CARREFOURS
DE L'INNOVATION AGRONOMIQUE

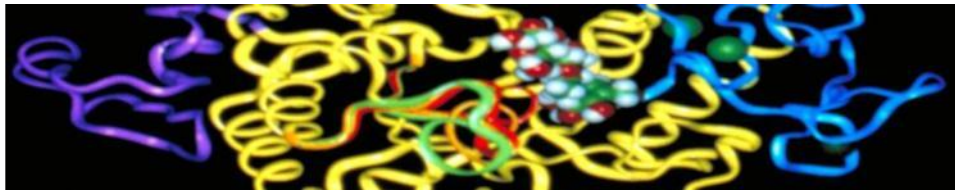
# Les microalgues, promesses et défis

## Pour relever le défi du carbone renouvelable

Jean-Philippe Steyer
Laboratoire de Biotechnologie de l'Environnement – INRA Narbonne

Jeudi 18 avril 2013

INRA
SCIENCE & IMPACT



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

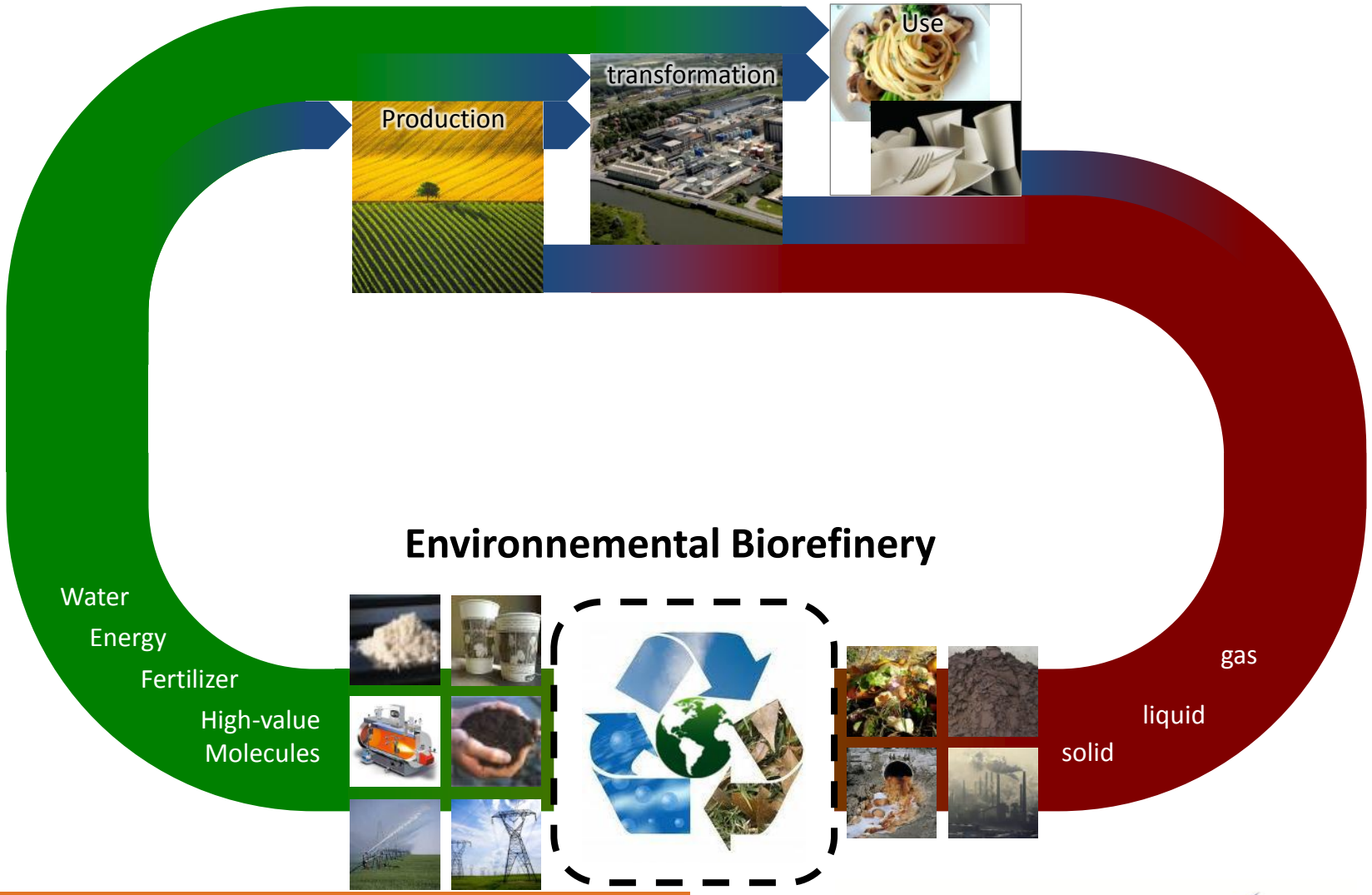


http://www.montpellier.inra.fr/narbonne

INRA SCIENCE & IMPACT

CARREFOURS DE L'INNOVATION AGRONOMIQUE

# The Environmental Biorefinery



# The Environmental Biorefinery

## Multiple and Complex Inputs within a Territory

Agro-industries

Biowaste

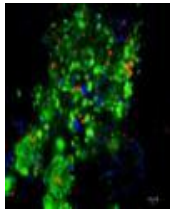
**Residus from human activities (gas, liquid, solid)**

Urban

Agriculture

New biomass

Ecosystems



Processes

## Services for Bioeconomy

$CH_4$ and/or $H_2$

Heat
Electricity
Biocarburant
Natural gas

Platform Molecules

Lactate, EtOH, VFAs…

$CO_2$

Microalgae, greenhouse

N, P

Fertilisers

$H_2O$

Reuse, irrigation

Fibers

Compost
Biomaterial

**under environmental and sanitary constraints**

INRA SCIENCE & IMPACT

CARREFOURS DE L'INNOVATION AGRONOMIQUE

# Most of you know MACROalgae…

# Most of you know MACROalgae…


# … but MACROalgae can be very useful

# … but MACROalgae can be very useful

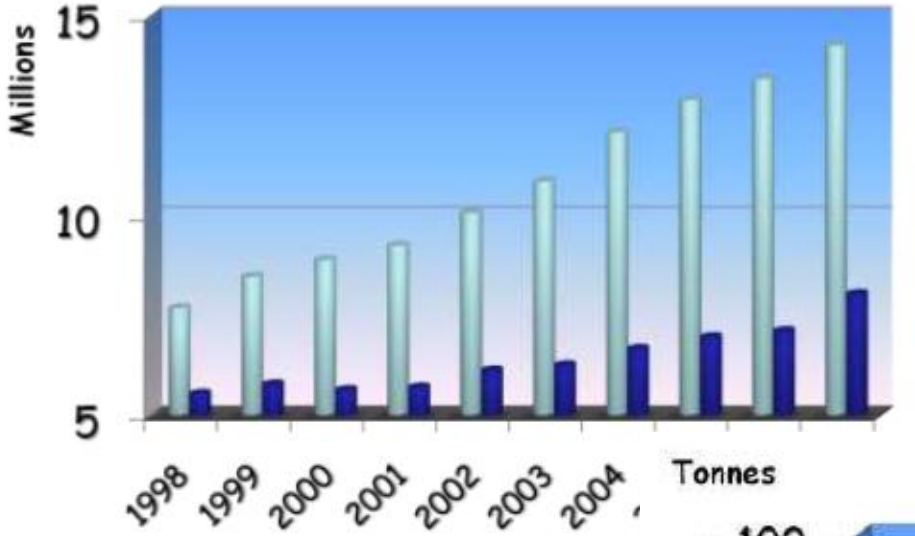



Figure 30 : Évolution de la production mondiale en
(Source: CEVA d'après FAO –Fisheries Stat. - Division 5.

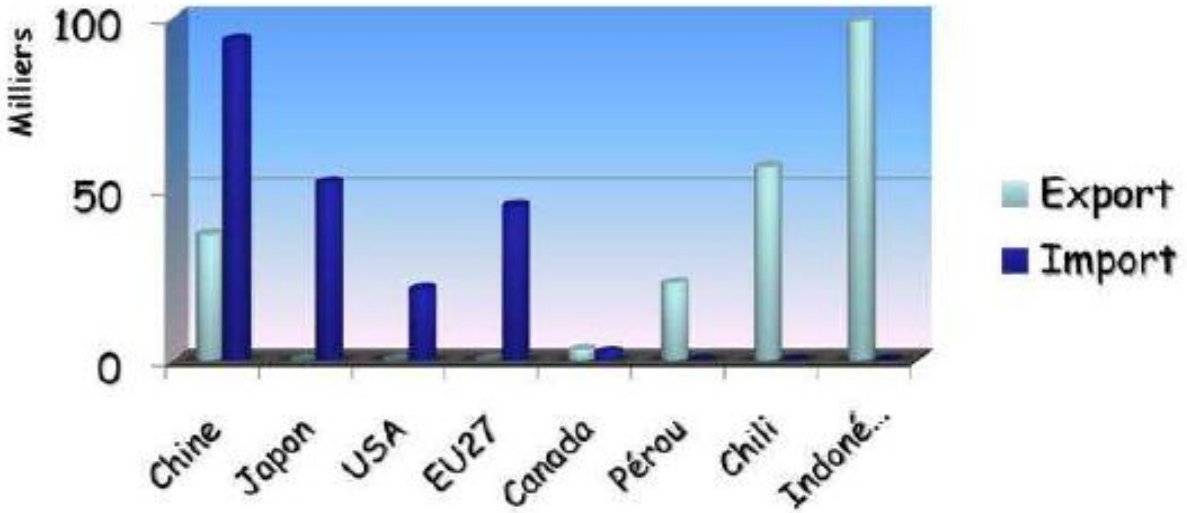
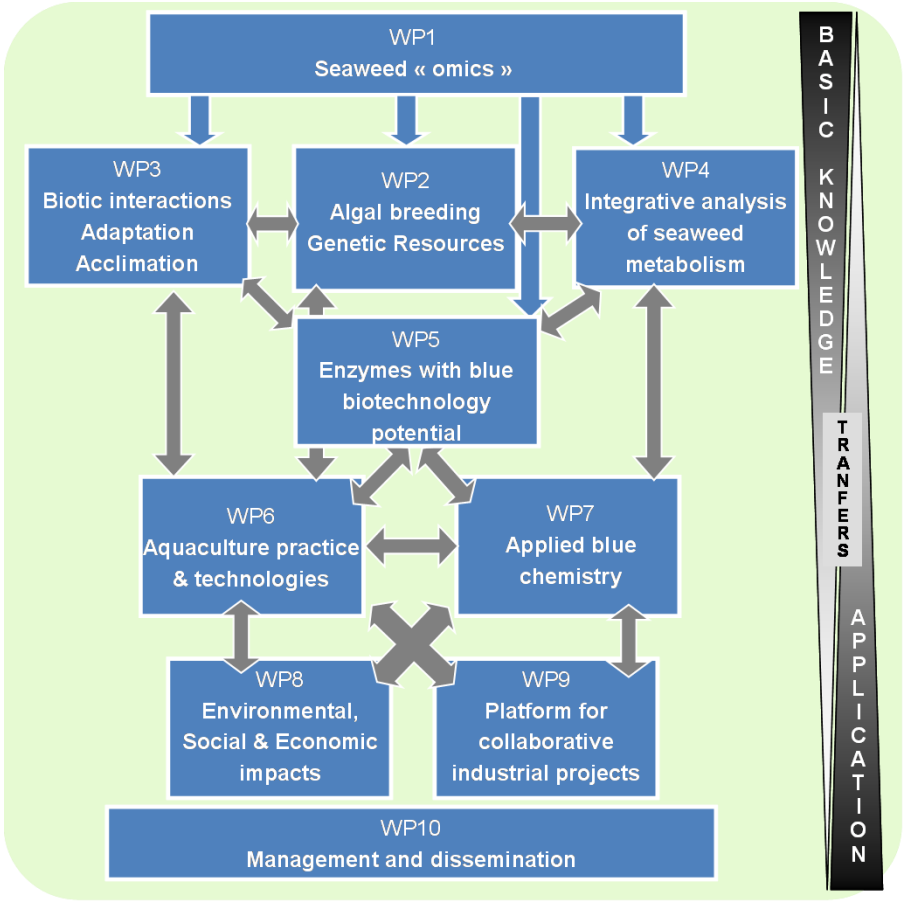


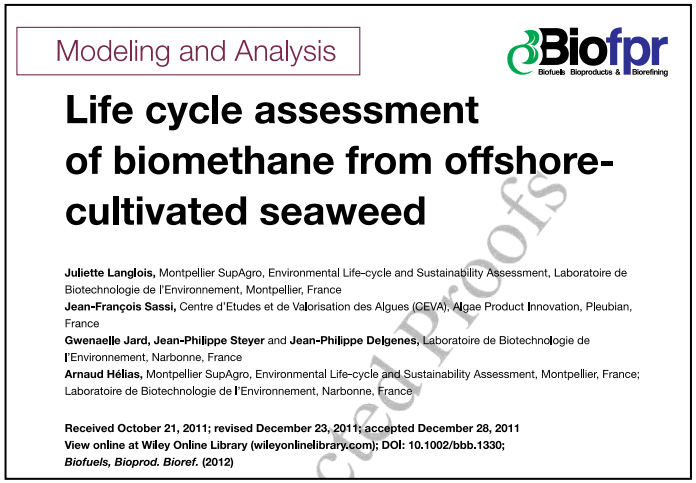

Figure 31 : Flux d'import / export mondiaux 2008.
(Source : CEVA d'après UN Comtrade, 1212.20 commodity)

INRA SCIENCE & IMPACT

# The IDEALG project


# Seaweed production between offshore wind turbines



Modeling and Analysis

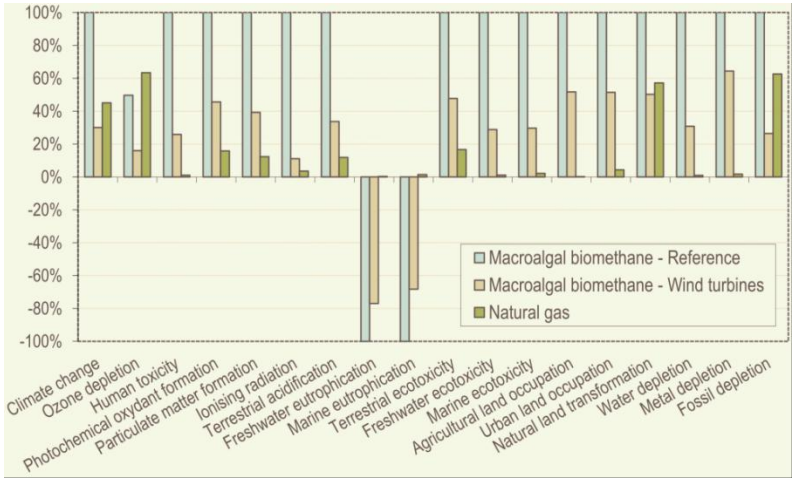
Biofpr
Biofuels, Bioproducts & Biorefining

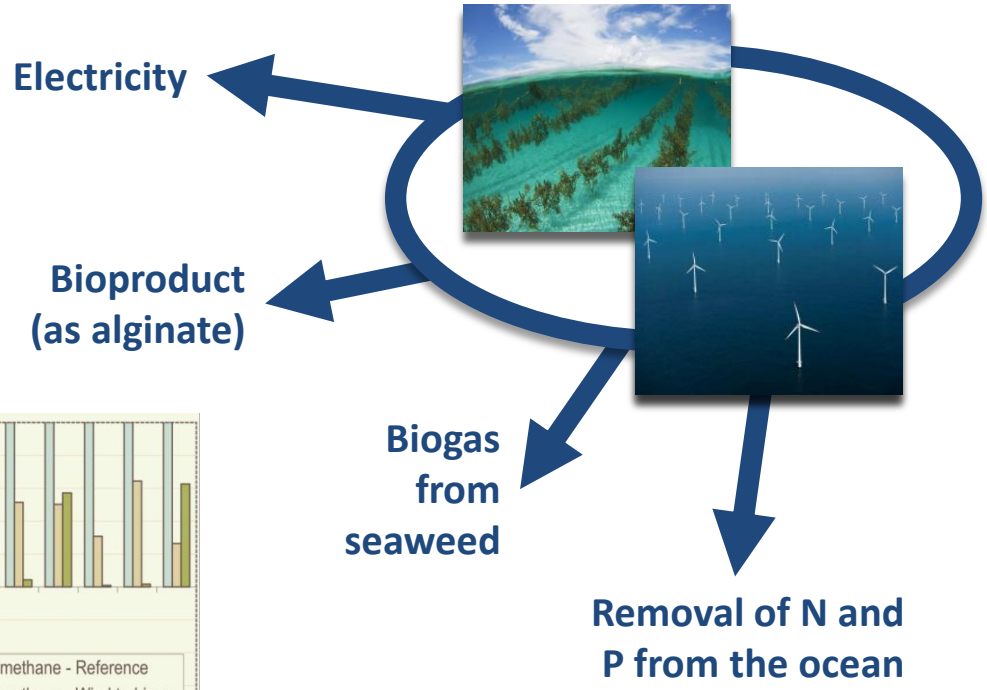
**Life cycle assessment of biomethane from offshore-cultivated seaweed**

**Juliette Langlois,** Montpellier SupAgro, Environmental Life-cycle and Sustainability Assessment, Laboratoire de Biotechnologie de l'Environnement, Montpellier, France
**Jean-François Sassi,** Centre d'Etudes et de Valorisation des Algues (CEVA), Algae Product Innovation, Pleubian, France
**Gwenaelle Jard, Jean-Philippe Steyer** and **Jean-Philippe Delgenes,** Laboratoire de Biotechnologie de l'Environnement, Narbonne, France
**Arnaud Hélias,** Montpellier SupAgro, Environmental Life-cycle and Sustainability Assessment, Montpellier, France; Laboratoire de Biotechnologie de l'Environnement, Narbonne, France

**Received October 21, 2011; revised December 23, 2011; accepted December 28, 2011**
**View online at Wiley Online Library (wileyonlinelibrary.com); DOI: 10.1002/bbb.1330;**
***Biofuels, Bioprod. Bioref.* (2012)**



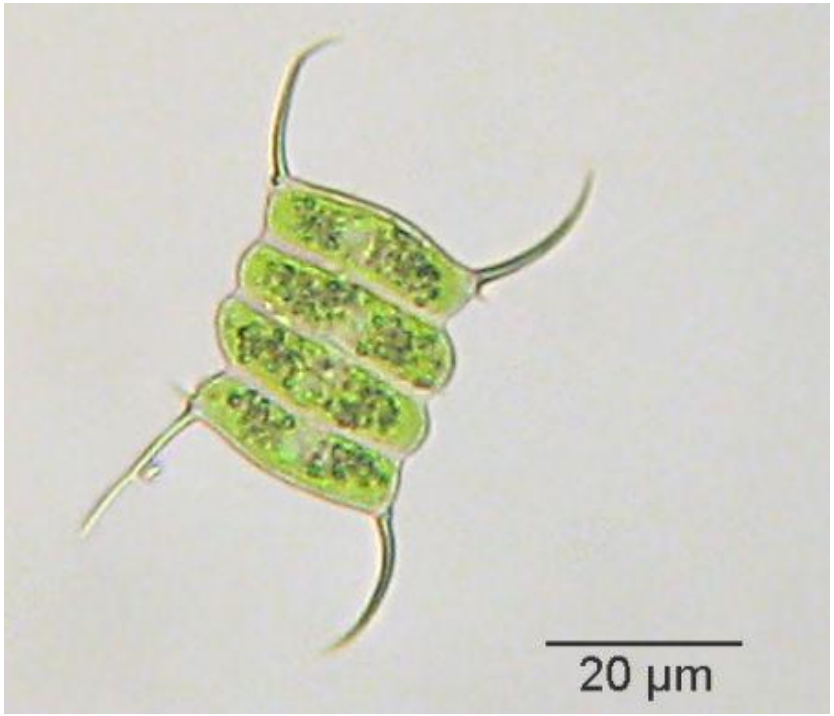



INRA SCIENCE & IMPACT

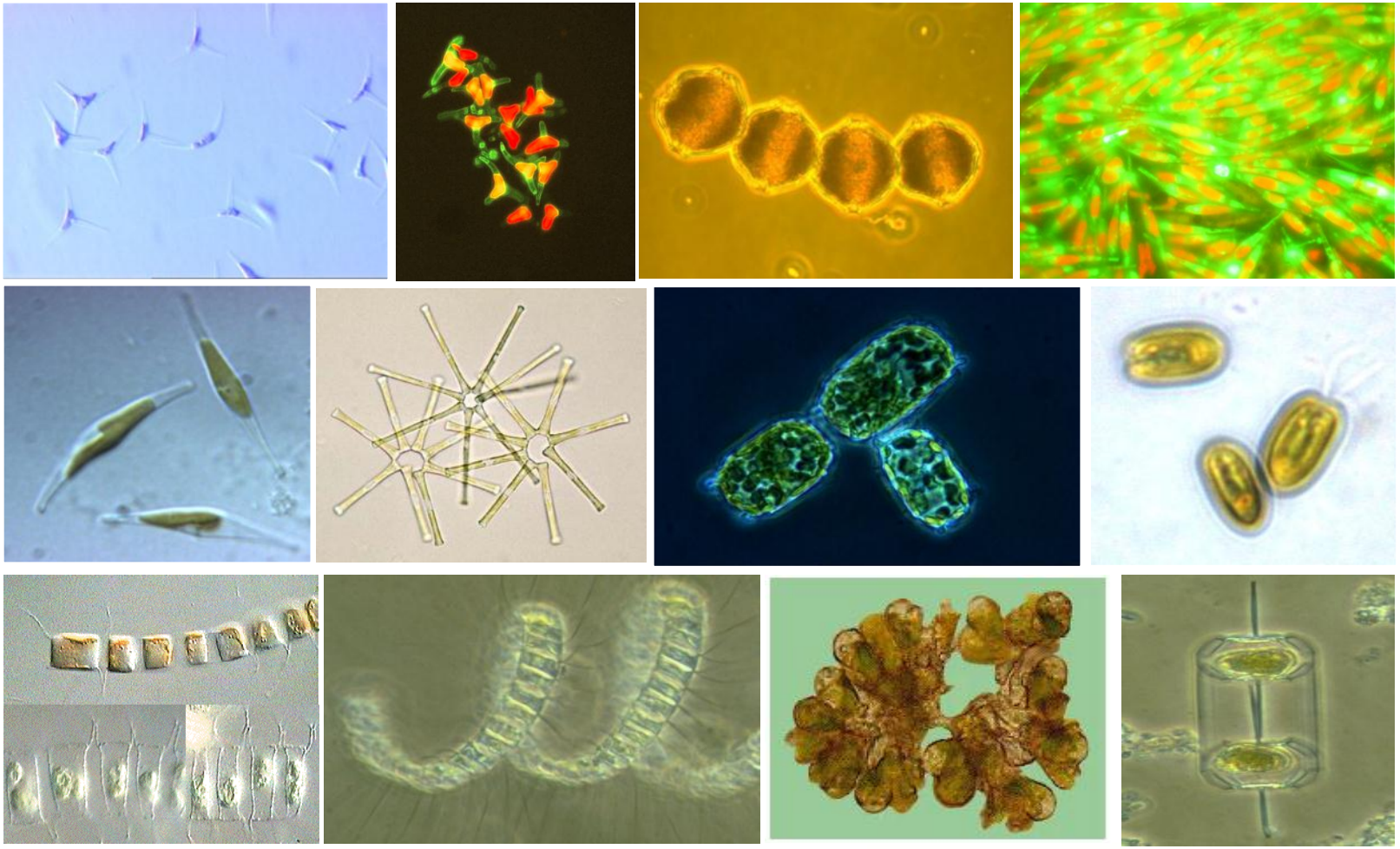
CARREFOURS DE L'INNOVATION AGRONOMIQUE

# Some of you might also know MICROalgae

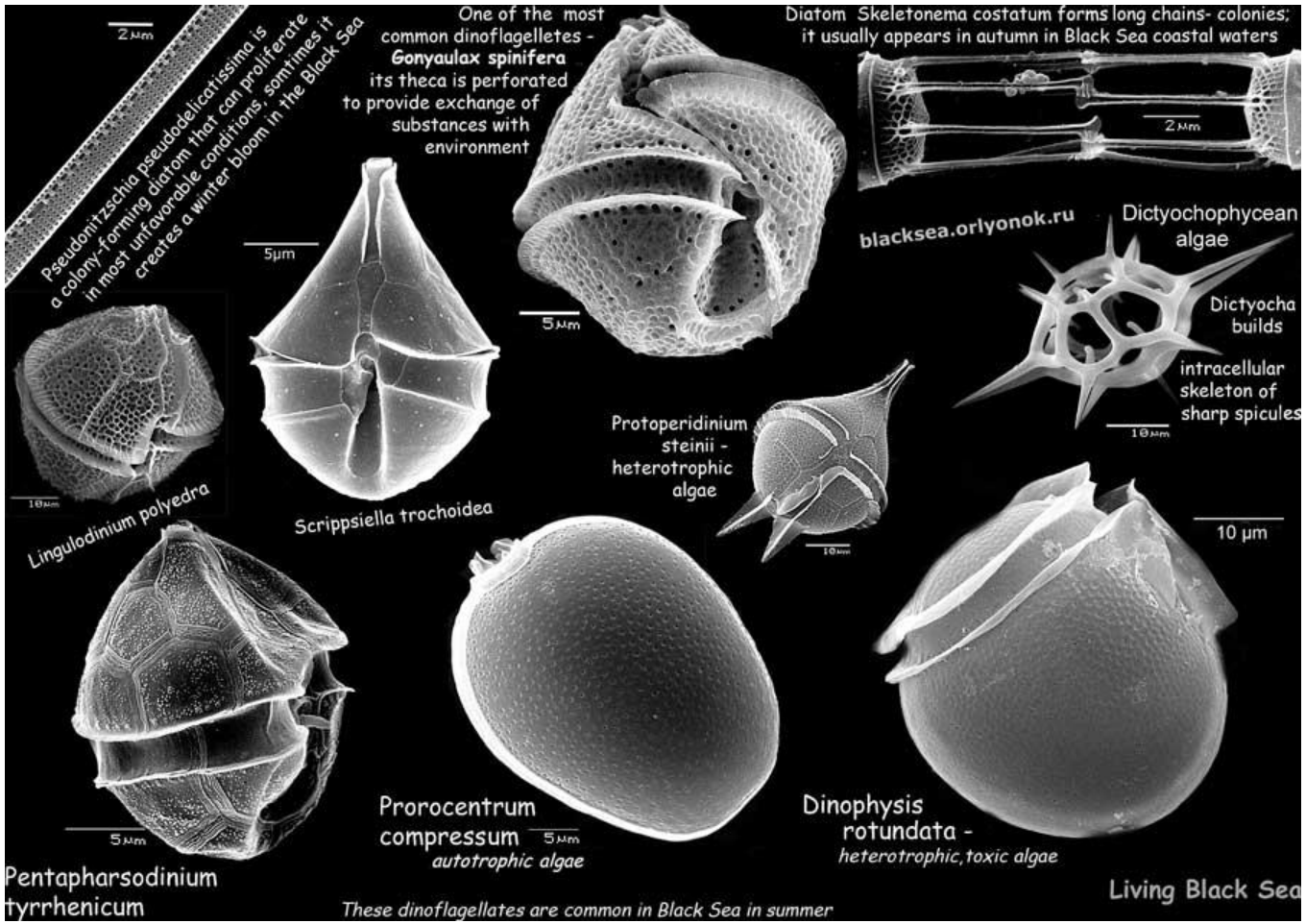


# Microalgae are everywhere

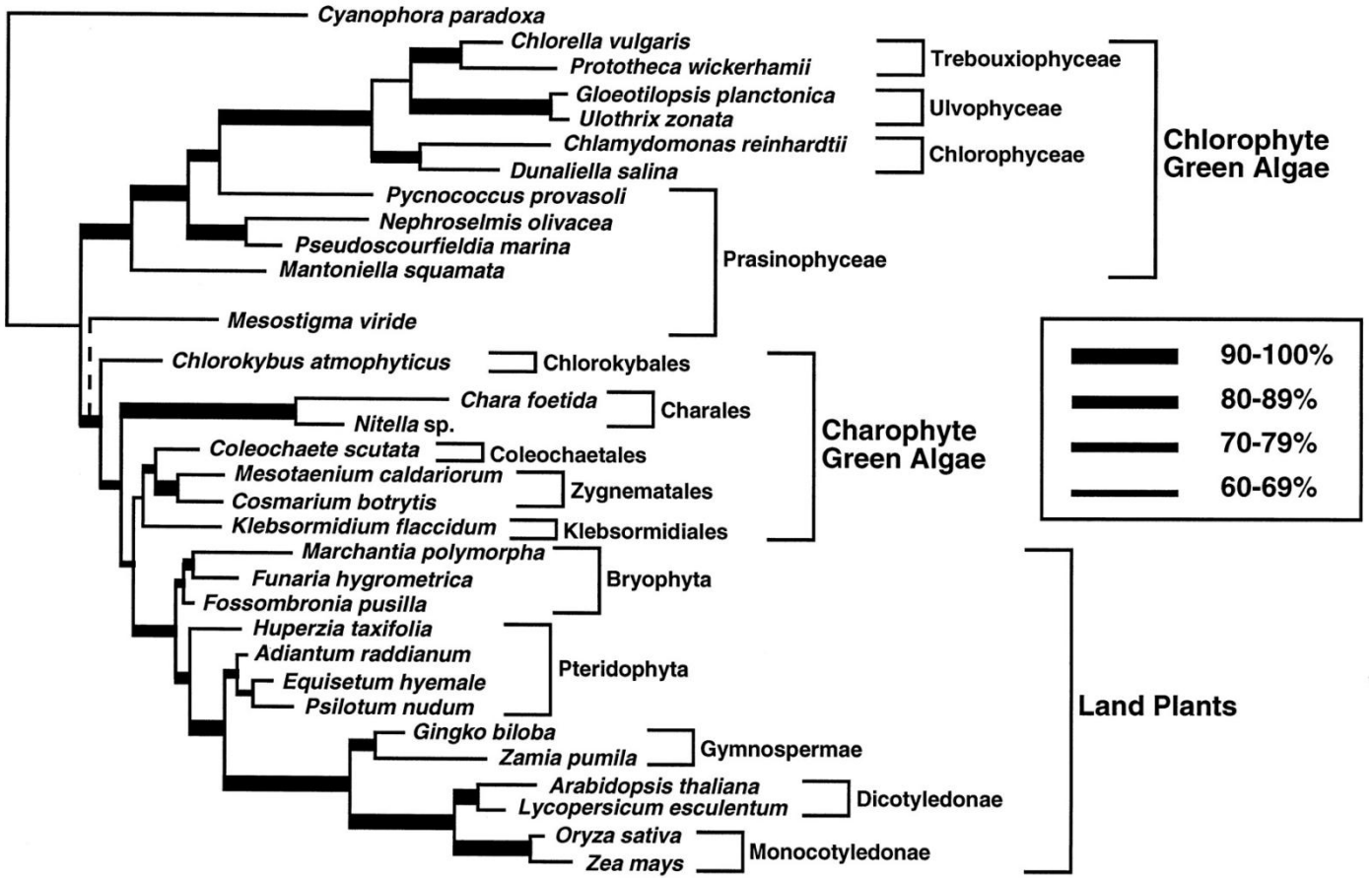
# Microalgae are beautiful



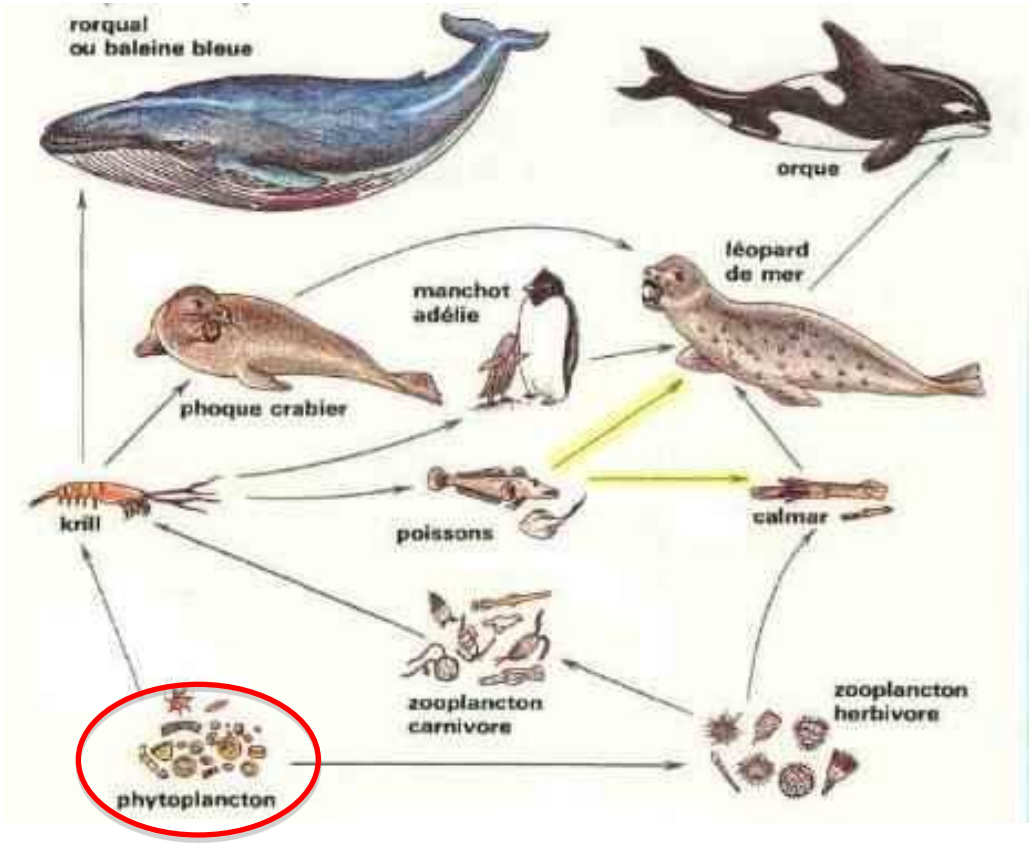
# Microalgae are beautiful



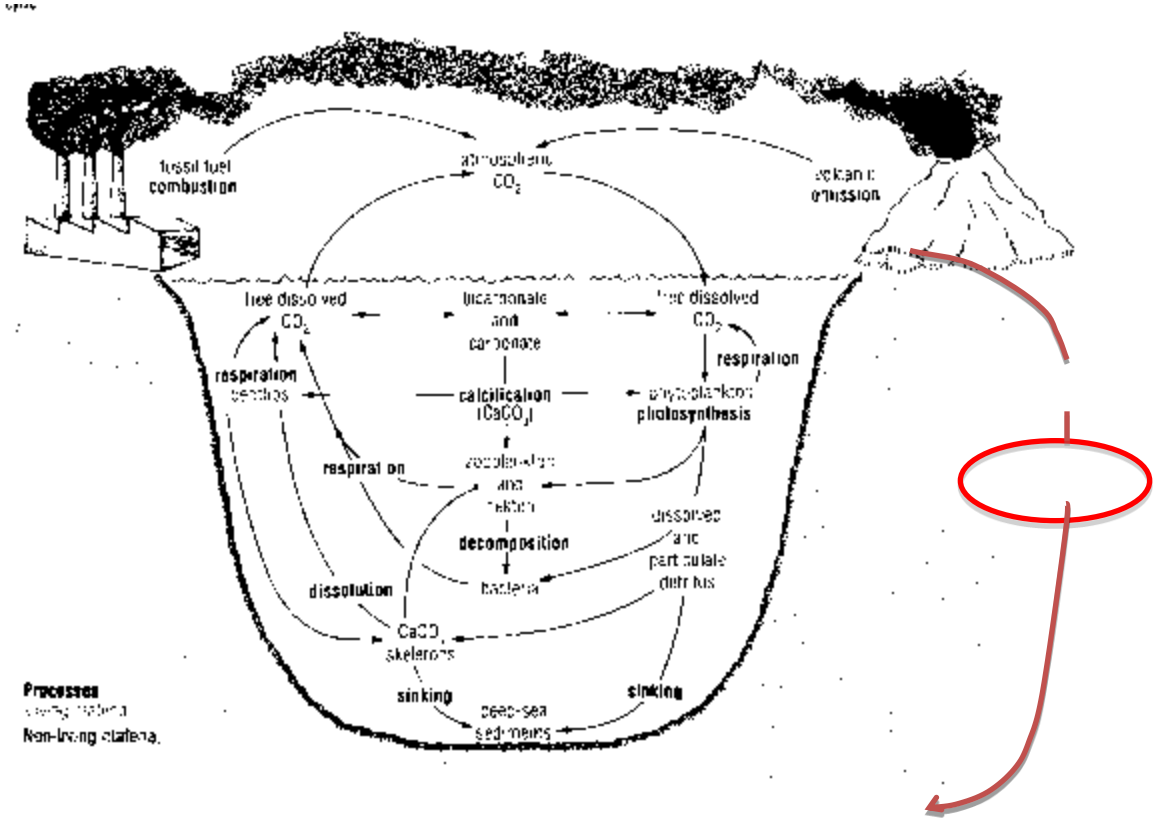
# Microalgae, our photosynthetic ancestors



# Microalgae, the first element of the food web



# Microalgae, a key element in $CO_2$ capture




# Microalgae, many outputs everywhere !

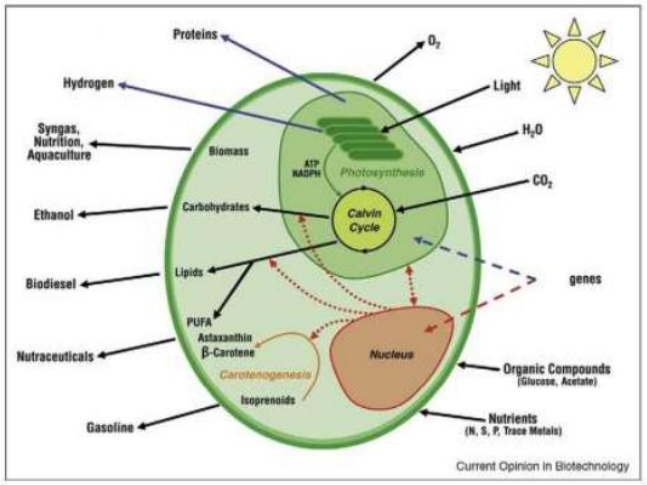
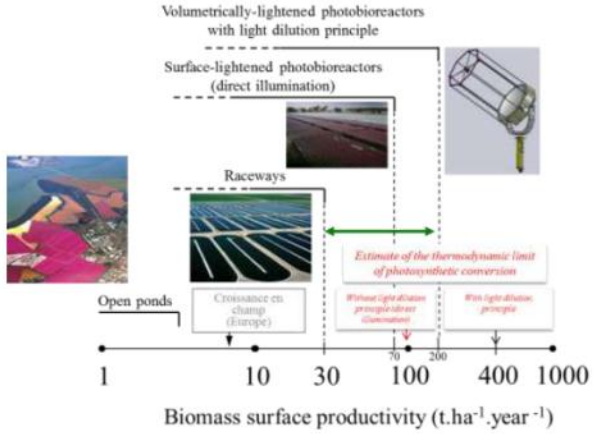




Figure 5 : Schéma de fonctionnement d'une micro-algue, intrants, produits, applications.
(Source : Rosenberg et al. , Current Opinion in Biotechnology ,2008, modifiée par nos soins)




INRA SCIENCE & IMPACT

CARREFOURS DE L'INNOVATION AGRONOMIQUE

# Microalgae, many outputs everywhere !

*Production mondiale de microalgues (d'après* Spolaore *et al.,*2006*)*

| Algue | Production annuelle (t poids sec) | Pays producteur | Applications et produits |
|---|---|---|---|
| **Spirulina** | 3,000 | Chine, Inde, USA, République de l'Union du Myanmar, Japon | Nutrition animale et humaine, phycobiliprotéines,cosmétique |
| **Chlorella** | 2,000 | Taiwan, Allemagne, Japon | Nutrition humaine, aquaculture, cosmetique |
| **Dunaliella** | 1,200 | Australie, Israel, USA, Chine | Nutrition humaine, cosmetique, b-carotene |
| **Aphanizomenon** | 500 | USA | Nutrition humaine |
| **Haematococcus** | 300 | USA, Inde, Israel | Aquaculture, Astaxanthine |
| **Crypthecodinium** | 240 t DHA | USA | Acide docosahexaénoïque DHA (Omega-3) |
| **Schizochytrium** | 10 t DHA | USA | Acide docosahexaénoïque DHA (Omega-3) |

# Microalgae, many outputs everywhere !

3 years | 5 years | 7 years | 10 years

Time of access to market

Aquaculture

Nutrition

Cosmetic

Green Chemistry

Energy

**Challenges:**
- adapted species
- recovery, extraction
- low production costs

High volume markets
Lower added value molecules

Low volume markets
High value molécules

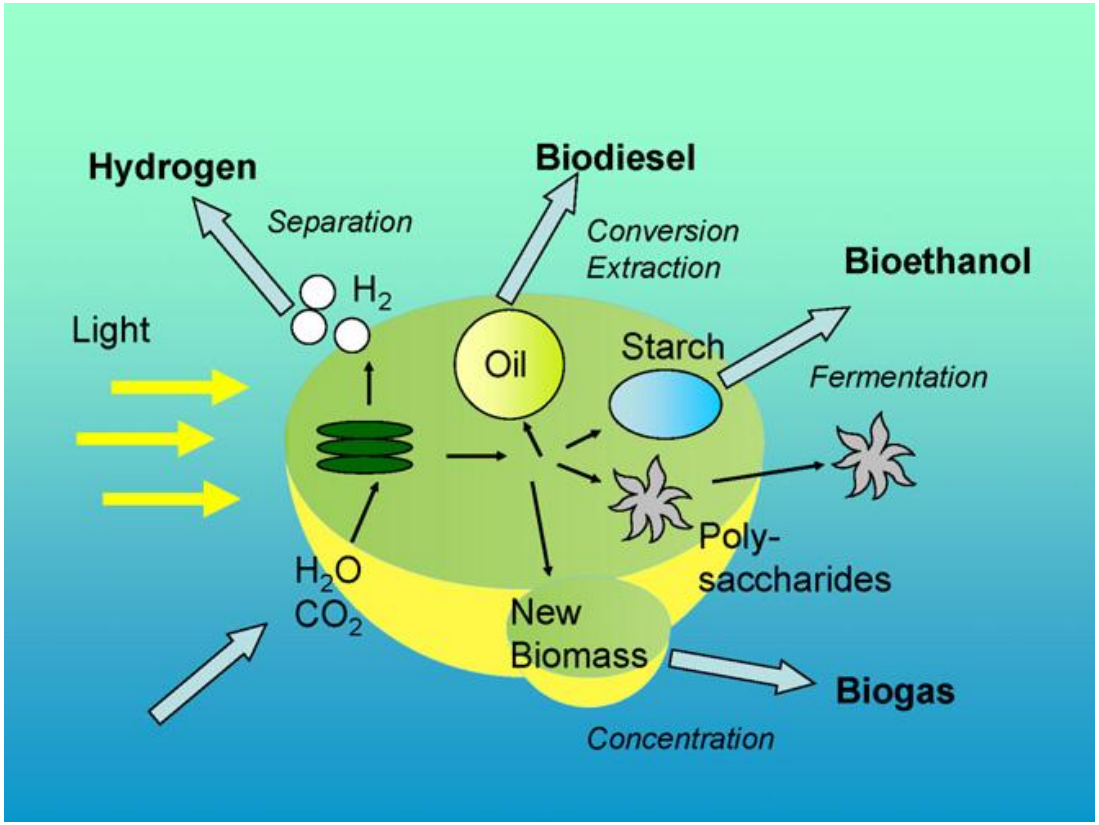
Biogas

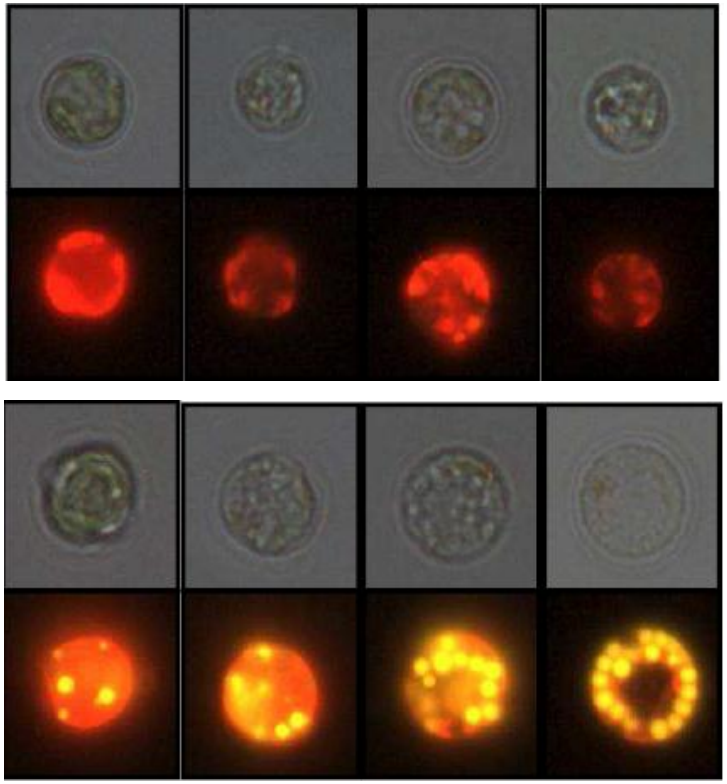
Animal feed

INRA SCIENCE & IMPACT

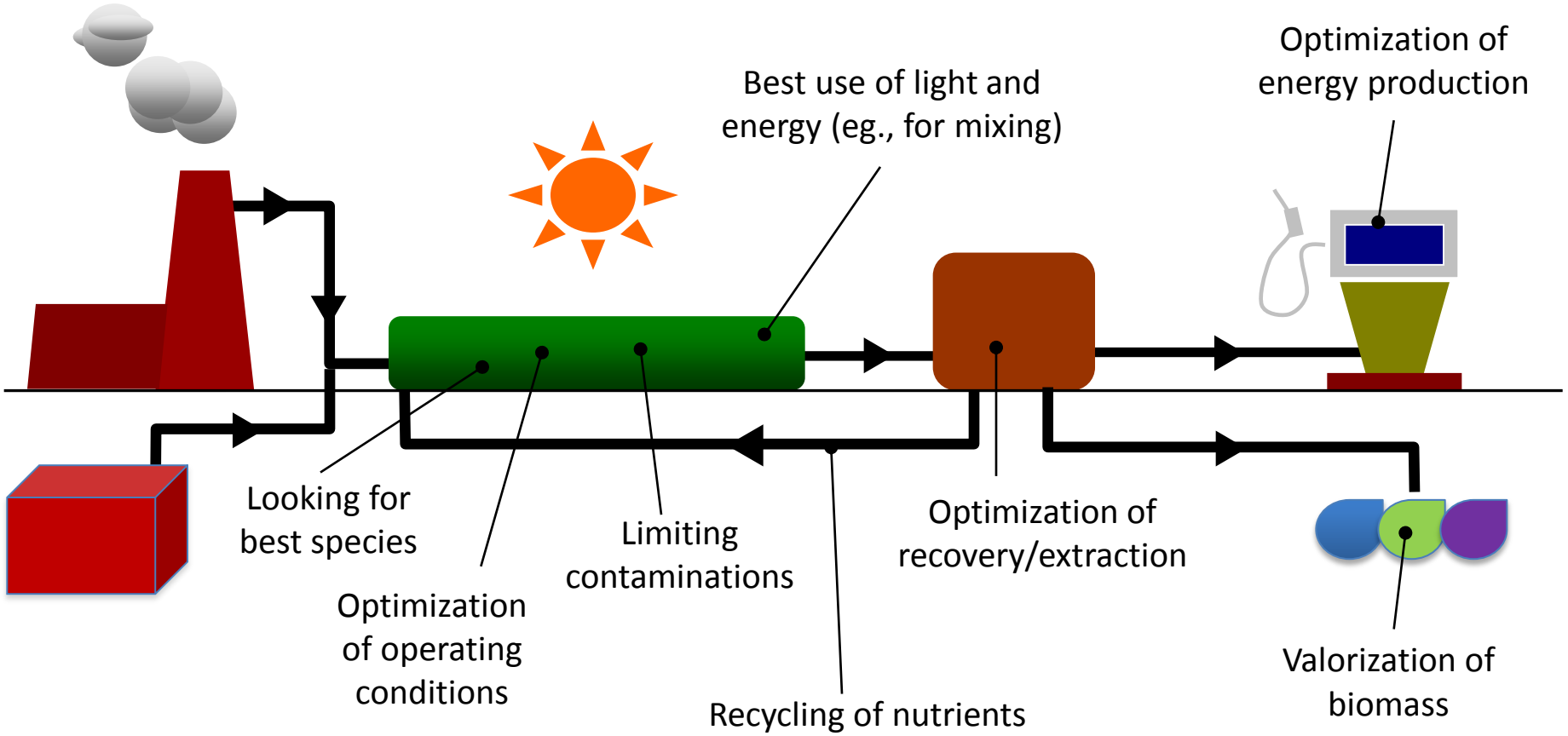
CARREFOURS DE L'INNOVATION AGRONOMIQUE

# Microalgae, many outputs in bioenergy



# Challenges have to be tackled on all involved aspects !



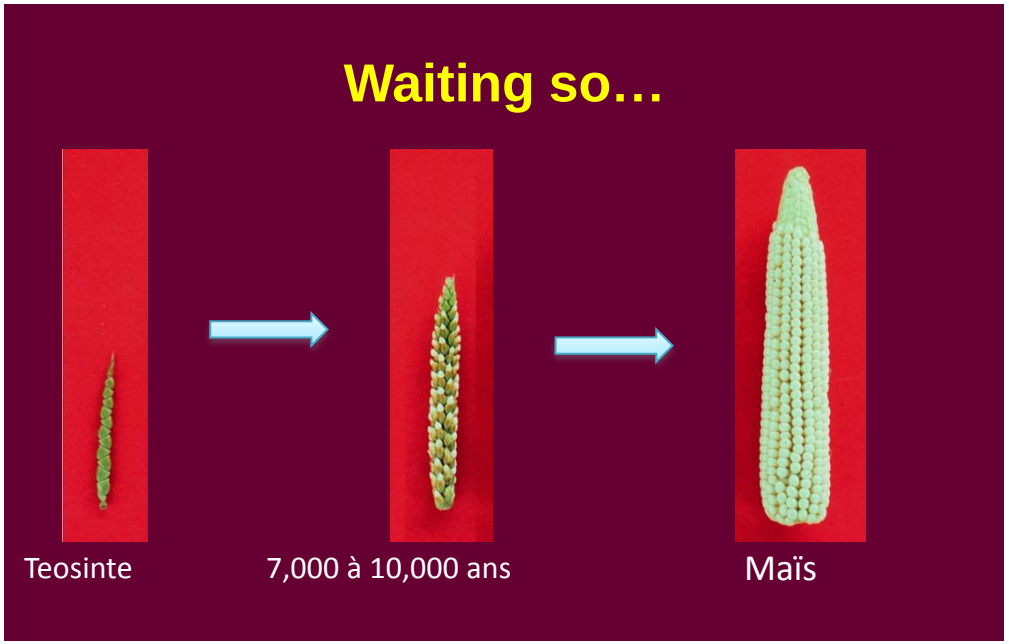

**Together with modeling, control, LCA, economic analysis, legislation, social acceptance, landscape impact**

INRA SCIENCE & IMPACT

CARREFOURS DE L'INNOVATION AGRONOMIQUE

# Why did we study microalgae at INRA ?

**At least 10 years of intense research are needed for…**

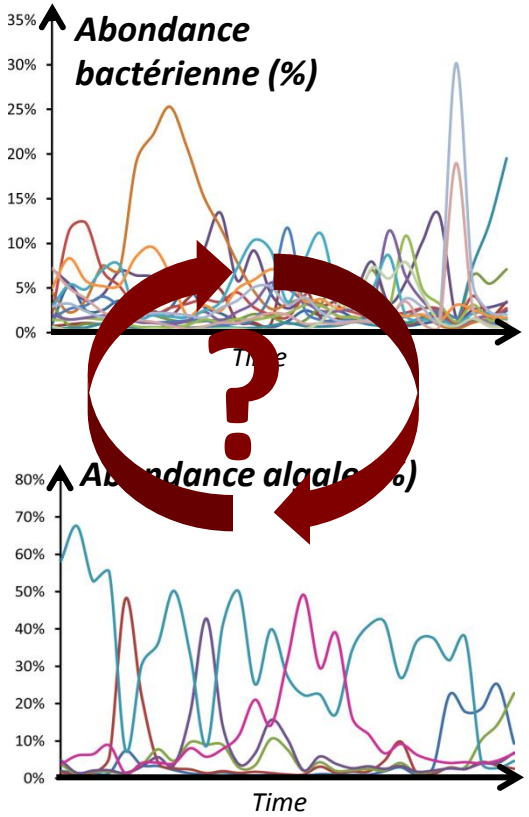




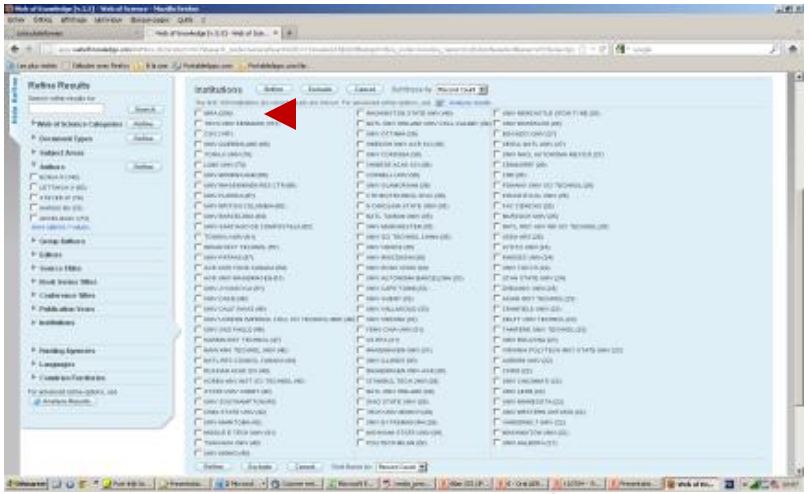
**The agro-ecologic vision of INRA is mandatory !**

# Why did we study microalgae at INRA ?

## A huge potential for new agronomic discoveries !




# Why did we study microalgae at LBE ?

INRA SCIENCE & IMPACT

CARREFOURS DE L'INNOVATION AGRONOMIQUE

# Volta discovering the « marsh gas » in 1776…

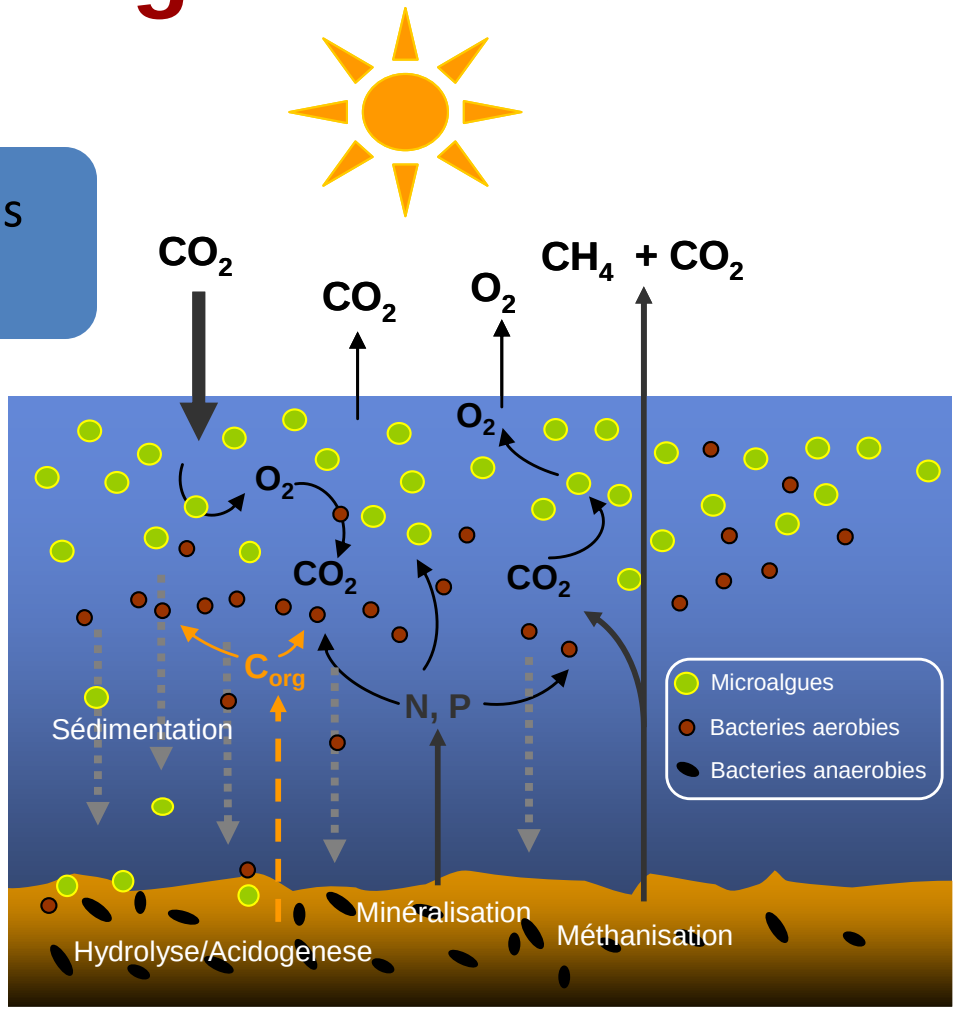
# When looking at Nature

A large part of nitrogen and phosphorus is recycled through the « microbial loop »

Production of biomass

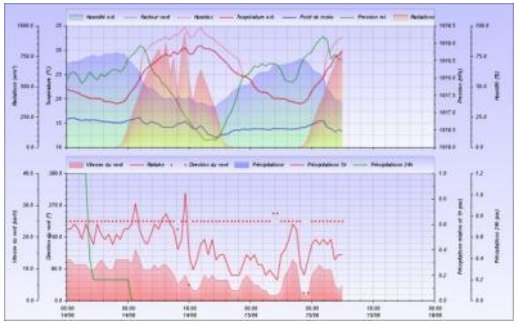
Fixation of $CO_2$

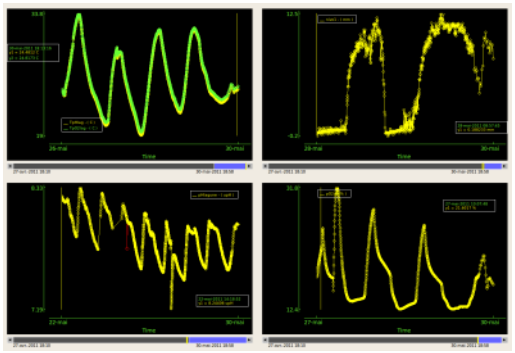
Synergy between algae and bacteria

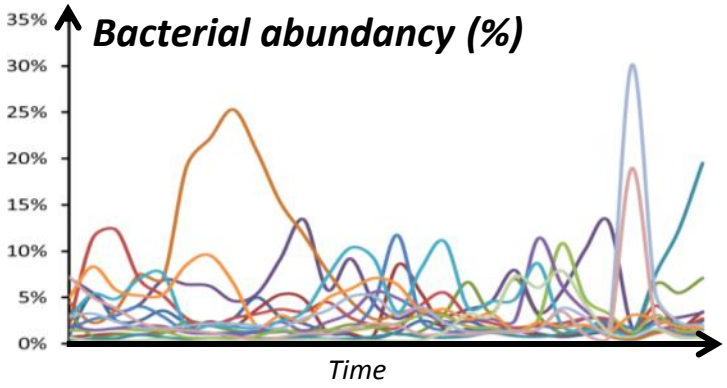


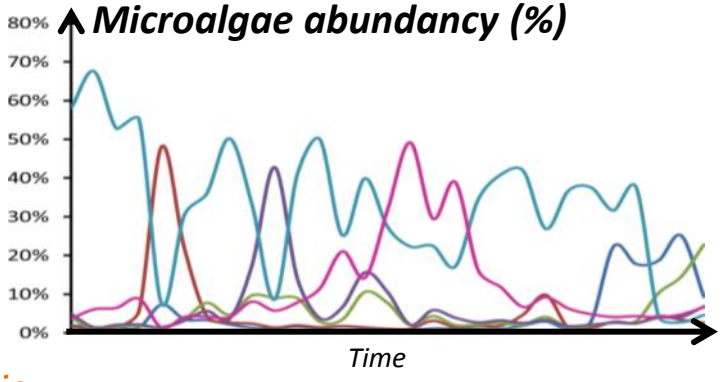

Anaerobic Digestion

# The Algotron process







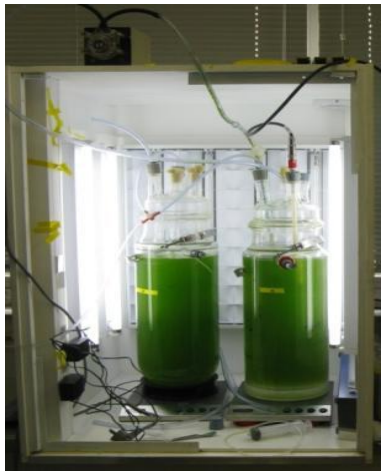

*CE-SSCP : 1 color = 1 specie*
*(1 sample every 3 days)*

# Laboratoire de Biotechnologie de l'Environnement

**Few open and closed microalgae cultivation systems** are also running (up to 450 liters PBR and 56 $m^2$ raceway)








# Anaerobic Digestion of Microalgae

Biotechnology Advances 27 (2009) 409–416

Contents lists available at ScienceDirect

Biotechnology Advances

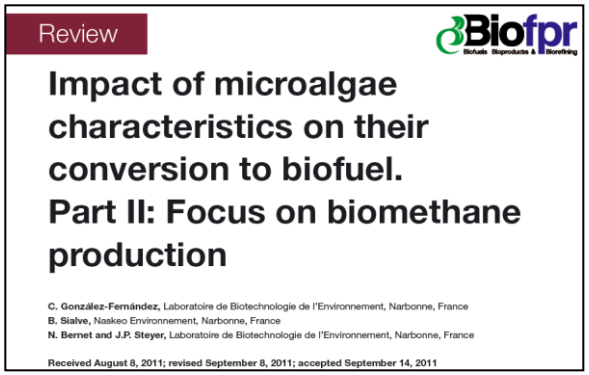
journal homepage: www.elsevier.com/locate/biotechadv

Research review paper

Anaerobic digestion of microalgae as a necessary step to make microalgal biodiesel sustainable

Bruno Sialve [a,*], Nicolas Bernet [a], Olivier Bernard [b]

[a] INRA, UR050, Laboratoire de Biotechnologie de l'Environnement, Avenue des Etangs, Narbonne F-11100, France
[b] INRIA-COMORE, 2004 Avenue des lucioles, BP93, Sophia-Antipolis F-06902, France



Review

Biofpr

Impact of microalgae characteristics on their conversion to biofuel. Part II: Focus on biomethane production

C. González-Fernández, Laboratoire de Biotechnologie de l'Environnement, Narbonne, France
B. Sialve, Naskeo Environnement, Narbonne, France
N. Bernet and J.P. Steyer, Laboratoire de Biotechnologie de l'Environnement, Narbonne, France

Received August 8, 2011; revised September 8, 2011; accepted September 14, 2011

| Organism | Mode | T (° C) | HRT (d) | L $CH_4$ g $VS^{-1}$ | % $CH_4$ |
|---|---|---|---|---|---|
| *Chlorella and Scenedesmus* | Batch | 35-50 | | 0.17-0.32 | 62-64 |
| *Tretraselmis* | CSTRa | 35 | 14 | 0.31 | 72-74 |
| *Spirulina* | Semicontinuous | 30 | 33 | 0.26 | 68-72 |
| *Dunaliella* | Batch | 35 | 28 | 0.44 | ns |
| *Chlorella vulgaris* | Batch | 28-31 | 64 | 0.31-0.35 | 68-75 |
| *Chlorella* | Batch | 34 | 14 | 0.35 | 65 |
| *Chlorella* | Batch | 34 | 25 | 0.44 | 65 |
| *Chlorella* | Batch | 34 | 45 | 0.60 | 65 |
| *Chlorella and Scenedesmus* | CSTRa | 35 | 10 | 0.09-0.136 | 69 |
| *Arthrospira Platensis* | Batch | 38 | 32 | 0.29 | 61 |
| *Chlamydomonas reinhardtii* | Batch | 38 | 32 | 0.39 | 66 |
| *Chlorella Kessleri* | Batch | 38 | 32 | 0.22 | 65 |
| *Dunaliella salina* | Batch | 38 | 32 | 0.32 | 64 |
| *Euglena Gracilis* | Batch | 38 | 32 | 0.32 | 67 |
| *Scenedesmus obliquus* | Batch | 38 | 32 | 0.18 | 62 |
| *Chlorella and Scenedesmus* | Batch | 35 | 40 | 0.16 | 70 |

# Anaerobic Digestion of Microalgae

Bioresource Technology 102 (2011) 200–206

Contents lists available at ScienceDirect

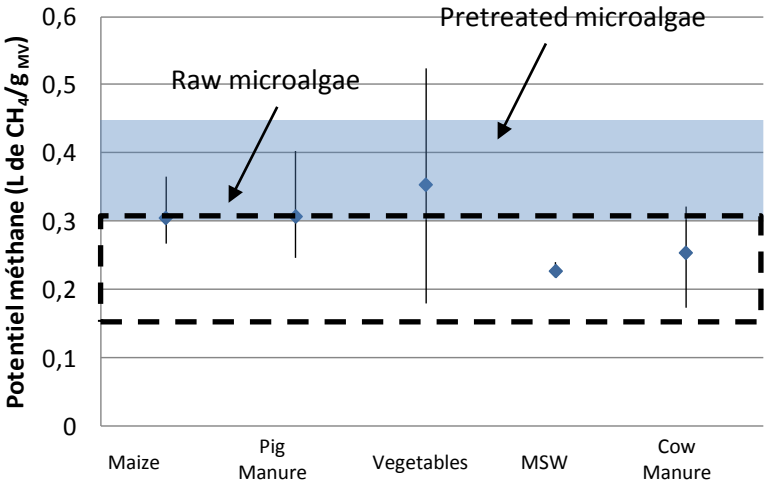
Bioresource Technology

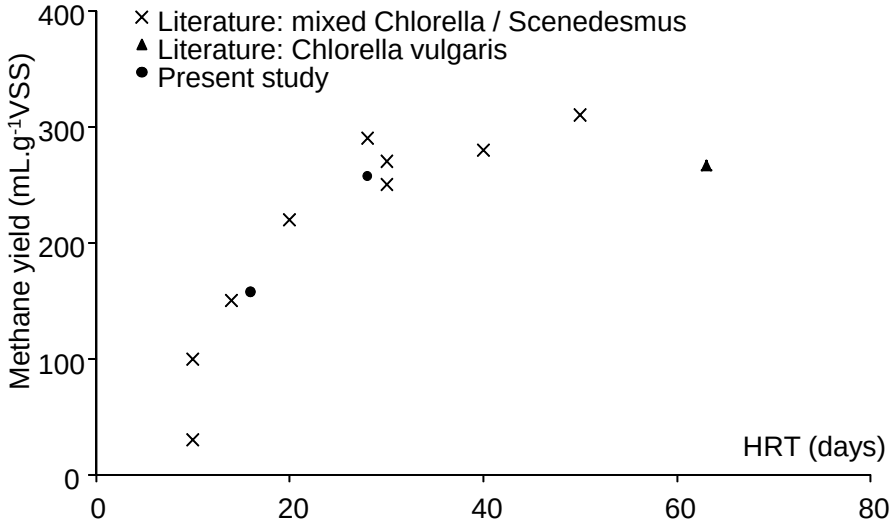
journal homepage: www.elsevier.com/locate/biortech

## Experimental study on a coupled process of production and anaerobic digestion of *Chlorella vulgaris*

Monique Ras [a], Laurent Lardon [a,*], Sialve Bruno [b], Nicolas Bernet [a], Jean-Philippe Steyer [a]

[a] INRA, UR50, Laboratoire de Biotechnologie de l'Environnement, Avenue des Etangs, 11000 Narbonne, France
[b] Naskeo, Avenue des Etangs, 11000 Narbonne, France



# Recycling Digestate to Microalgae

Bioresource Technology 119 (2012) 79–87

Contents lists available at SciVerse ScienceDirect

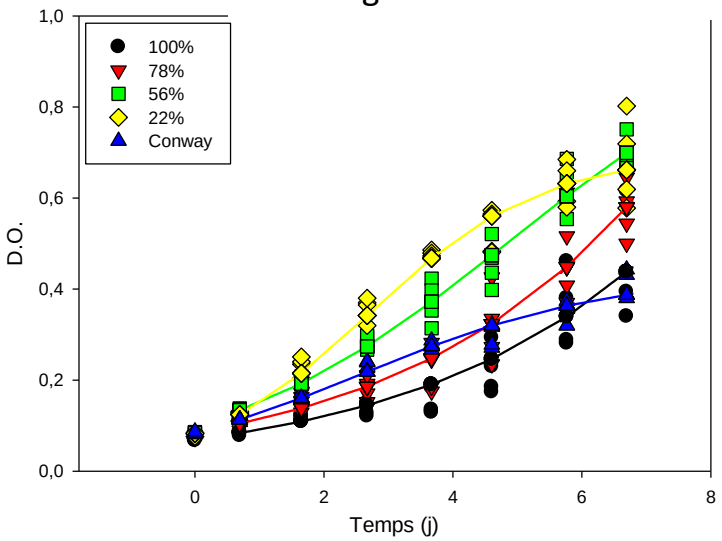
Bioresource Technology

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

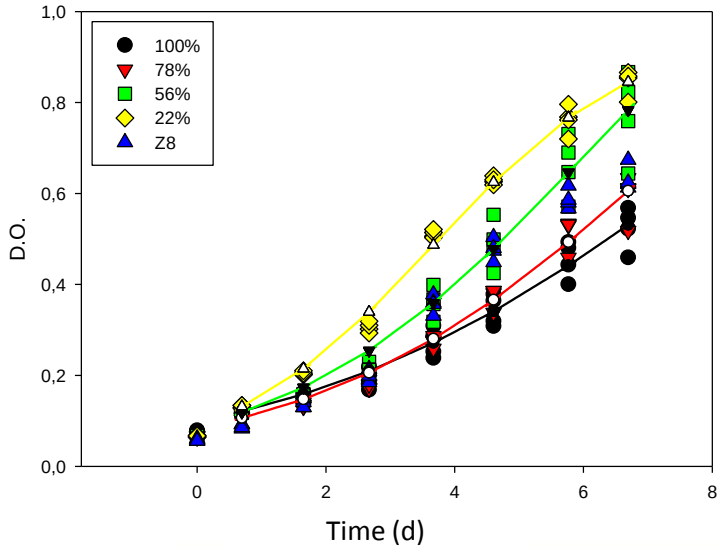
Carbon conversion efficiency and population dynamics of a marine algae–bacteria consortium growing on simplified synthetic digestate: First step in a bioprocess coupling algal production and anaerobic digestion

Christophe Vasseur [a], Gaël Bougaran [b], Matthieu Garnier [b], Jérôme Hamelin [c], Christophe Leboulanger [a], Myriam Le Chevanton [b], Behzad Mostajir [a,d], Bruno Sialve [e], Jean-Philippe Steyer [c], Eric Fouilland [a,*]

Microalgae from sea water




Microalgae from fresh water




INRA SCIENCE & IMPACT

CARREFOURS DE L'INNOVATION AGRONOMIQUE

# Life Cycle Assessment and Ecodesign

VOL. 43, NO. 17, 2009 / ENVIRONMENTAL SCIENCE & TECHNOLOGY ■ 6475

## Life-Cycle Assessment of Biodiesel Production from Microalgae

LAURENT LARDON,*,† ARNAUD HÉLIAS,†,‡ BRUNO SIALVE,§ JEAN-PHILIPPE STEYER,† AND OLIVIER BERNARD§

*INRA, UR50 Laboratoire de Biotechnologie de l'Environnement, Avenue des Etangs, 11100 Narbonne, France, Montpellier SupAgro, 2 Place Pierre Viala, 34060 Montpellier Cedex 1, France, and Comore, INRIA, BP93, Sophia-Antipolis Cedex 06902, France*

*Received March 10, 2009. Revised manuscript received June 8, 2009. Accepted June 18, 2009.*

Bioresource Technology 102 (2011) 207–214

Contents lists available at ScienceDirect

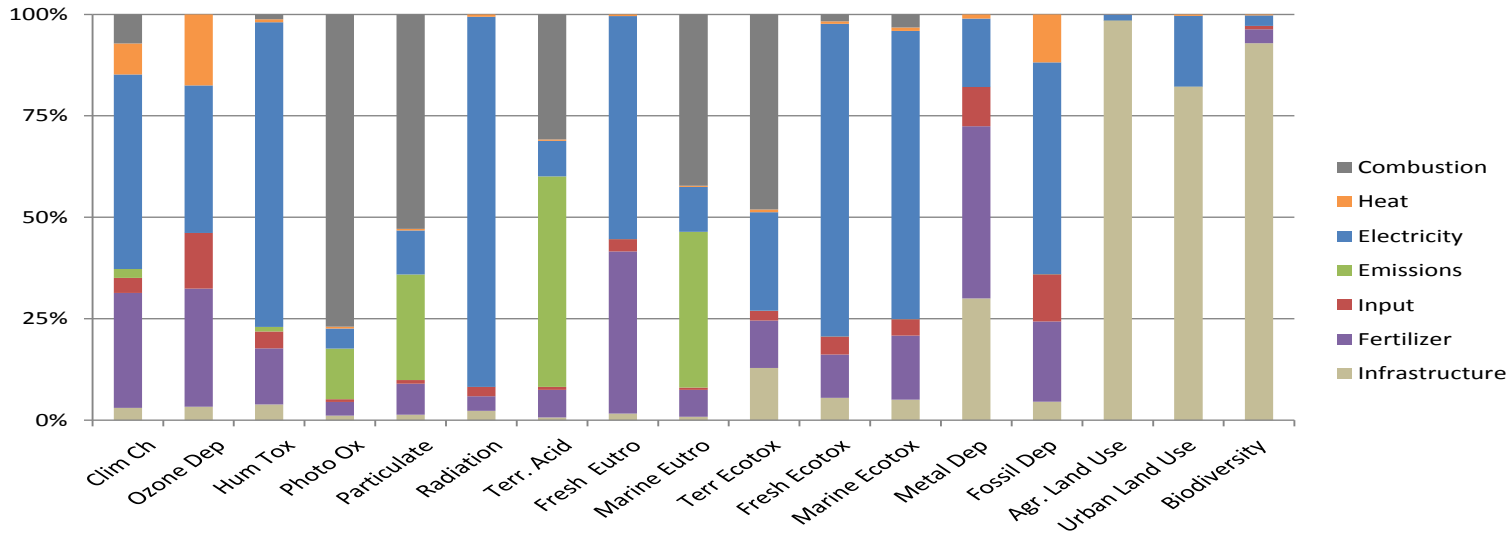
Bioresource Technology

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

## Life-cycle assessment of microalgae culture coupled to biogas production

Pierre Collet [a,*], Arnaud Hélias [a,b], Laurent Lardon [a], Monique Ras [a], Romy-Alice Goy [c], Jean-Philippe Steyer [a]

[a] INRA, UR50, Laboratoire de Biotechnologie de l'Environnement, Avenue des Etangs, 11000 Narbonne, France
[b] Montpellier SupAgro, 2 Place Viala, 34060 Montpellier Cedex 1, France
[c] Naskeo, Laboratoire de Biotechnologie de l'Environnement, Avenue des Etangs, 11000 Narbonne, France




**Need to improve the electricity consumption and/or origin**

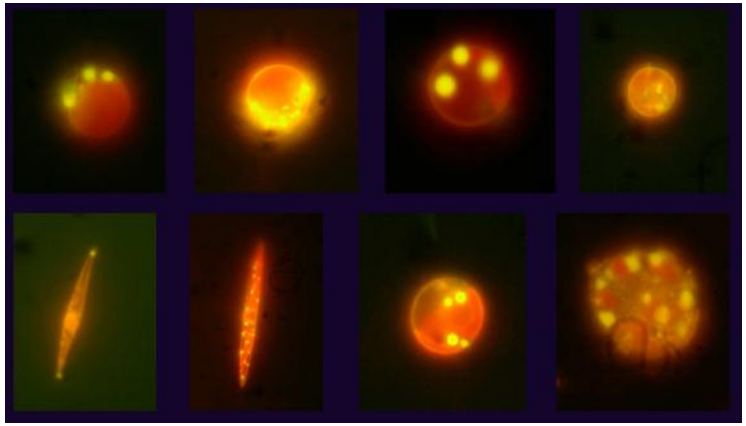
INRA SCIENCE & IMPACT

CARREFOURS DE L'INNOVATION AGRONOMIQUE

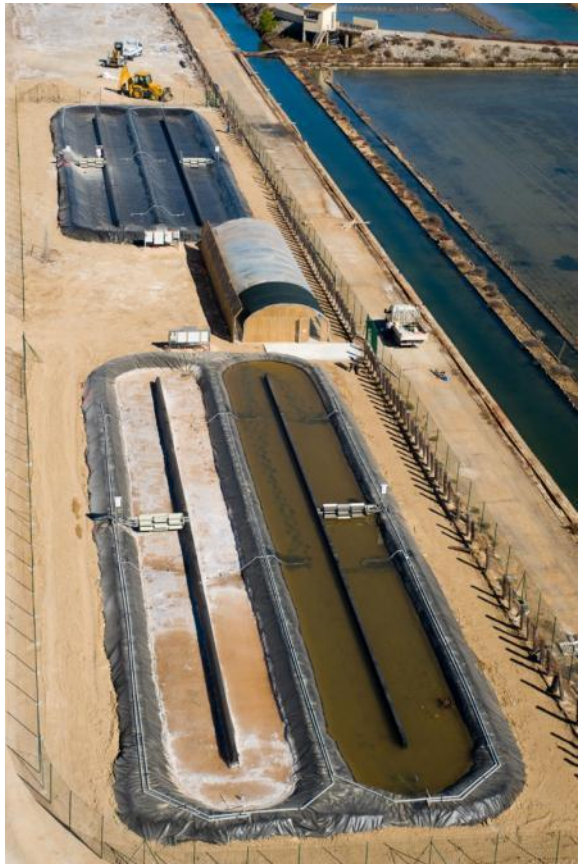
# Salinalgue, an integrated project



Ecology (flamingos)
& environmental impact

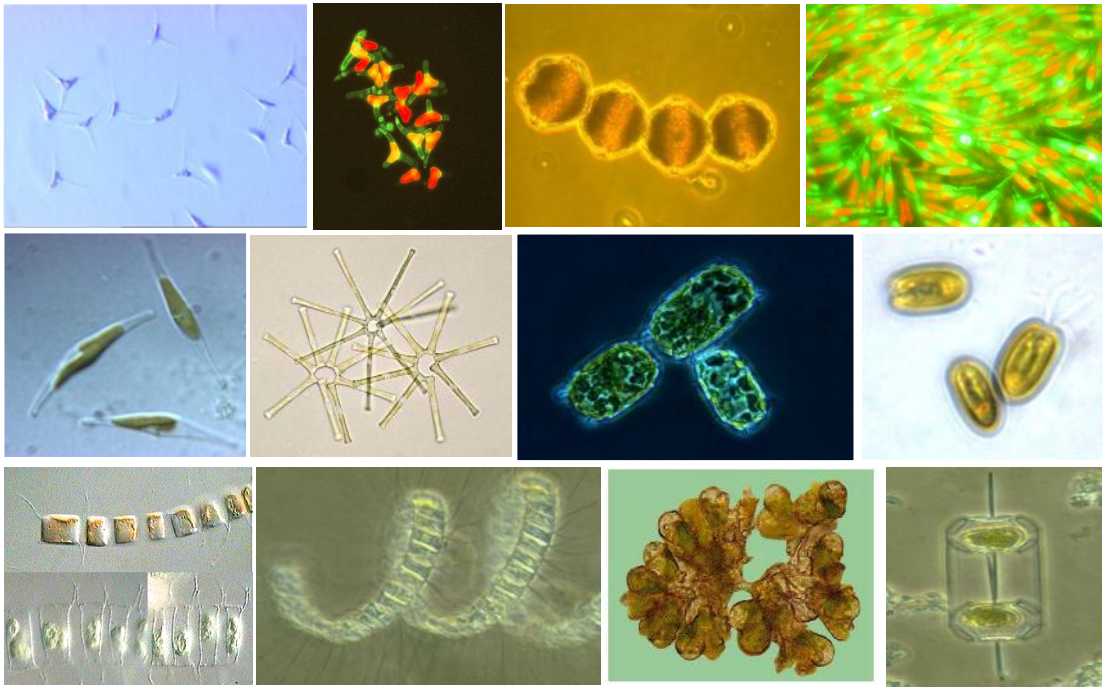


# Salinalgue, an integrated project



# To conclude

## Microalgae are beautiful…



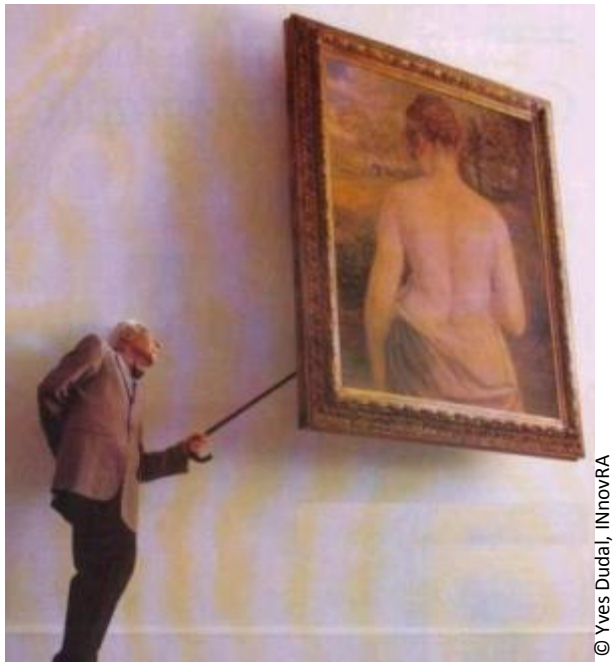
## … and useful !!!

# To conclude

## Macroalgae can also be very useful !

# Thank you very much for your attention

**Curiosity and innovation are needed :**
**Think differently!**



© Yves Dudal, INnovRA

INRA SCIENCE & IMPACT

CARREFOURS DE L'INNOVATION AGRONOMIQUE

# I will be happy to answer any question


For more information

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

Jean-Philippe.Steyer@supagro.inra.fr

# Brachypodium distachyon

Plante modèle pour la génomique fonctionelle chez les graminées

Switchgrass Brachypodium
(photo: John Vogel)

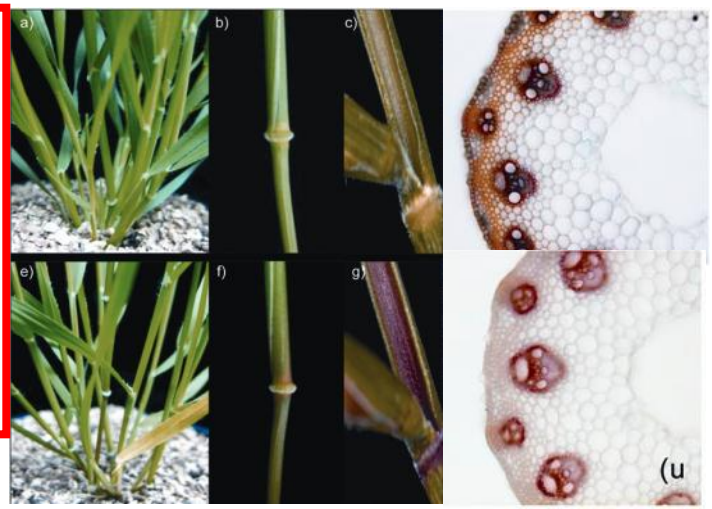
Brachypodium: collection en serre
(photo: Richard Sibout)

INRA SCIENCE & IMPACT

CARREFOURS DE L'INNOVATION AGRONOMIQUE

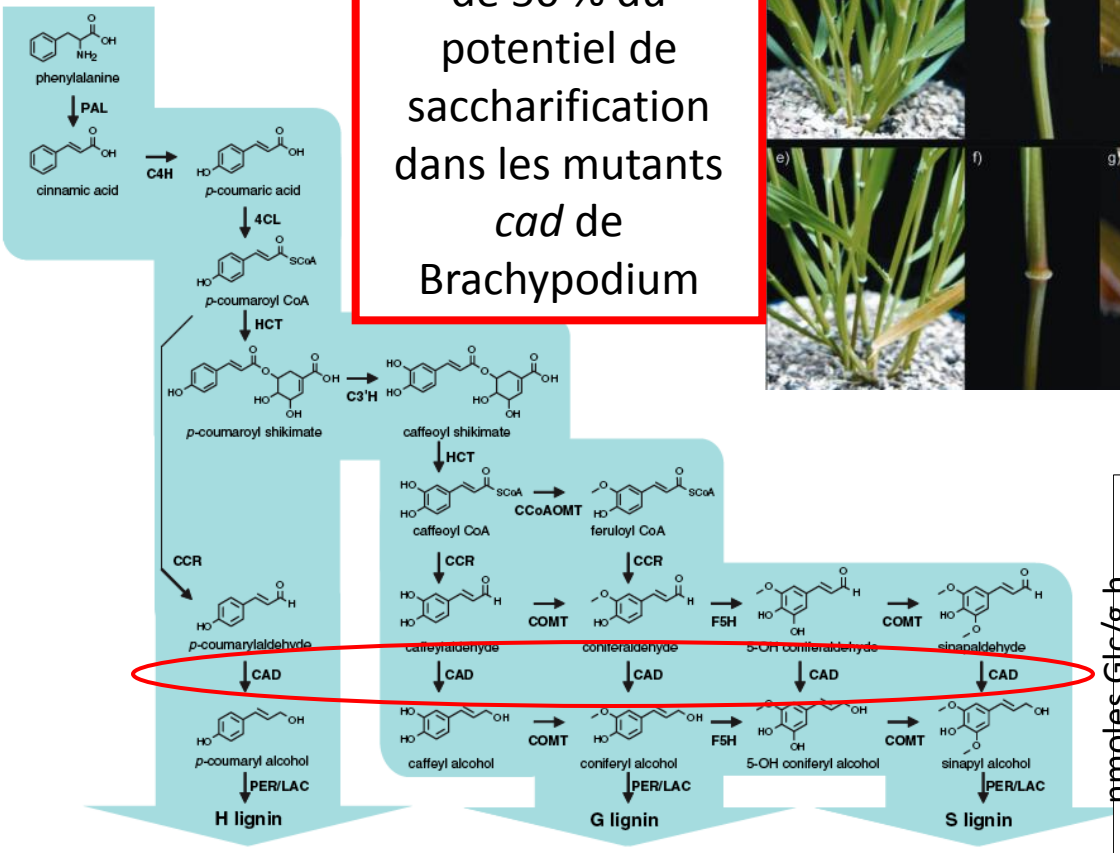
# L'ingénierie du potentiel de saccharification

Une augmentation de 50 % du potentiel de saccharification dans les mutants *cad* de Brachypodium



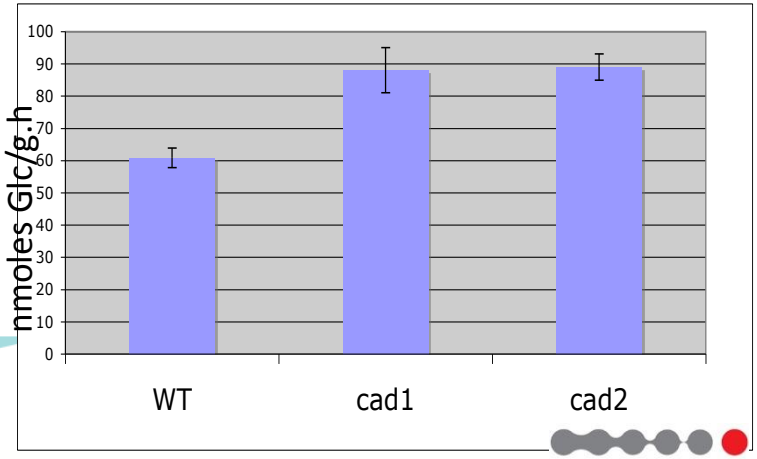
WT

*cad* mutant: Lignines modifiés




Voie de biosynthèse des lignines

Efficacité de saccharification




Bouvier d'Yvoire et al 2013

Renewall

INRA SCIENCE & IMPACT

CARREFOURS DE L'INNOVATION AGRONOMIQUE