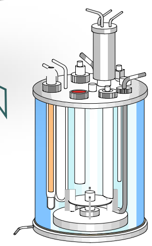
Scales of study

- Molecular
- Cellular
- Population
- Medium-Matrix
- Process
- System



Yeast

Bacteria



Growth

Bioconversion

Micro-organism’s physiology
Process operating conditions

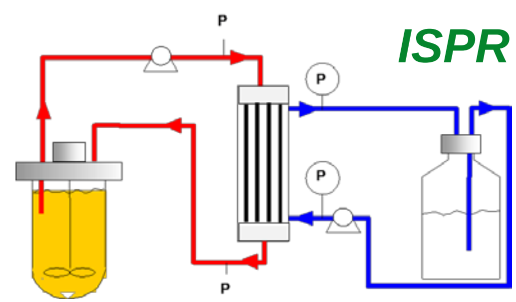
Stabilization

Freeze drying
Freezing
. . . Drying

STABLE ferment
made in GMPA

Extractive Bioconversion

ISPR



Extraction : membrane contactors, pervaporation, permeation

Optimized bioprocesses

Improved / stabilized functionalities

Chair of Ago-Industrial Biotechnology AgroParisTech

Belongs to the European Institute of Biorefinery, Pomacle

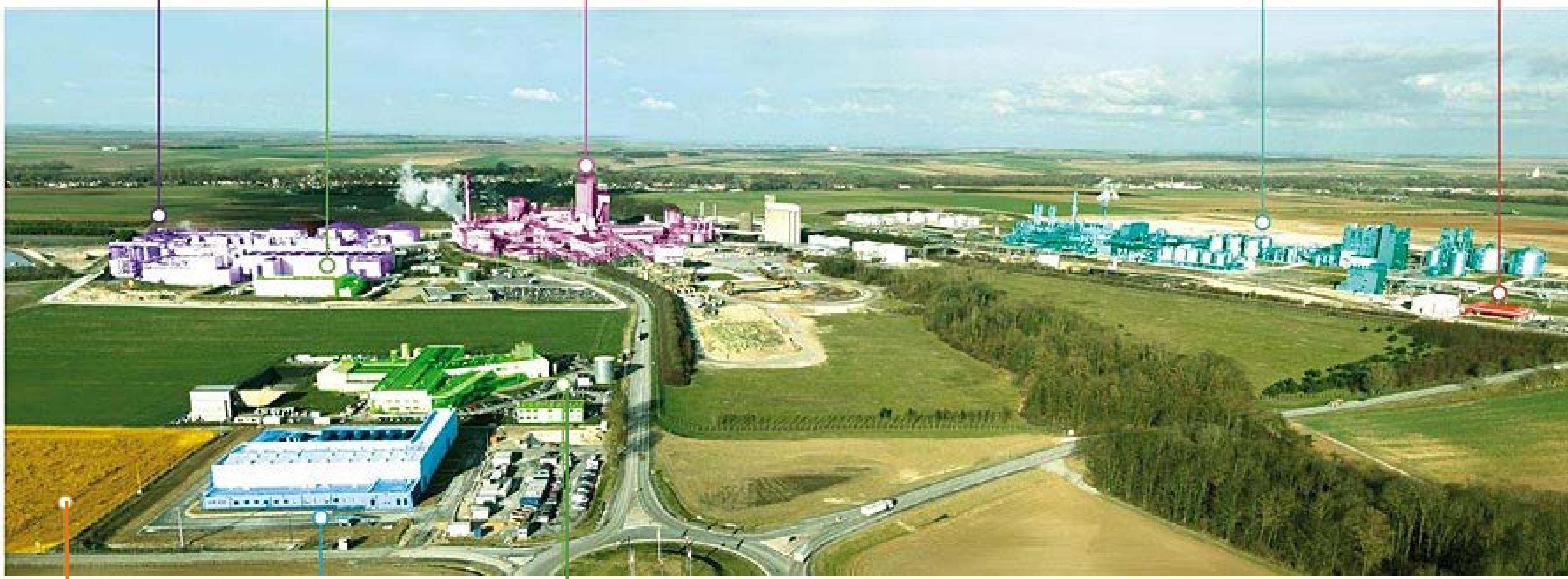
BioDemo
Pilot scale demonstration unit

Chamtor
Glucosery

Cristal Union
Sugar refinery

Cristanol
1^{st} generation distillery

Air Liquide



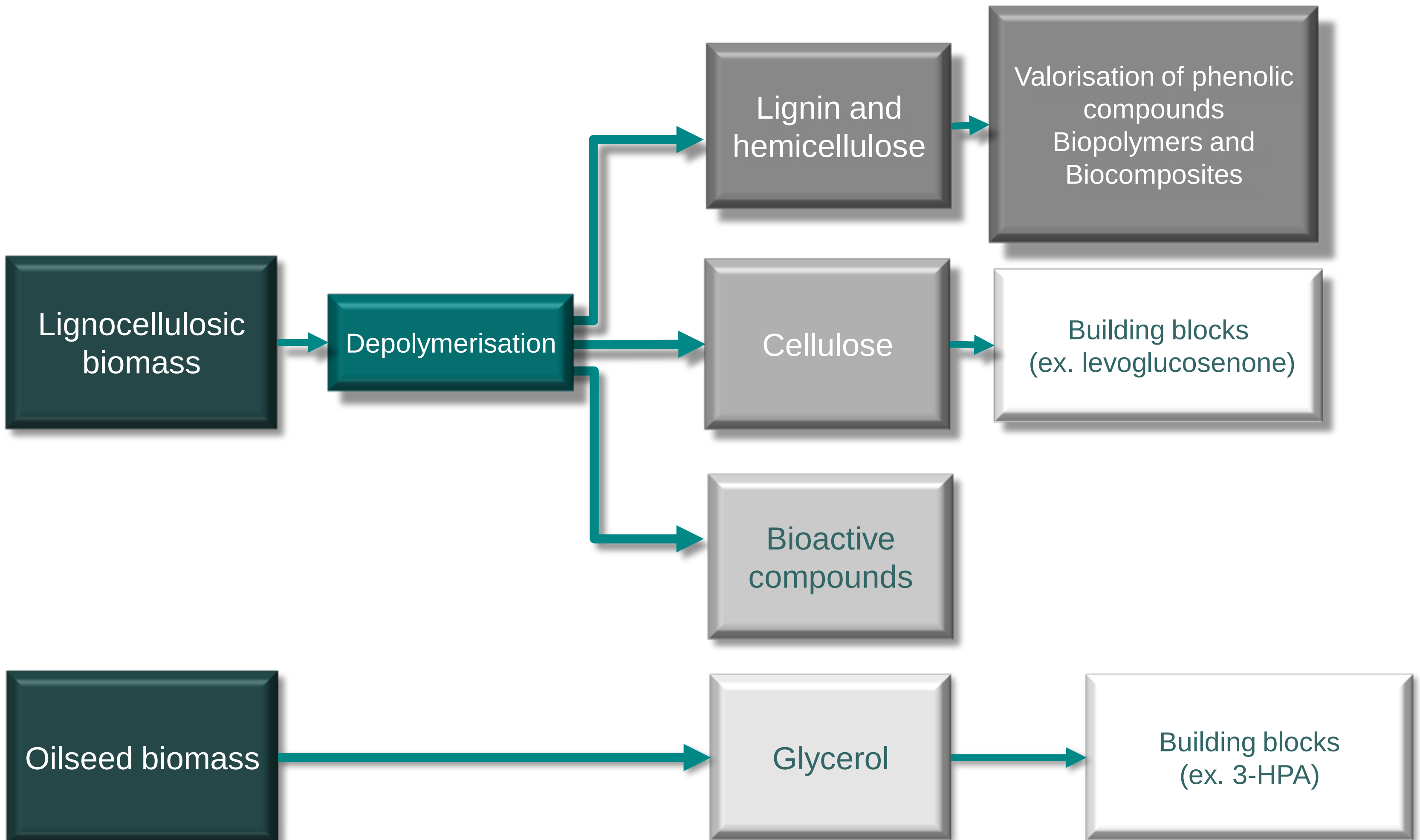
Procethol 2G – Futurol
2^{nd} generation biofuels
Pilot scale demonstration unit

ARD Private Research Centre
Soliance Biobased cosmetics
Wheataleo Biobased surfactants

CEBB (European Center of Biotechnology and Bioeconomy)
Public Research Center

CHAIRE Agro Biotechnologies Industrielles

- **Valorization** of **agro-resources** and **byproducts streams**
- **Synthesis** and/or **purification** of new and value-added molecules
- **Substitution** of petroleum-based molecules → **Biobased molecules**



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Institute of **technology for life**, **food**
and **environmental sciences**

CHAIRE Agro Biotechnologies Industrielles

INRA SCIENCE & IMPACT

the team

Prof. C. BEAL

Prof. F. ALLAIS

Prof. V. ATHES

Prof. H.E. SPINNLER

Ass. Prof. C. SAULOU-BERION

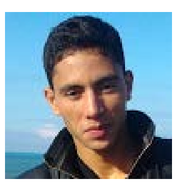
Prof. M. BOUIX

PhD Student F. CHEMARIN

PhD Student G.BURGE

PhD Student A. KALANTARI

Msc. Student R. BOUNADER



Msc. Student M. CHADNI

Ing. A. FLOURAT

Ing. B. POLLET

Tech. J. DELETTRE

Ing. S. GHORBAL

Downstream processing in biorefining and white biotechnology

Agro-Ressources, agrowastes

Pre- treatment: mechanical, chemical, enzymatic, microbial

Separation

By-products

Fermentation / Conversion

Separation- purification

By-products

Transformation and value creation

REVERSE-INGENIERIE

<u>Separation</u> : 40 to 70% of investment and operating costs in bio-industries*

**Ramaswamy et al., 2013*
Humphrey et Keller, 2001

Downstream processing in biorefining and white biotechnology

Obtaining a bio-based molecule:

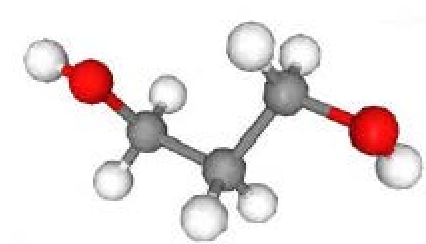
Renewable feed-stock

Chemical catalysys

Biocatalysis

Fermentation

Target molecule



What is expected

Adapted from Boissier (NOVASEP2013)

Downstream processing in biorefining and white biotechnology

Obtaining a bio-based molecule:

Renewable feed-stock

Chemical catalysys

Biocatalysis

Fermentation

Target molecule in water medium

+ Substrate & nutrients
+ by-products
+ Cell biomass
+ Proteins
+ Salts…

What is obtained…

Need for selective processes, adapted to complex media

Need for intensification through process integration

Adapted from Boissier (NOVASEP2013)

Integrated fermentation and separation for process intensification

Highlight 1: Pervaporation and vapor permeation for the *in situ* recovery and purification of bio-alcohols

Highlight 2: Membrane contactors for the *In situ* reactive extraction of organic acids

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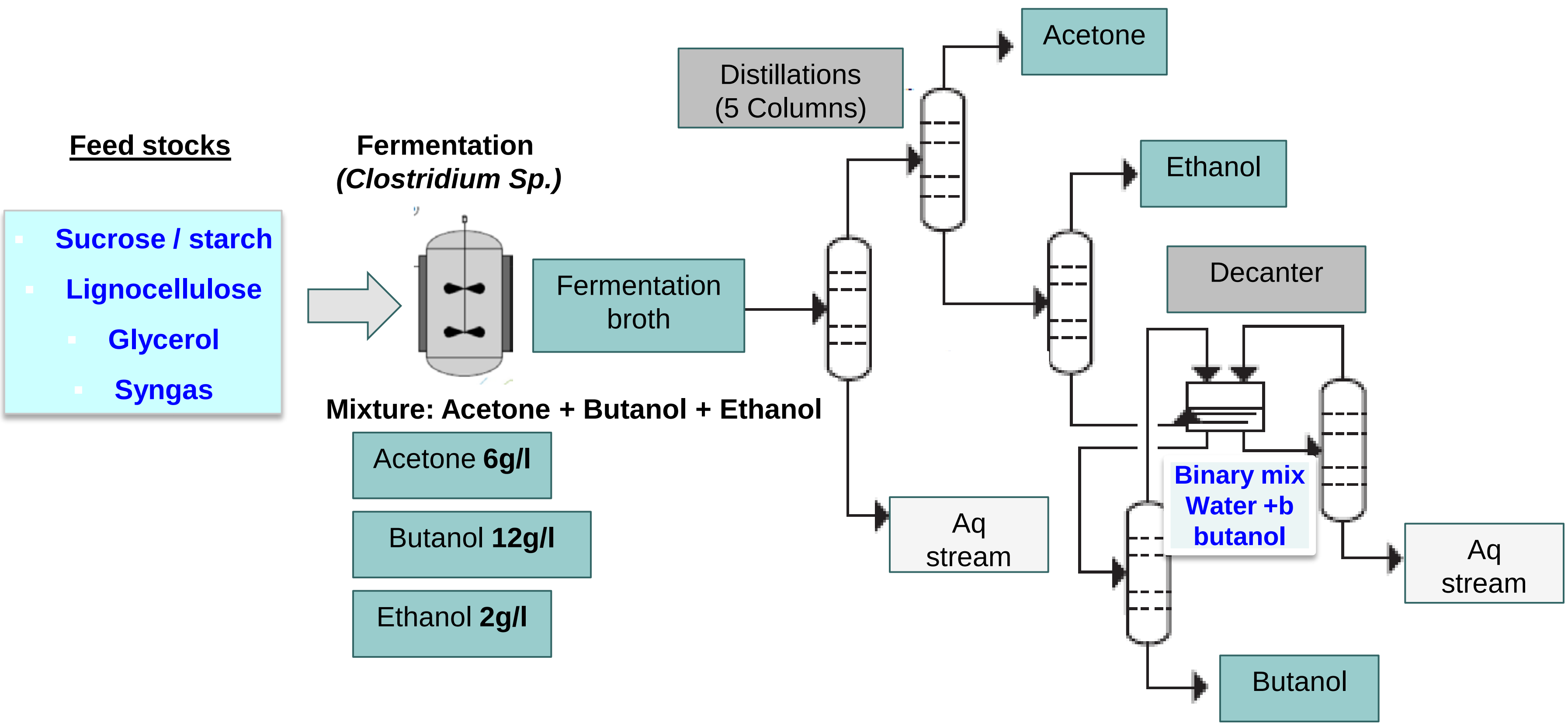
Biobutanol conventional process

Based on several classical distillation steps



High energy consumption

High water footprint

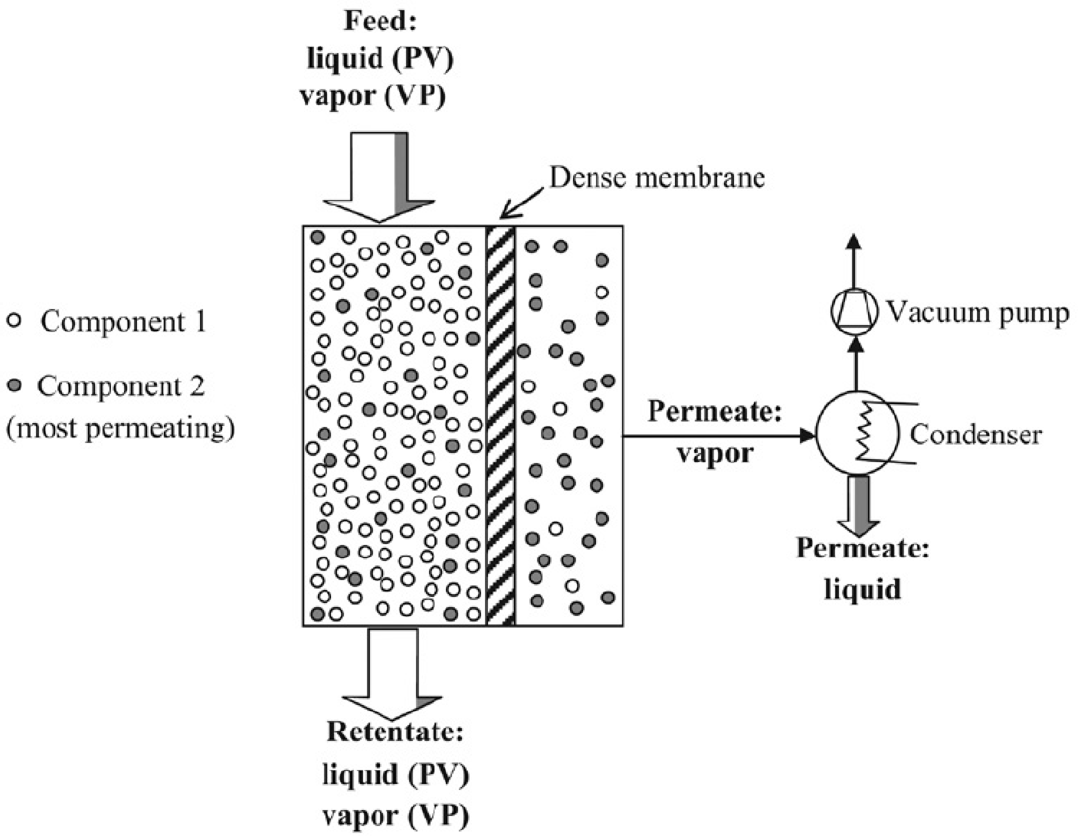
Non-flexible process

A.B. van der Merwe et al. / Fuel 105 (2013) 451–458

Alternative process

Basic principles :

Pervaporation (PV) vs VP (Vapor permeation)



Schematic Diagram of PV and VP Principles where a Vacuum Pump is Operating on the Permeate Side

Athès, **Moussa** & Souchon, 2015a

Alternative process

ISPR of ABE using hydrophobic pervaporation: <u>proof of concept</u>

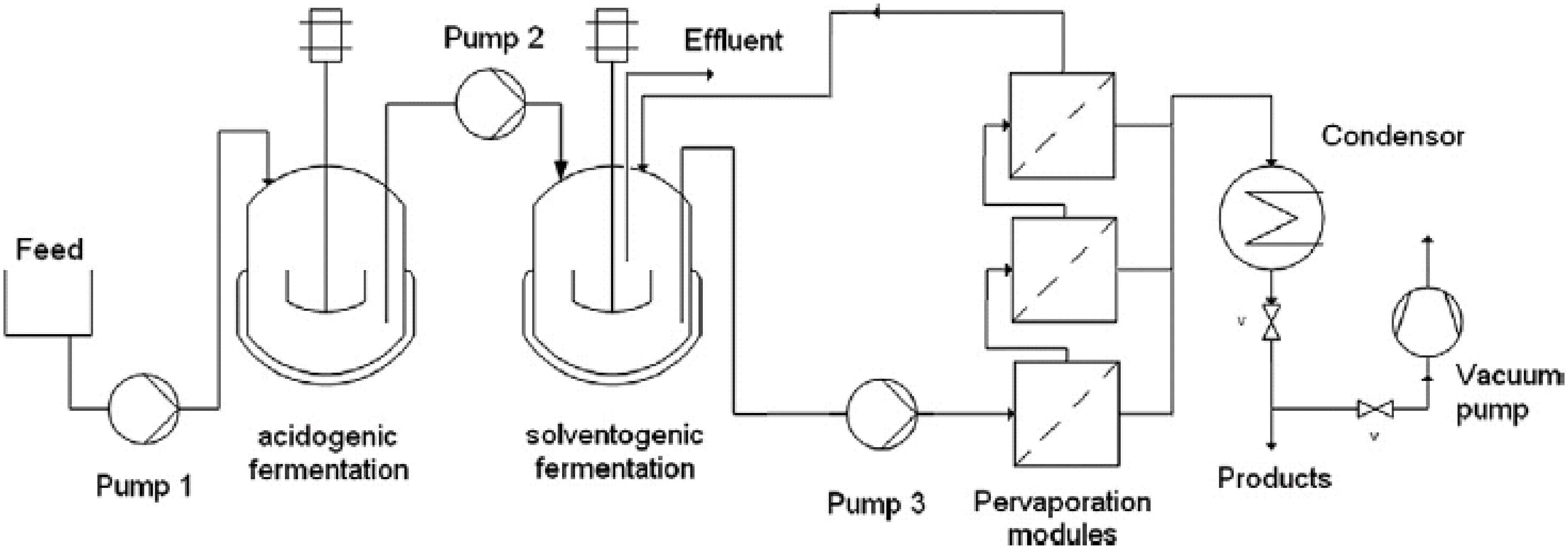
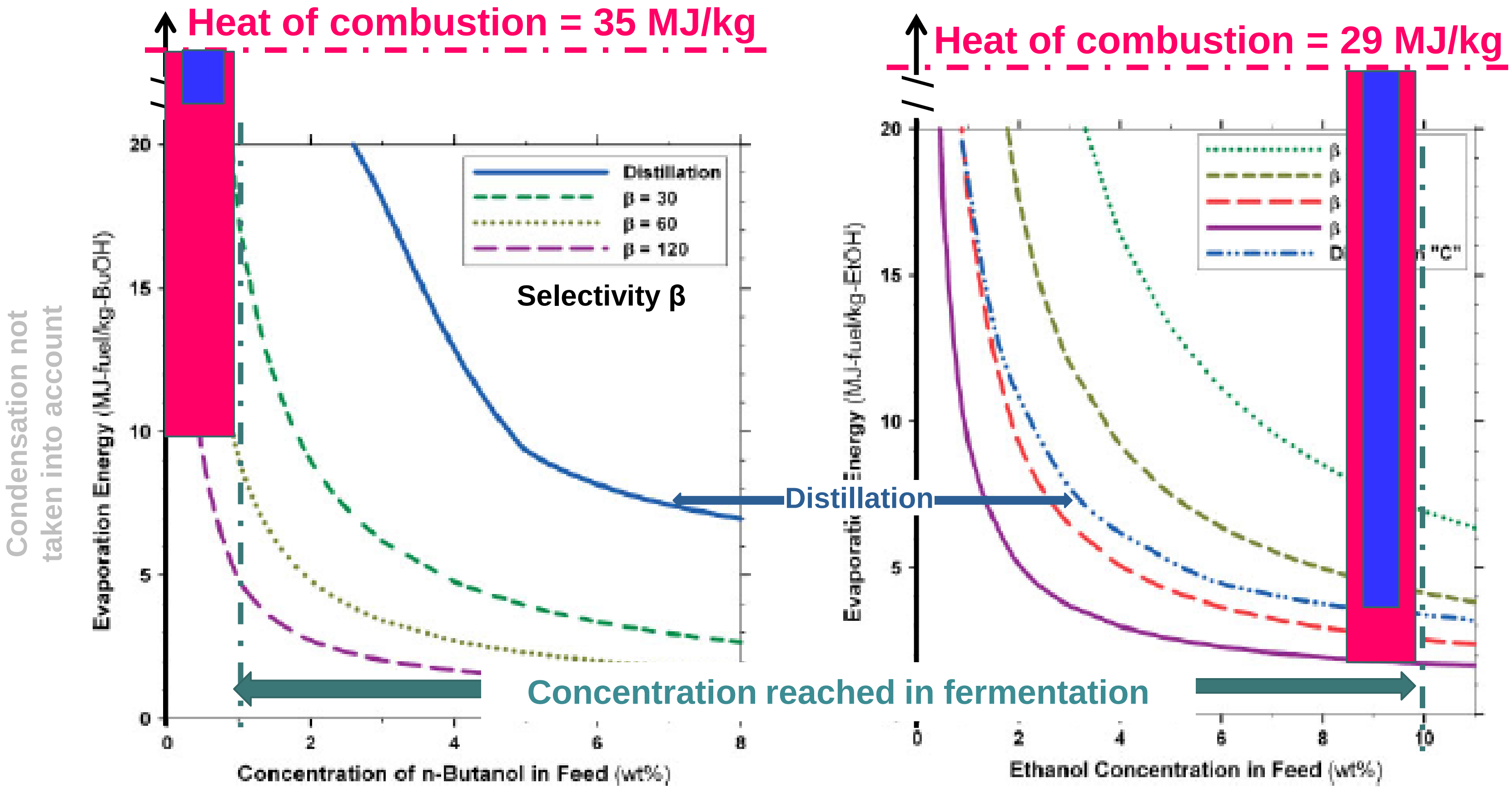


Fig. 1. Schematic of a two-stage ABE fermentation integrated with a pervaporation unit. Arrows show the direction of liquid flow.

(Van Hecke et al, 2012)

Alternative process vs Conventional process

ISPR of ABE using hydrophobic pervaporation: energy considerations



Butanol 99,9% w/w

Ethanol 94% w/w

Pervaporation = promising for butanol and 2G ethanol recoverory

Leland M.V. *in Biofuels, Bioproducts & Biorefining* (2008)

Bioethanol dehydration for gasoline mix using hydrophilic pervaporation

NF EN 15376 : 2008-03

Propriété	Unités	Limites	
		Minimum	Maximum
Teneur en éthanol+alcools supérieurs saturés	% (m/m)	98,7	
Teneur en mono-alcools supérieurs saturés (C3-C5)	% (m/m)		2,0
Teneur en méthanol	% (m/m)		1,0
Water content	**% (w/w)**		**0.3**
Teneur en chlorures minéraux	mg/l		20,0
Teneur en cuivre	mg/kg		0,100
Acidité totale (exprimée en teneur en acide acétique)	% (m/m)		0,007
Apparence		Clair et limpide	
Teneur en phosphore	mg/l		0,50
Teneur en produits non volatils	mg/100ml		10
Teneur en soufre	mg/kg		10,0

Bioethanol dehydration for gasoline mix using hydrophilic pervaporation

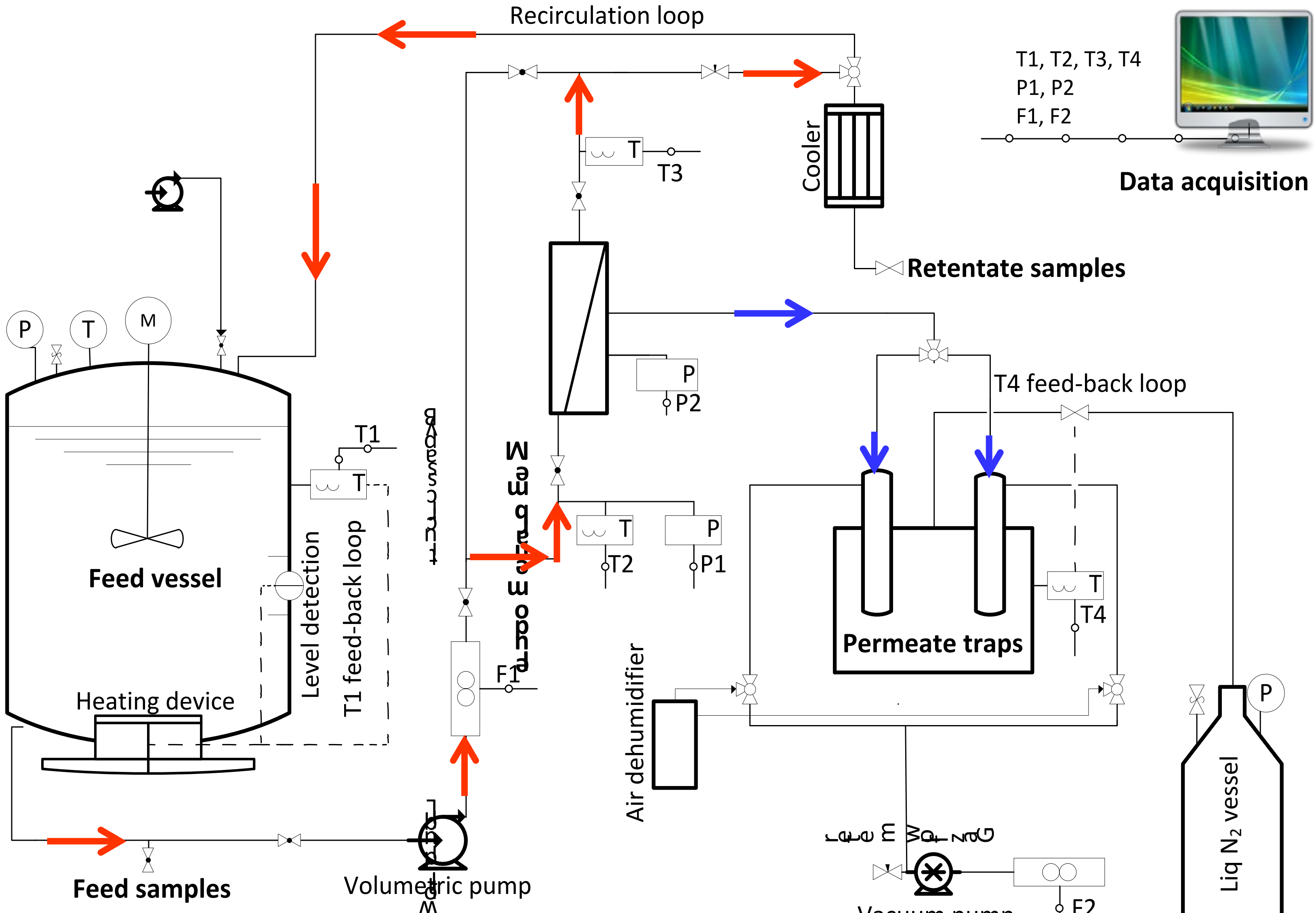
Bioethanol dehydration using pervaporation : interesting alternative to traditional processes (azeotropic distillation and molecular sieves)

Extensive works have been focused on the development of **membranes with optimized flux and selectivity**

Little is known about membrane performances in the case of (**complex bioethanol, including 2G**)

Study the effects of VOCs impurities on mass transfer mechanisms & process performances

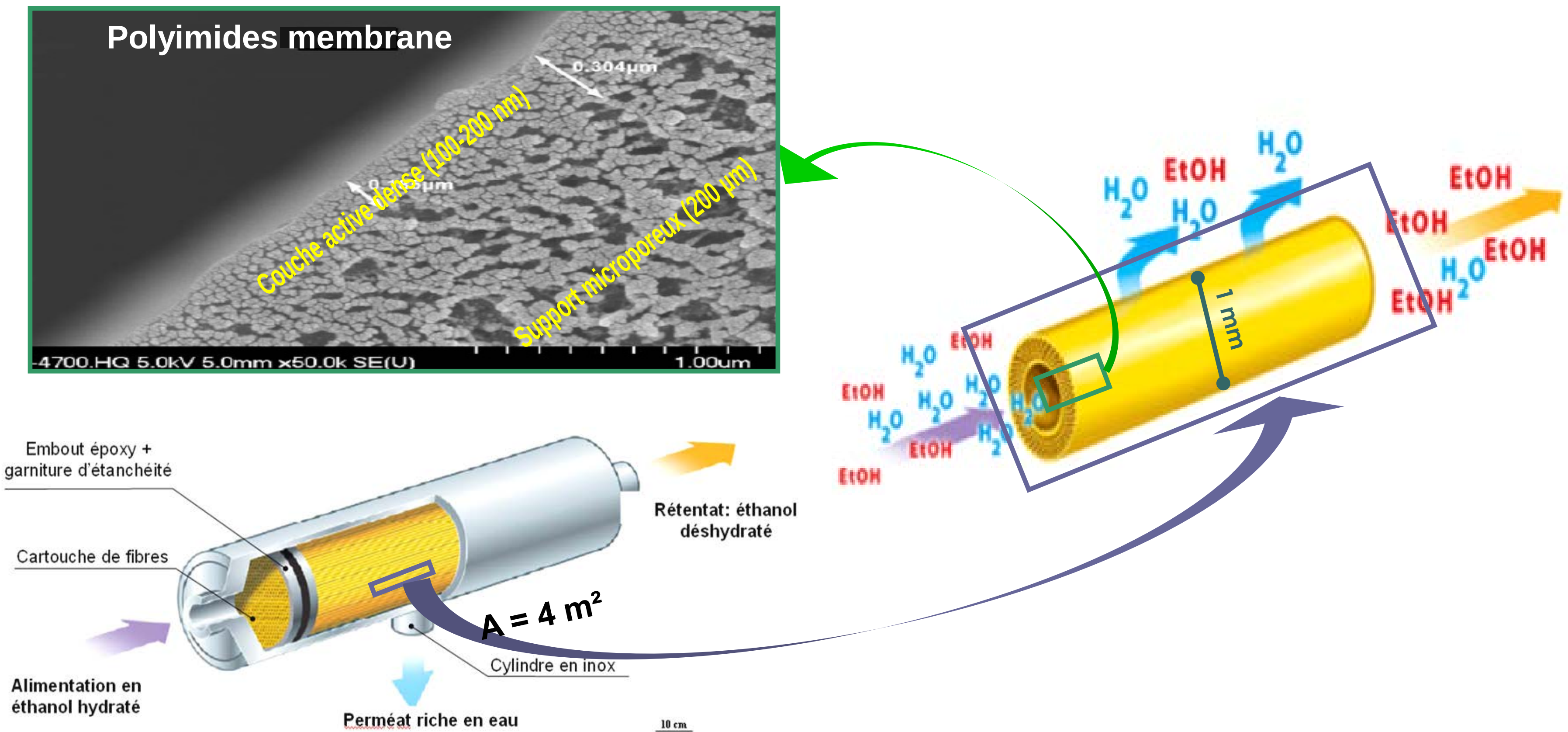
Bioethanol dehydration for gasoline mix using hydrophilic pervaporation



Experimental set-up for hydrophilic pervaporation (Moussa et al, 2015a)

Bioethanol dehydration for gasoline mix using hydrophilic pervaporation

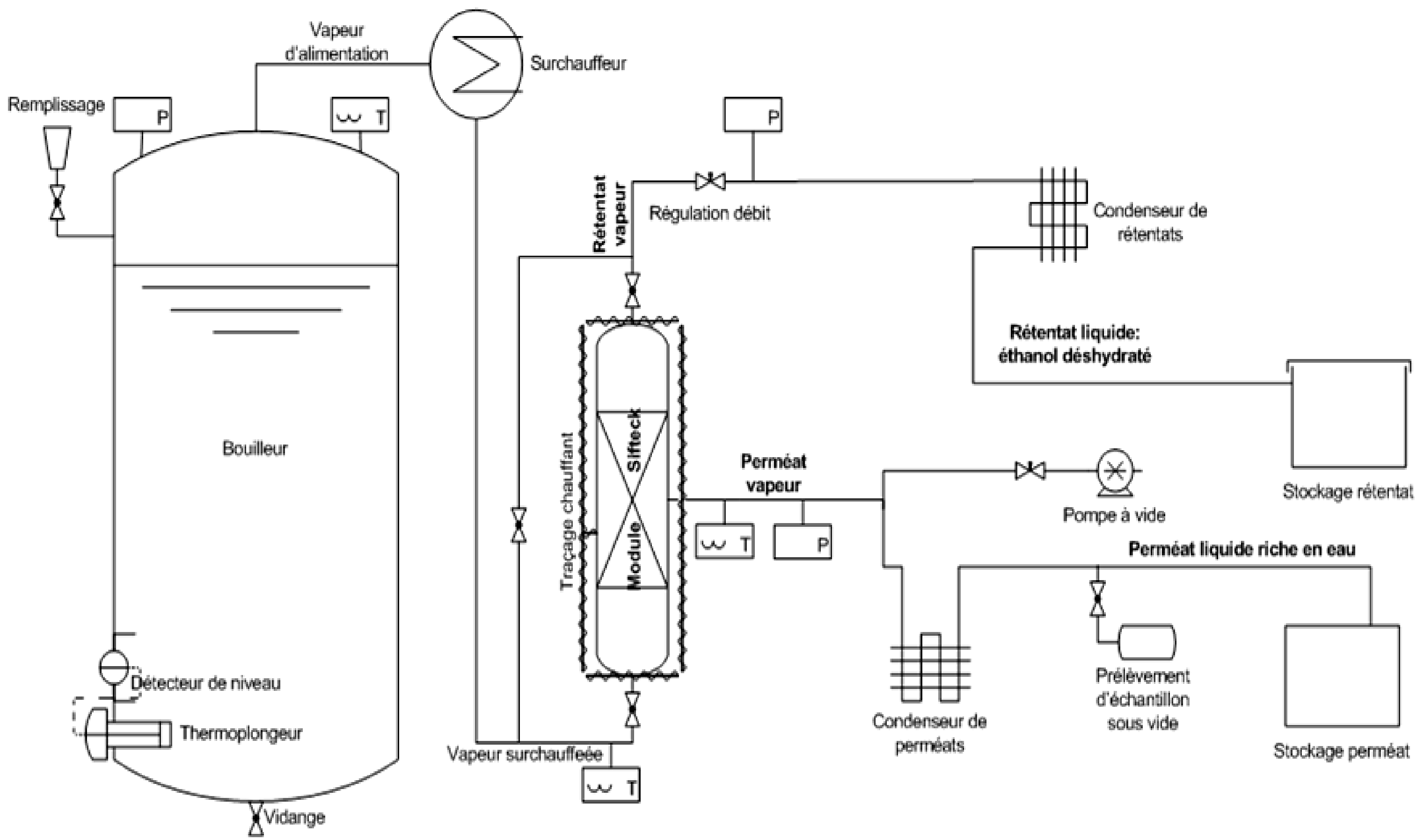
Experimental set-up for hydrophilic vapor permeation (Moussa et al, 2013)



Sifteck® technology

Bioethanol dehydration for gasoline mix using hydrophilic pervaporation

Experimental set-up for hydrophilic vapor permeation (Moussa et al, 2013)



Sifteck® technology

Bioethanol dehydration for gasoline mix using hydrophilic pervaporation

Experimental set-up for hydrophilic vapor permeation (Moussa et al, 2013)

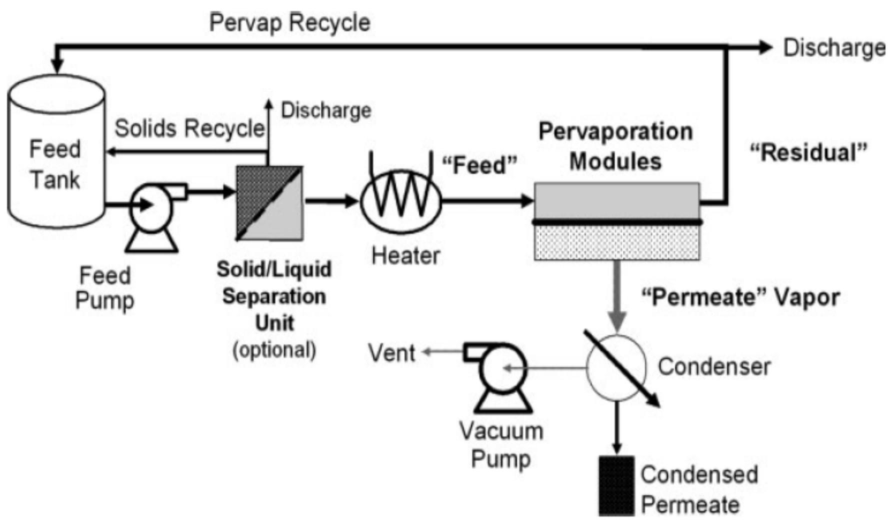
50 cm

Pilot plant, INRA, Paris

Highlight 1 outcomes

Efficiency proven at:

- The technical level (feasibility, scaling-up)
- Economic level (50% less energy consumption than conventional processes)
- Environmental level (50% less CO_2 emission)
- Continuous and flexible process



Real opportunities for the intensification of bioalcohol fermentation processes (recovery and purification)

Need the active involvement of membrane suppliers

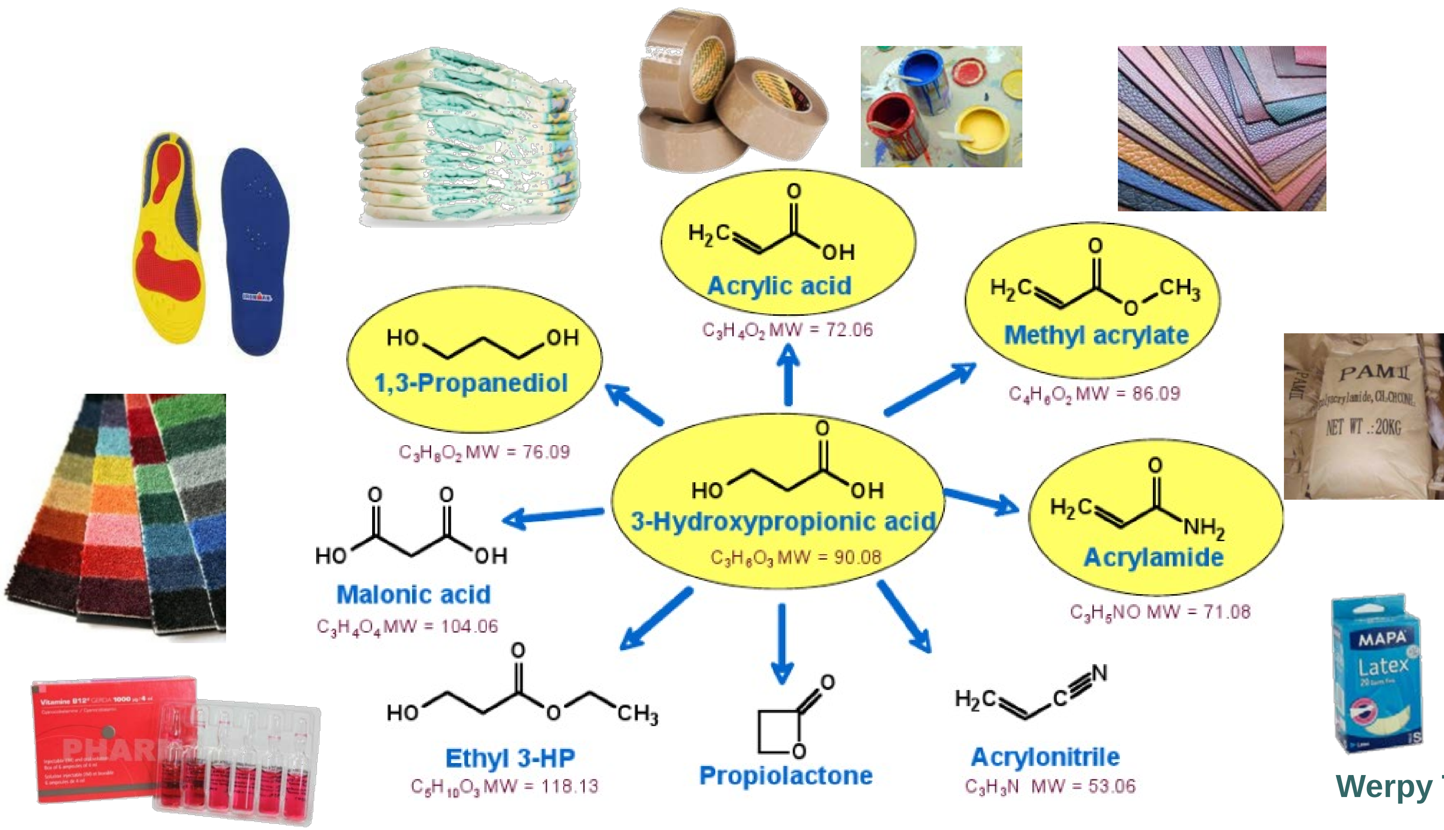
Integrated fermentation and separation for process intensification

Highlight 1: Pervaporation and vapor permeation for the *in situ* recovery and purification of bio-alcohols

Highlight 2: Membrane contactors for the *In situ* reactive extraction of organic acids

Scientific Context

3-hydroxypropionic acid (3-HP): a key platform chemical

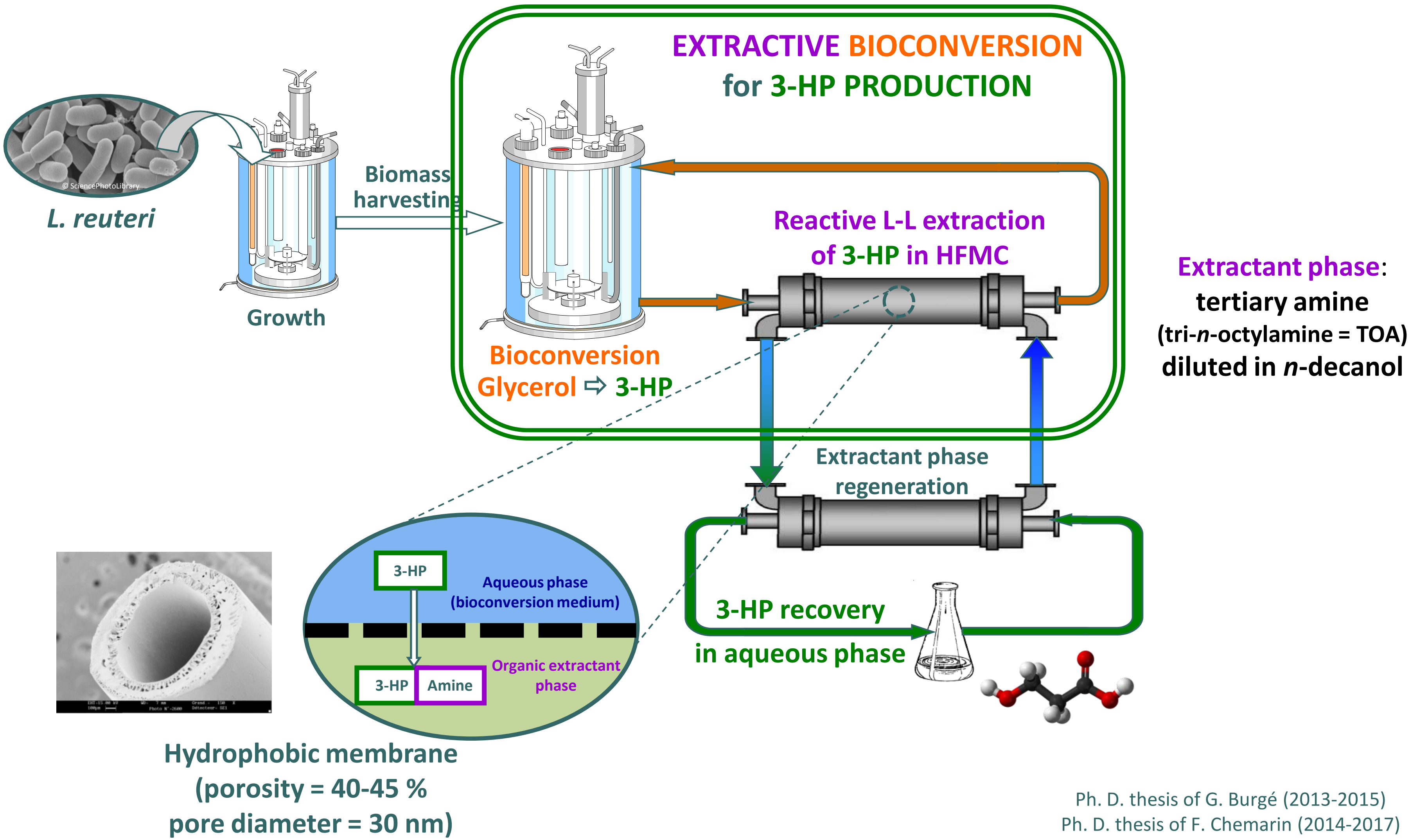


Werpy T. *et al* (2004)

Biotechnology: a promising route for a sustainable production of 3-HP from renewable feedstocks (*e.g.* glycerol bioconversion)

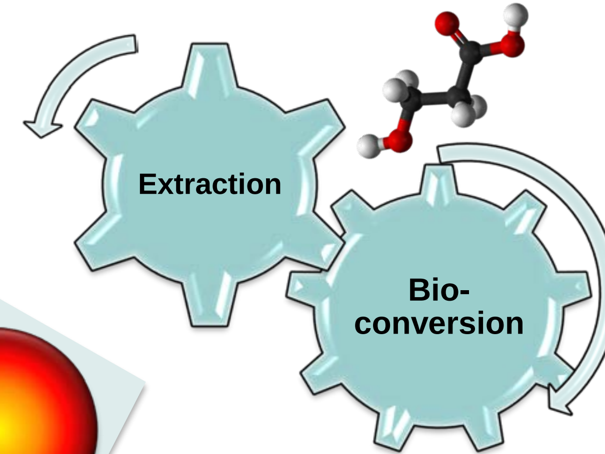
Strategy of the project

Separation Technology: reactive liquid-liquid extraction assisted by hollow-fiber membrane contactors (HFMC)



Ph. D. thesis of G. Burgé (2013-2015)
Ph. D. thesis of F. Chemarin (2014-2017)
Moussa et al (2015a)
Burgé et al (2015 a, b and c)

Highlight 2 outcomes



First experimental study focused on **3-HP** reactive extraction

Effective conditions for the *ISPR* of 3-HP from bioconversion processes were pointed out:
→ **synergistic mixture of TOA and Aliquat 336**

Compromises can easily be found between **bioconversion** and **extraction** operating conditions.

Successful back extraction of 3-HP

Significant decrease of the extraction performances in real bioconversion broth, even if the selectivity remained relatively high

→ Further work is needed to better understand the involved mechanisms

Successful implementation of HFMC

Coordination between upstream and downstream operations

→ Solvent and extractants biocompatibility

General outcomes for the Joint Call Brazil-UE

Section "c": Development of new fermentation and separation technologies for advanced liquid biofuels and applied research to increase the energy efficiency of advanced biofuel processes.

- Interested partners: INRA-AgroParisTech (JRU GMPA) and Chair of IAB
- Other partners can be involved from the INRA and AgroParisTech networks
- Expertise in:
  - fermentation: study and optimization; physiological cell state as a key indicator (flow cytometry)
  - separation: membrane based processes
  - integrated extractive fermentation
  - bioethanol and biobutanol extractive fermentation
  - green chemistry through the valorization of lignocellulosic and oilseeds oil valorization

Thank you for your attention

Marwen MOUSSA
Maître de Conférences / Associate Professor, Ph.D.
marwen.moussa@agroparistech.fr
marwen.moussa@grignon.inra.fr
Tel. : +33 (0)1 30 81 54 39
Fax : +33 (0)1 30 81 55 97
UMR782 GMPA Génie et Microbiologie des Procédés Alimentaires
Food Process Engineering and Microbiology
Key words: BioProcess Engineering, Separation, Membranes
Bat CBAI AgroParisTech, 1, rue Lucien Brétignières
78850 Thiverval Grignon, France
http://www6.versailles-grignon.inra.fr/gmpa
http://www.agroparistech.fr
http://www.chaire-abi-agroparistech.com

Short Biography:

Dr. Eng. Marwen MOUSSA is Associate Professor (Maître de Conférences) in AgroParisTech (Institute of Technology for Life, Food and Environmental Sciences) in the field of bioprocess engineering and biorefining-green chemistry. He obtained a Ph.D. in process engineering from AgroSup Dijon (University of Burgundy-France) in 2009 and belongs to the INRA-AgroParisTech Joint Research Unit "Food Process Engineering and Microbiology" based in Grignon-France. Being a member of the "BioMiP" team (Bioproducts, food, Microorganisms and Processes), his multidisciplinary research activities deal with integrated membrane-based processes in white biotechnology: *in situ* product recovery and purification of bioalcohols, biobased organic acids and aroma compounds. The general aim of these activities is the sustainable transformation of agro-resources through the rationalised management of fermentation and separation processes.

Significant projects:

2016-2017: «Development of a new extractive fermentation process for n-butanol production at high concentration, yield and productivity». 3BCAR Carnot Institute funding; partnership with the Laboratory of Biosystems and Process Engineering.

2013-2017: «Integrated process of glycerol bioconversion and membrane assisted reactive extraction for 3-hydroxypropionic acid production». Co-funding from the Chair of Industrial Agro-Biotechnology and INRA.

2009-2013: «Bioethanol dehydration using pervaporation and vapor permeation processes». Co-funding from ADEME, INRA, industrial distilleries and equipment suppliers.