Università degli Studi di Napoli Federico II

Dipartimento di Ingegneria Civile, Edile e Ambientale

Dottorato di Ricerca in

Ingegneria dei Sistemi Civili

XXX Ciclo

Anaerobic processes for waste biomass treatment: applications and mathematical modeling

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Tutor

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Outlines

- **Section I**
  - *Introduction*
- **Section II**
  - *Research activities and biorefining examples*
- **Section III**
  - *Achievements and Conclusions*

Introduction

- **What is *waste biomass*?**

- *"The biomass is the biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste."*

Directive 2009/28/EC European Parliament

Introduction

▪ What is *waste biomass*?

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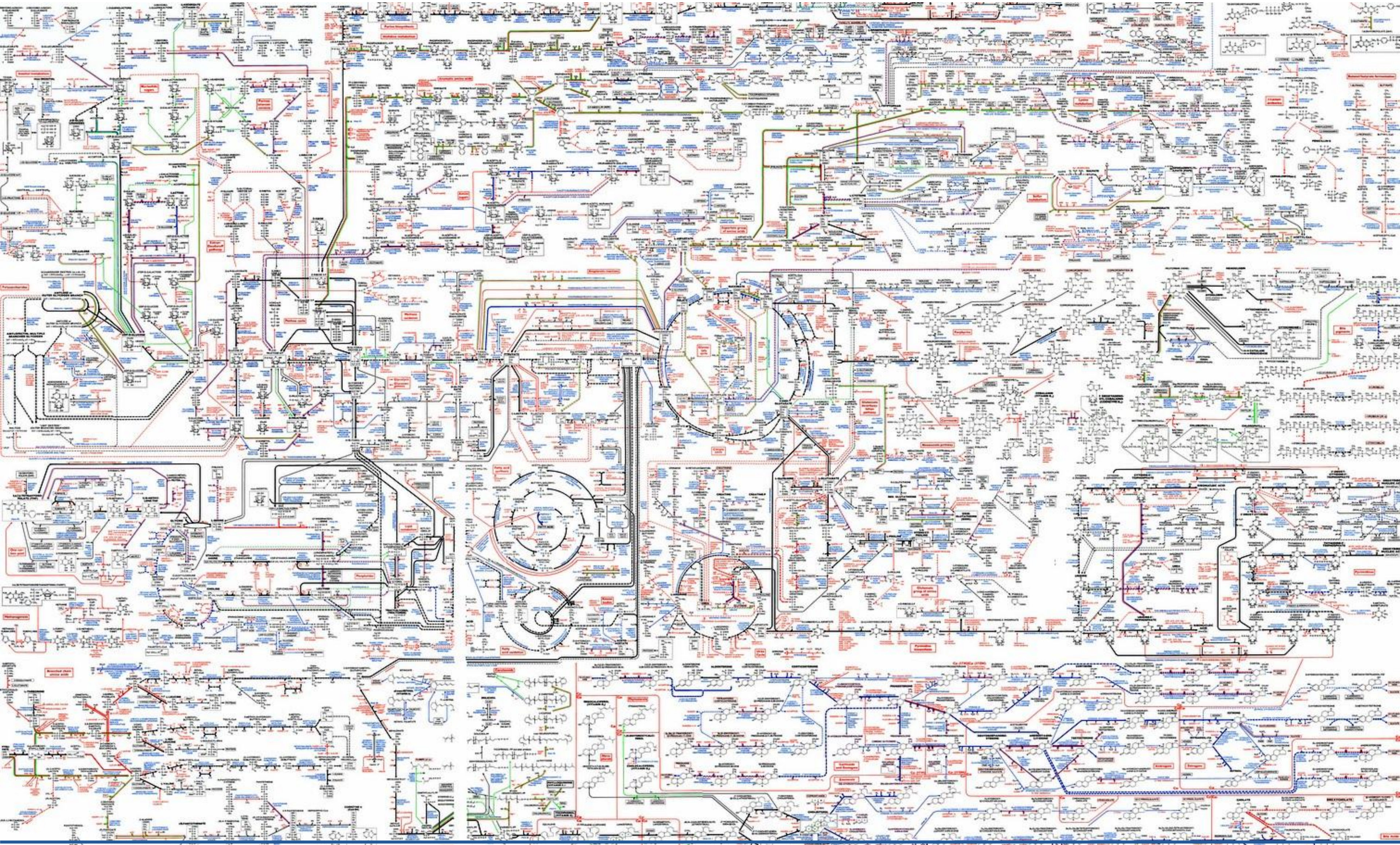
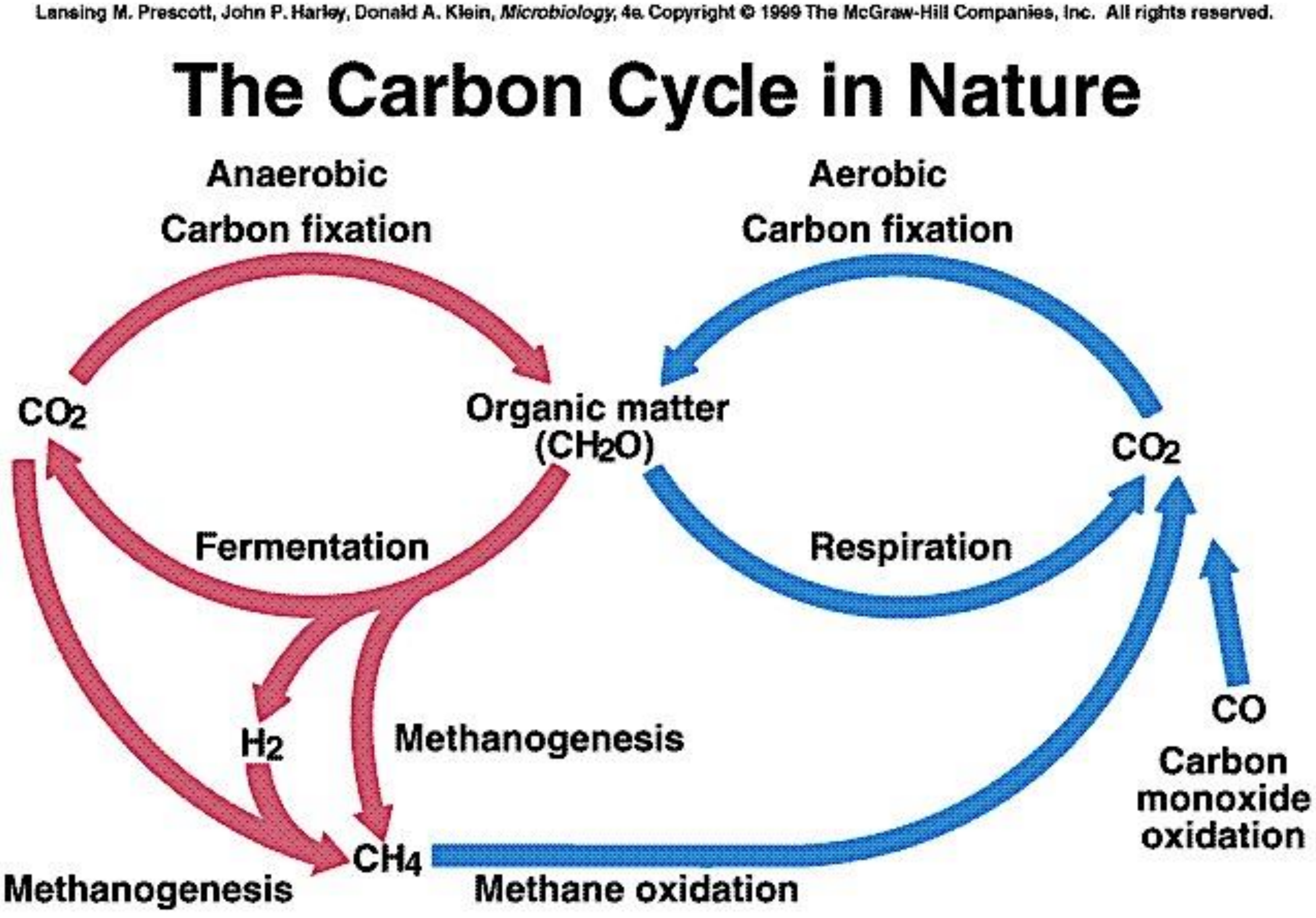
$$\boldsymbol{Organic\ substrates} \xrightarrow{Microorganisms} New\ microorganisms\ + \boldsymbol{BIOGAS}$$

Introduction



Introduction



Introduction

- **Why anaerobic processes?**

  - **Costs (O_2 not used as electron acceptor)**
  - **Energy/Value added chemicals production**
  - **GHG emission mitigation**

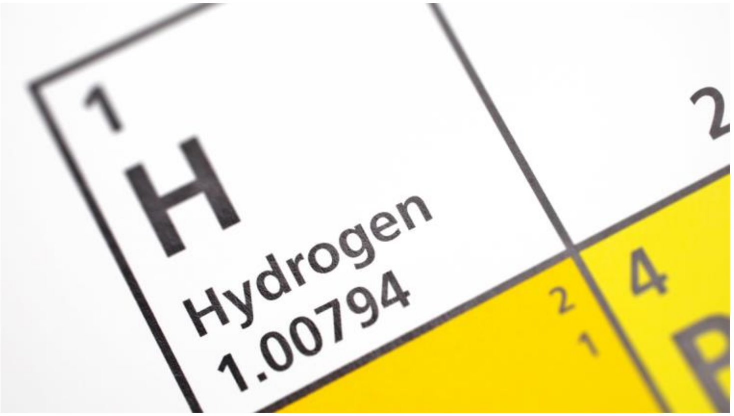
Biogas CH_4 e H_2

Organic Substrate	$Nm^3 Biogas/t_{VS}$
Manure	200-500
Residual Crops	350-400
Agroindustrial Organic Wastes	400-800
Butchery Organic Wastes	550-1000
WWT sludges	250-350
Food Wastes	400-600
Energetic Crops	550-750

Biogas CH_4 e H_2

Agroindustrial Organic Wastes 400-800

H_2 production



PCI 119.90 MJ/Kg

$2H_2 + O_2 \rightarrow H_2O$

η_{MAX} fuel cell 70%

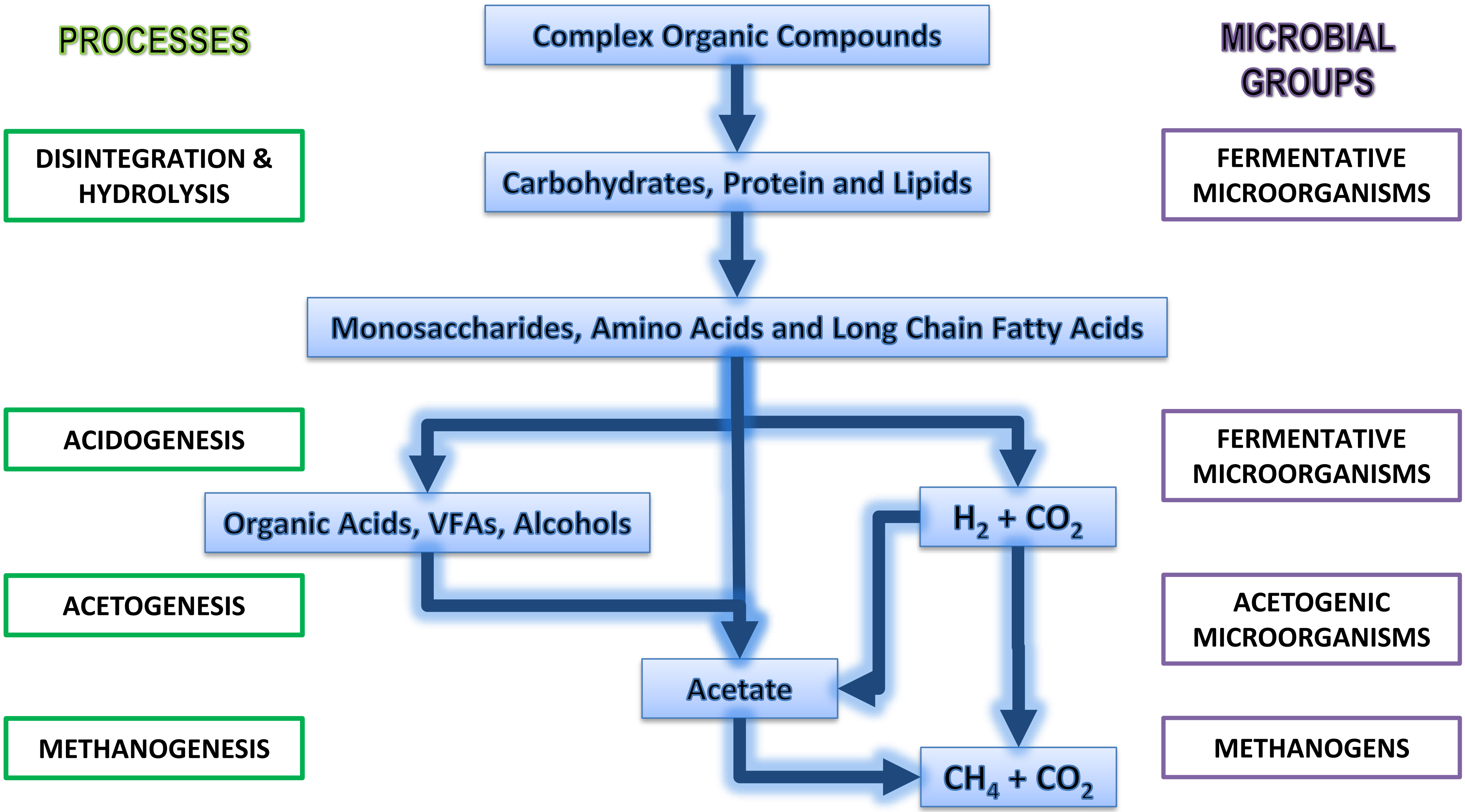
- *Efficiency conversion in internal combustion engines 50-60%*
- *Efficiency conversion (fossil fuels) ~25%*

- *Low density*
- *Production technology*

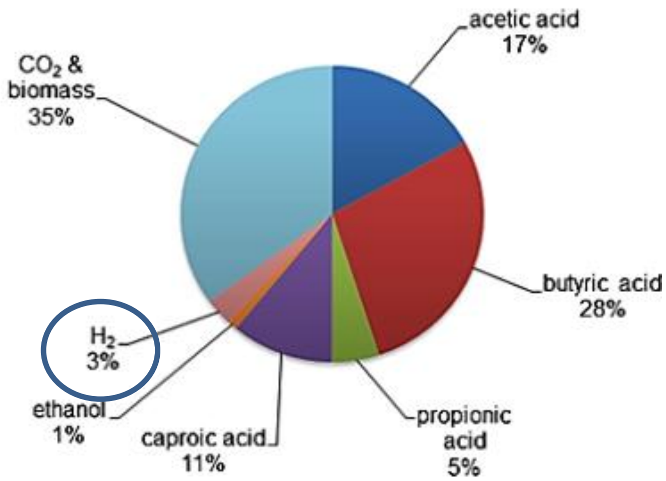
81.7% of the global energy requirement is provided by fossil fuels

International Energy Agency - 2014

Anaerobic Digestion - Dark Fermentation



Main issues of DF



Dark fermentation of organic waste

Market Value of Platform Chemicals

Chemicals	Price per unit $/t
Succinic acid	2000 - 5000
Acetic acid	400 - 800
Lactic acid	800 - 1200
Propionic acid (salt)	600 - 1200
Butyric acid	1600 - 2000
Polyhydroxyalkanoate PHA/PHB	2000 - 3000

Bastidas-Oyanedel et al., 2015. Reviews in Environmental Science and Bio/Technology 14 (3), 473-498.

Objectives

- ***Increase biogas yields by coupling DF with other biological processes***
- ***Reuse/Recovery of DFEs***

Biorefining is the sustainable processing of biomass into a spectrum of bio-based products (food, feed, chemicals, materials) and bioenergy (biofuels, power and/or heat)... facility that integrates biomass conversion processes and equipment to produce fuels, power, heat, and value-added chemicals from biomass.

Biorefining examples

i. *Optimization of the start-up phase for a AD biofilm reactor*

ii. *Mathematical modeling of the start-up phase for a AD biofilm reactor*

iii. *Stand-alone DF of cheese whey using alternative buffer agents for H_2 production*

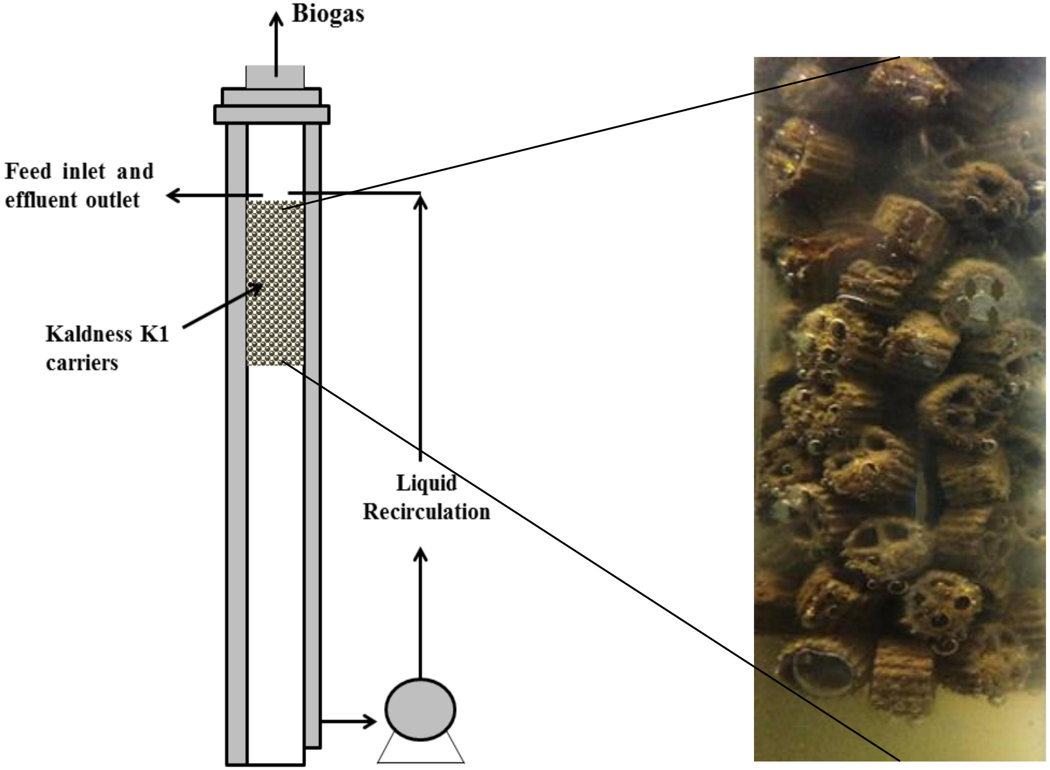
iv. *Integration of DF-PF systems for enhancing bio-H_2 production*

v. *Integration of DF-AD systems using microalgae as feedstock*

vi. *Lactic acid extraction from a Thermotoga neapolitana fermentation broth*

vii. *Organic acids production from DF for cement asbestos composites degradation*

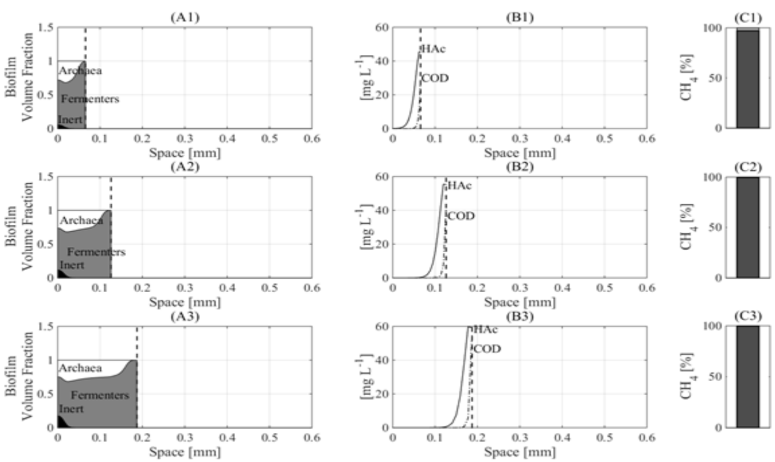
Biorefining examples

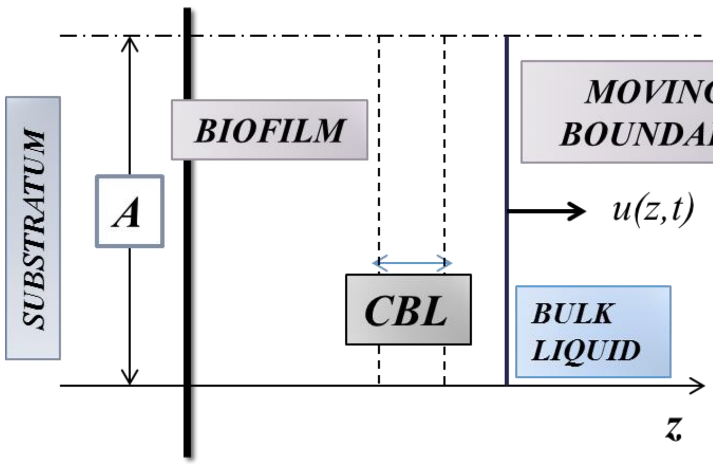


- **Yeshanew, M.M., Frunzo, L., Luongo, V., Pirozzi, F., Lens, P.N., Esposito, G., 2016. Start-up of an anaerobic fluidized bed reactor treating synthetic carbohydrate rich wastewater. Journal of Environmental Management, 184, pp.456-464.**

Biorefining examples

$\mathbf{X} = (X_1, ..., X_n)$, $\mathbf{S} = (S_1, ..., S_m)$,
$X_i(z,t)$ concentration of microorganism i,
n number of microbial species,
$S_j(z,t)$ concentration of substrate j,
m number of substrates.

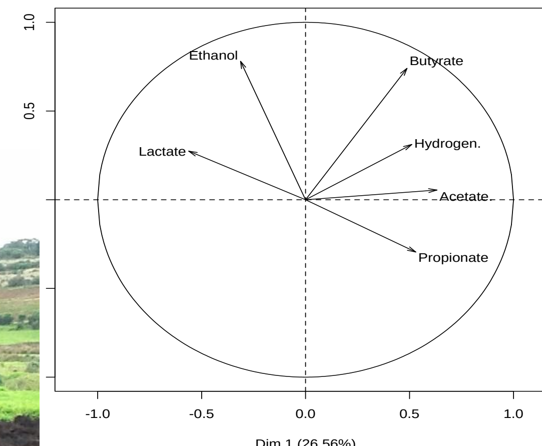




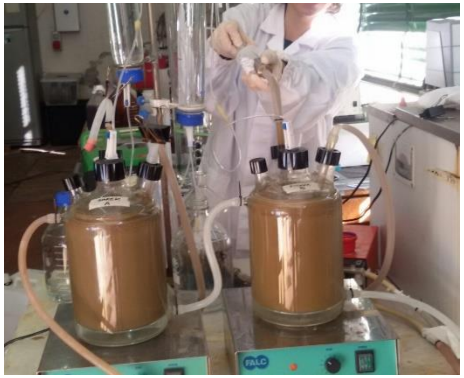
- **D'Acunto, B., Frunzo, L., Luongo, V., Mattei, M.R., 2017. Invasion moving boundary problem for a biofilm reactor model. Submitted.**

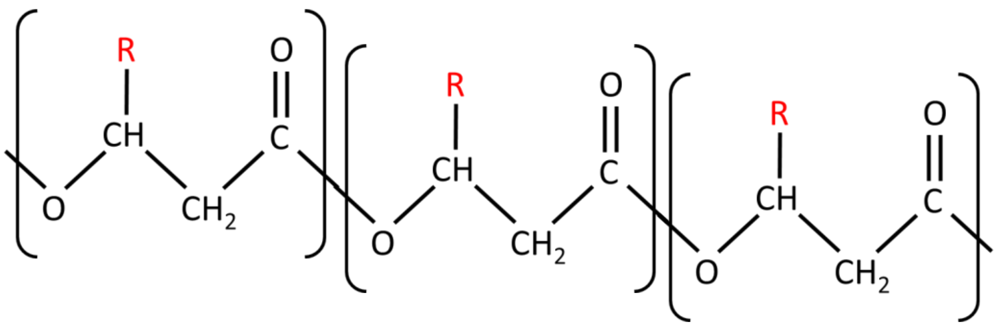
Biorefining examples

- **Ghimire, A., Luongo, V., Frunzo, L., Pirozzi, F., Lens, P.N., Esposito, G., 2017. Continuous biohydrogen production by thermophilic dark fermentation of cheese whey: Use of buffalo manure as buffering agent. International Journal of Hydrogen Energy, 42(8), pp.4861-4869.**



Biorefining examples

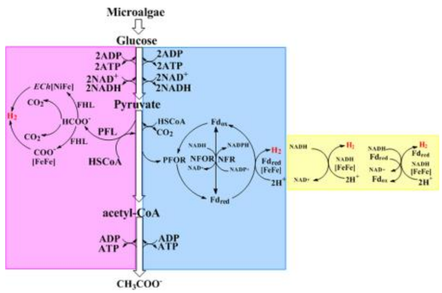


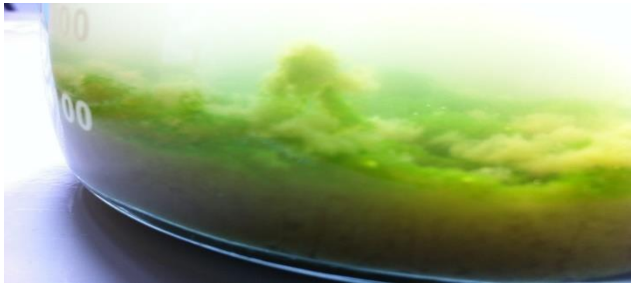


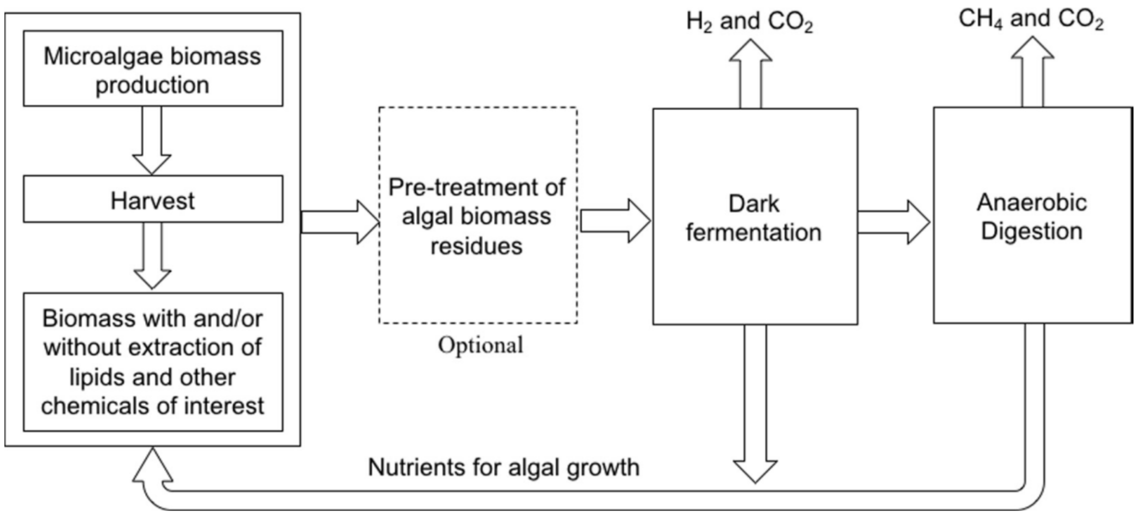
- **Luongo, V., Ghimire, A., Frunzo, L., Fabbricino, M., d'Antonio, G., Pirozzi, F., Esposito, G., 2017. Photofermentative production of hydrogen and poly-β-hydroxybutyrate from dark fermentation products. Bioresource Technology, 228, pp.171-175.**

Biorefining examples

- **Ghimire, A., Kumar, G., Sivagurunathan, P., Shobana, S., Saratale, G.D., Kim, H.W., Luongo, V., Esposito, G. Munoz, R., 2017. Bio-hythane production from microalgae biomass: key challenges and potential opportunities for algal bio-refineries. Bioresource Technology, 241, pp.525-536.**

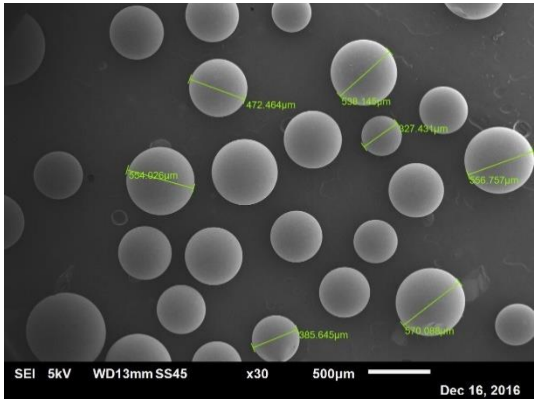


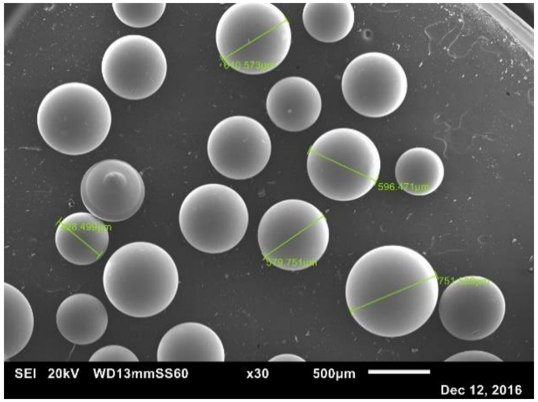


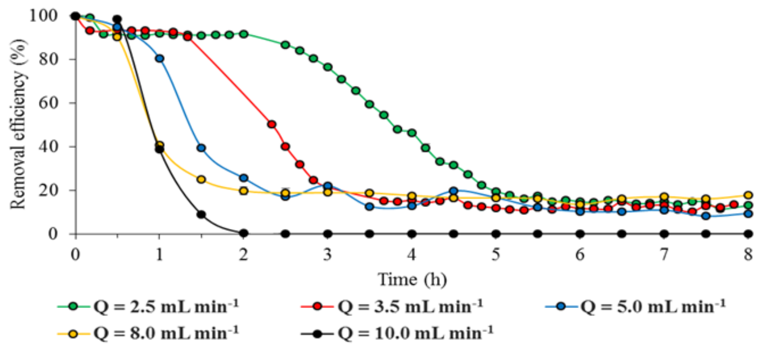


Biorefining examples

- **Luongo, V., Palma, A., Rene, E.R., Fontana, A., Pirozzi, F., Esposito, G., Piet N. L. Lens, P.N.L., 2017. Lactic acid recovery from a simplified mimic of *Thermotoga neapolitana* fermentation broth using ion exchange resins in batch and fixed-bed reactors. Submitted**

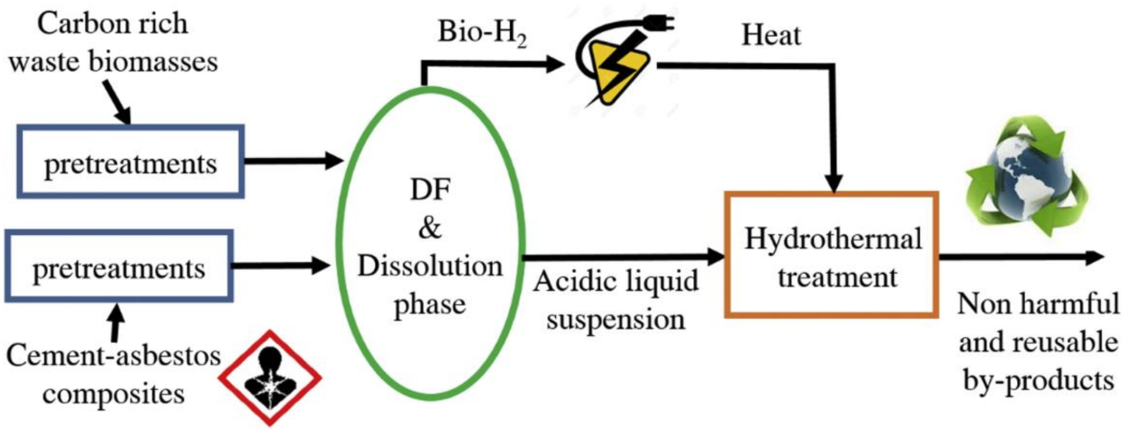






Biorefining examples

- **Spasiano, D., Luongo, V., Petrella, A., Alfè, M., Pirozzi, F., Fratino, U., Piccinni, A.F., 2017. Preliminary study on the adoption of dark fermentation as pretreatment for a sustainable hydrothermal denaturation of cement-asbestos composites. Journal of Cleaner Production, 166, pp.172-180.**



Scientific contributions

▪ Published works

- Yeshanew, M.M., Frunzo, L., Luongo, V., Pirozzi, F., Lens, P.N., Esposito, G., 2016. Start-up of an anaerobic fluidized bed reactor treating synthetic carbohydrate rich wastewater. Journal of Environmental Management, 184, pp.456-464.
- Luongo, V., Ghimire, A., Frunzo, L., Fabbricino, M., d'Antonio, G., Pirozzi, F., Esposito, G., 2017. Photofermentative production of hydrogen and poly-β-hydroxybutyrate from dark fermentation products. Bioresource Technology, 228, pp.171-175.
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Scientific contributions

Submitted work or under preparation

- **Moreno, J.H., Luongo, V., Pollio, A., Pinto, G., Frunzo, L., Lens, P.N.L., Esposito, G., 2017. Screening native *Chlorella pyrenoidosa* strain for nutrient removal from industrial wastewater. Submitted.**
- **Luongo, V., Palma, A., Rene, E.R., Fontana, A., Pirozzi, F., Esposito, G., Piet N. L. Lens, P.N.L., 2017. Lactic acid recovery from a simplified mimic of *Thermotoga neapolitana* fermentation broth using ion exchange resins in batch and fixed-bed reactors. Submitted.**
- **D'Acunto, B., Frunzo, L., Luongo, V., Mattei, M.R., 2017. Invasion moving boundary problem for a biofilm reactor model. Under revision.**
- **Luongo, V., Frunzo, L., Mattei, M.R., Ghimire, A., Esposito, D'Acunto, B., G., Pirozzi, F., 2018. Mathematical modeling of dark fermentation dynamics: the influence of biomass characteristics on hydrogen yield and acids accumulation. In preparation.**
- **Spasiano, D., Luongo V., Race, M., V., Petrella, A., Alfè, M., Pirozzi, F., Fratino, U. and Piccinni, A.F., 2017. Adoption of dark fermentation effluent of food waste as pretreatment for a sustainable hydrothermal denaturation of cement-asbestos composites. Submitted.**
- **Luongo, V., Ghimire, A., Frunzo, L., Fabbricino, M., Pirozzi, F., Esposito, G., 2018. Continuous lactic acid production from the mesophilic fermentation of cheese whey. In preparation.**
- **Luongo, V., La Mura, M., Ghimire, A., Frunzo, L., Villa, F., Fabbricino, M., Esposito, G., Pirozzi, F., 2018. Effect of substrate characteristics on photofermentative H_2 production by a mixed PNSB consortium. In preparation.**

What I have learned during my PhD!

- ***The integration of different biological systems can effectively lead to the production of value-added chemicals or bio-fuels***

- ***Each of the biological systems, or biorefining system, studied should be deeper investigated for further developments***

- ***The scale-up of the different processes represents the main goal for both academia and industry***

- ***Biomass conversion in the biorefining context is a promising energy alternative for all developed countries (reducing waste biomass while producing renewable energy)***

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My Family

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