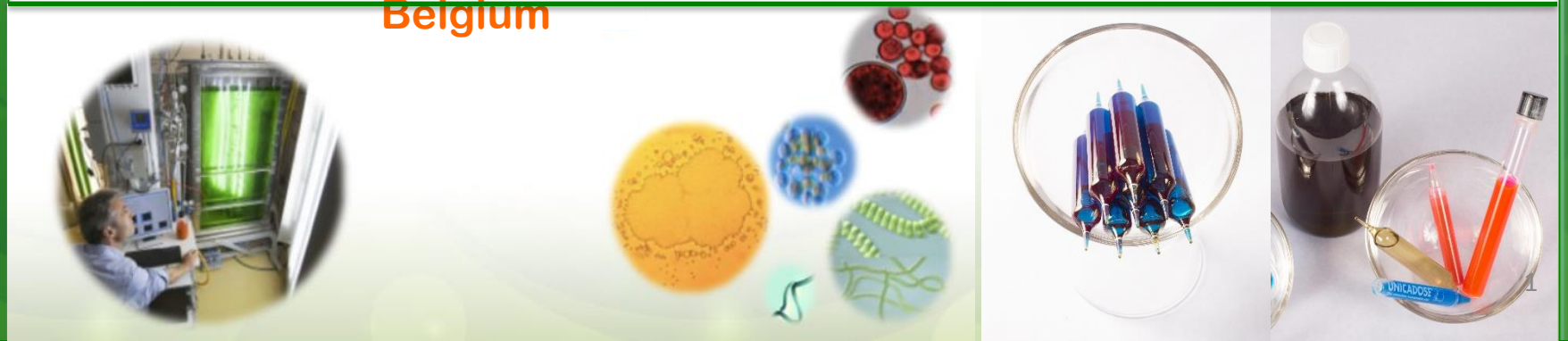
Christophe Lombard, Ph. D.
Manager of industrial integration

AlgoSource TECHNOLOGIES

Capture and recycling of CO_2 from cement plant by use of microalgae

UMONS
ecra chair
from CO_2 to energy

The 9th of November 2016 - Mons, Belgium



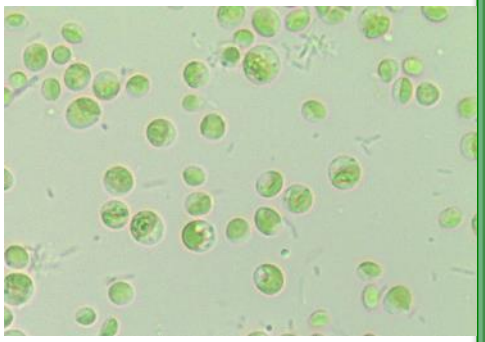
Agenda

- AlgoSource
- CO_2 capture by microalgae
- Microalgae and after ?

Agenda

- **AlgoSource**
- CO_2 capture by microalgae
- Microalgae and after ?

AlgoSource TECHNOLOGIES

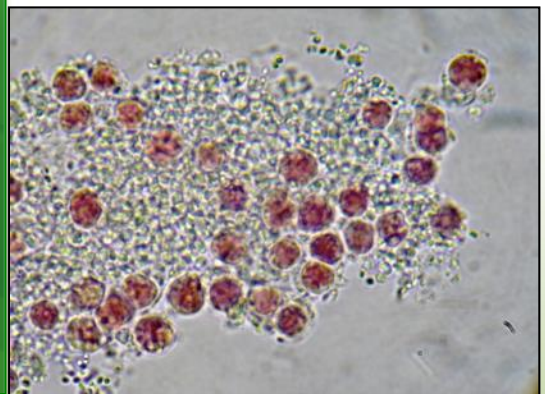


Chlorella vulgaris

Our field :

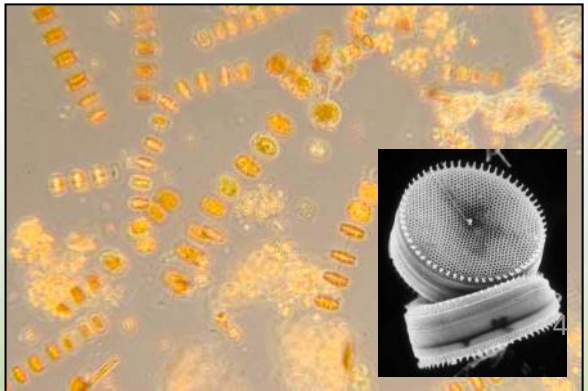
Microalgae

Porphyridium cruentum



Spiruline

Thalassiosira sp.



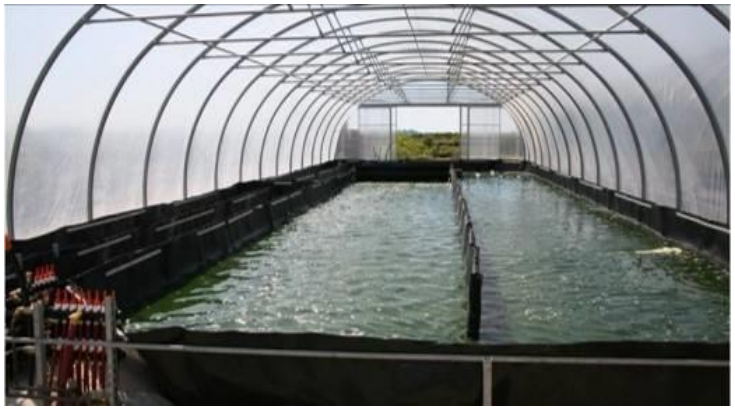
AlgoSource
Saint-Nazaire, France

- More than 20 years of experience, with Alpha-Biotech producing and transforming microalgae since 1993
- 26 people (20 employees, 6 partners)
- Turnover ~ 1,6 M € in 2015, profitable
- Key development : Algo-refining (bio-refining)
- 4 patents

Production and algo-refining

Microalgae engineering

We produce and refine our microalgae biomass



- Fresh- and sea-water strains
- 15 strains cultivated
- Biorefinery of microalgae

CERTIFIED
ISO 9001/14001

ENVIRONMENTAL MANAGEMENT SYSTEM
ISO 14001

Lloyd's Register
LRQA

Antioxidant and immune system booster

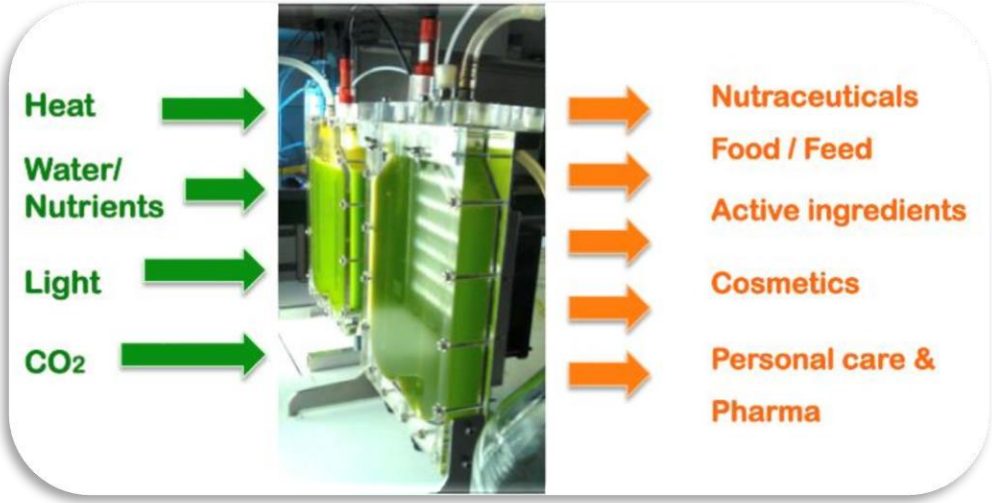
AlgoSource Products (Alpha Biotech)

Production of functional ingredients **for the cosmetic and nutraceutical industries since 1993**

Novel functional drink

Our expertise

PRODUCTION & ENGINEERING OF MICROALGAE From LAB to INDUSTRY



ALGO-REFINING of BIOMASS with ASSETS PRODUCTIO N

VALORISATION of WASTE and EFFLUENTS

MANAGEMENT OF PROJECTS & PARTNERSHIPS JV…

ADEME
Agence de l'Environnement et de la Maîtrise de l'Energie

SEVENTH FRAMEWORK PROGRAMME

Agence Nationale de la Recherche
ANR

EQUIPMENT, TRAINING & SALES

AlgoSource

Expert in production, engineering & biorefinery processes of microalgae

Our vision

We are deeply engaged in a circular economy / sustainable development vision with microalgae

4 concrete axis :

- CO_2 recycling – industrial symbiosis
- Bio-refining (production of bio-bitumen, bio-fuel, high added value compounds, etc…)
- Smart cities (bio-facades)
- Anaerobic digestion of microalgae residues

Smart cities : SymBIO2 project

First bio-façade in France – CSTB – Marnes la Vallée, 2016

"In Vivo" project Paris

Supported by French state (FUI funds)

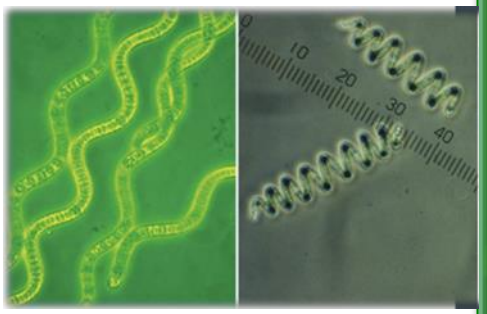
Bioproducts : bio-bitumen

Spirulina residue valorization

algoroute

Hydrothermal liquefaction as a route to transform microalgae residues in bio-asphalt

Patented process



?

AlgoSource
Saint-Nazaire, France

- Strong key **partnership** with GEPEA lab. (University of Nantes & CNRS)
- GEPEA lab. : Laboratory of Process Engineering for Environment and Food
- Around 190 persons, with 40 persons working on bioprocesses applied to microalgae, from biology to the refining of microalgal biomass
- Since **1985**, 300 publications, 10 patents on process engineering applied to microalgae
- Pr. Legrand, Pr. Jaouen & Pr. Pruvost : scientific advisors of AlgoSource

ALGOSOLIS

MICROALGAE R&D FACILITY

The biggest R&D facility in Europe to run industrial programs

cnrs dépasser les frontières

www.cnrs.fr

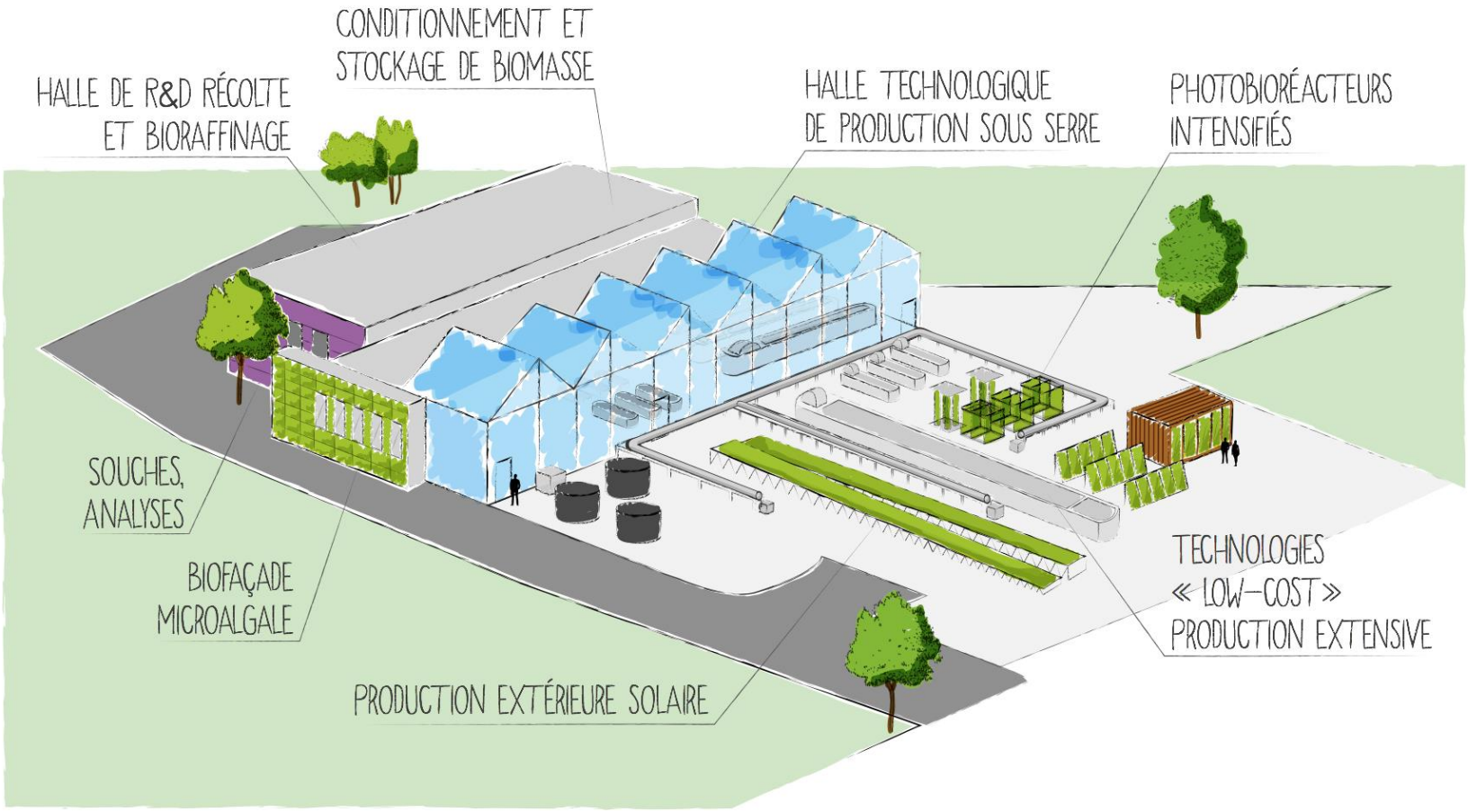
GEPEA

UMR CNRS 6144

UNIVERSITÉ DE NANTES

ALGOSOLIS
MICROALGAE R&D FACILITY

www.algosolis.com



cnrs www.cnrs.fr
GEPEA UMR CNRS 6144
UNIVERSITÉ DE NANTES

ALGOSOLIS

MICROALGAE R&D FACILITY

- Production area: 1500m²
  (350m² in thermoregulated greenhouse)
- Downstream processing R&D unit: 240m²

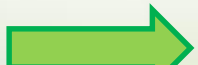
cnrs
www.cnrs.fr

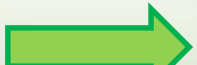
GEPEA
UMR CNRS 6144

UNIVERSITÉ DE NANTES

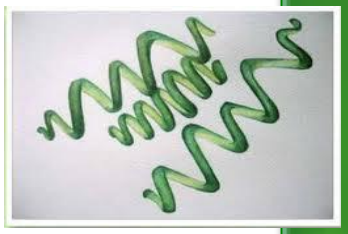
Agenda

- AlgoSource
- **CO_2 capture by microalgae**
- Microalgae and after ?

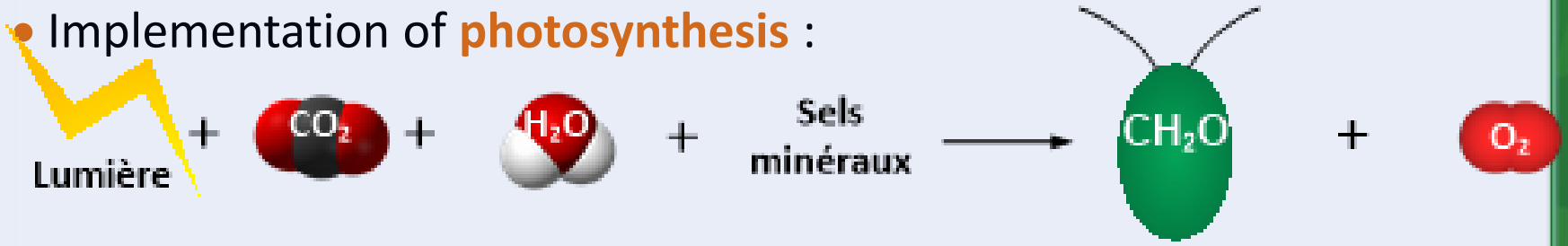




Presentation of microalgae

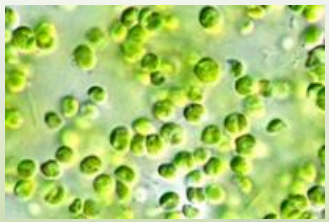


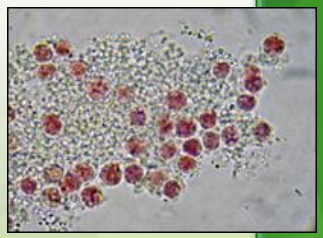
- Phytoplankton (µm)
- Good environmental adaptation
- Large diversity : more than 30 000 identified species (+300 000 ?!)
- High growth rate : 10 times faster than terrestrial green plants
- World annual production : 15000 – 20000 t of dry biomass
- Implementation of **photosynthesis** :



Sun	CO_2	Water	Mineral salts
Natural or artificial	HCO_3^-/CO_3^{2-}		K, N, S, Fe, Ca, Na, P, Mg, Cl, Mn, Zn ,Cu, …

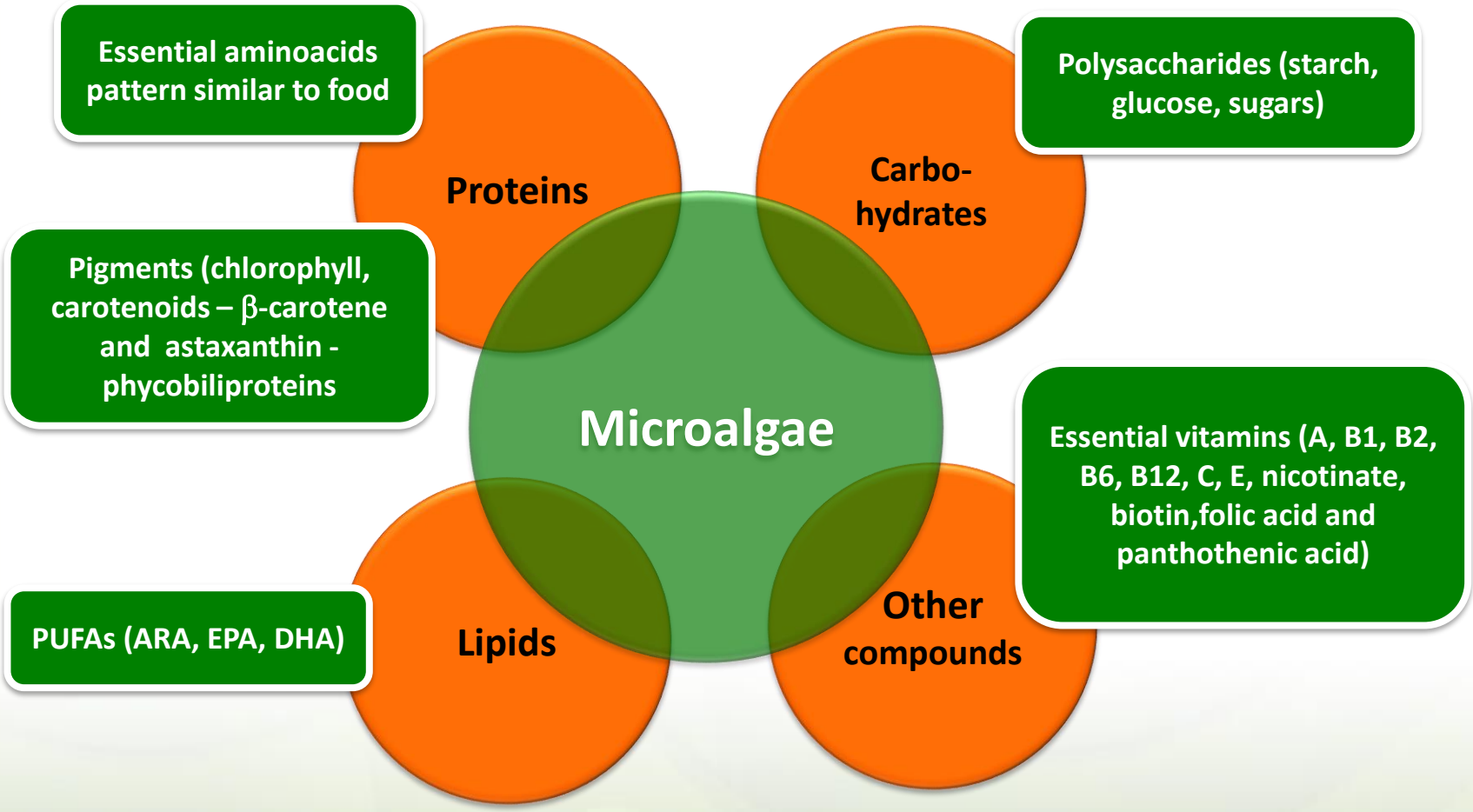
Requires also heat and cold





Presentation of microalgae

- Production of added value compounds by microalgae cells :



These products may represent 25% - 60% by weight of the cell microalgae

Culture of microalgae

- Open systems

AlgoSource (France)

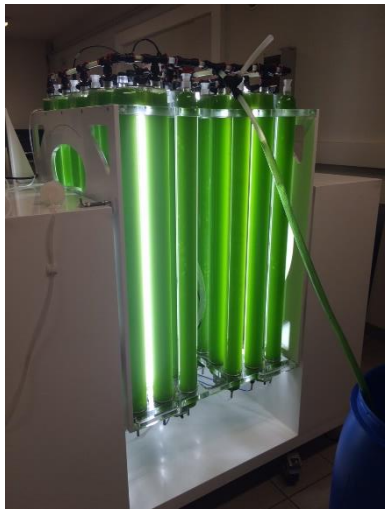
Open raceway ponds

Seambiotic (Israël)

Cyanotech (Hawaï – USA)

Culture of microalgae

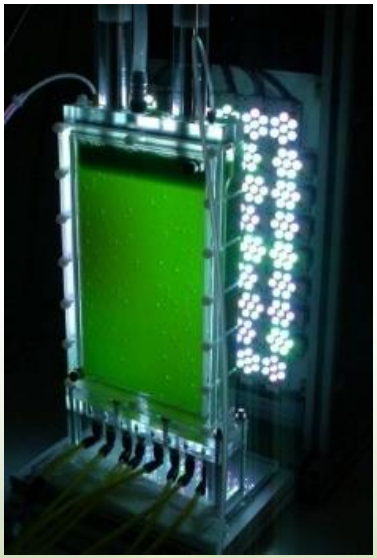
- Closed systems



AlgoSource (France)

Tubular photobioreactor

Algatechnologies (Israël)



Flat photobioreactor

GEPEA (France)

AlgoSolis platform (France)

Closed raceway ponds

General concept

New Industrial symbiosis

Fatal heat

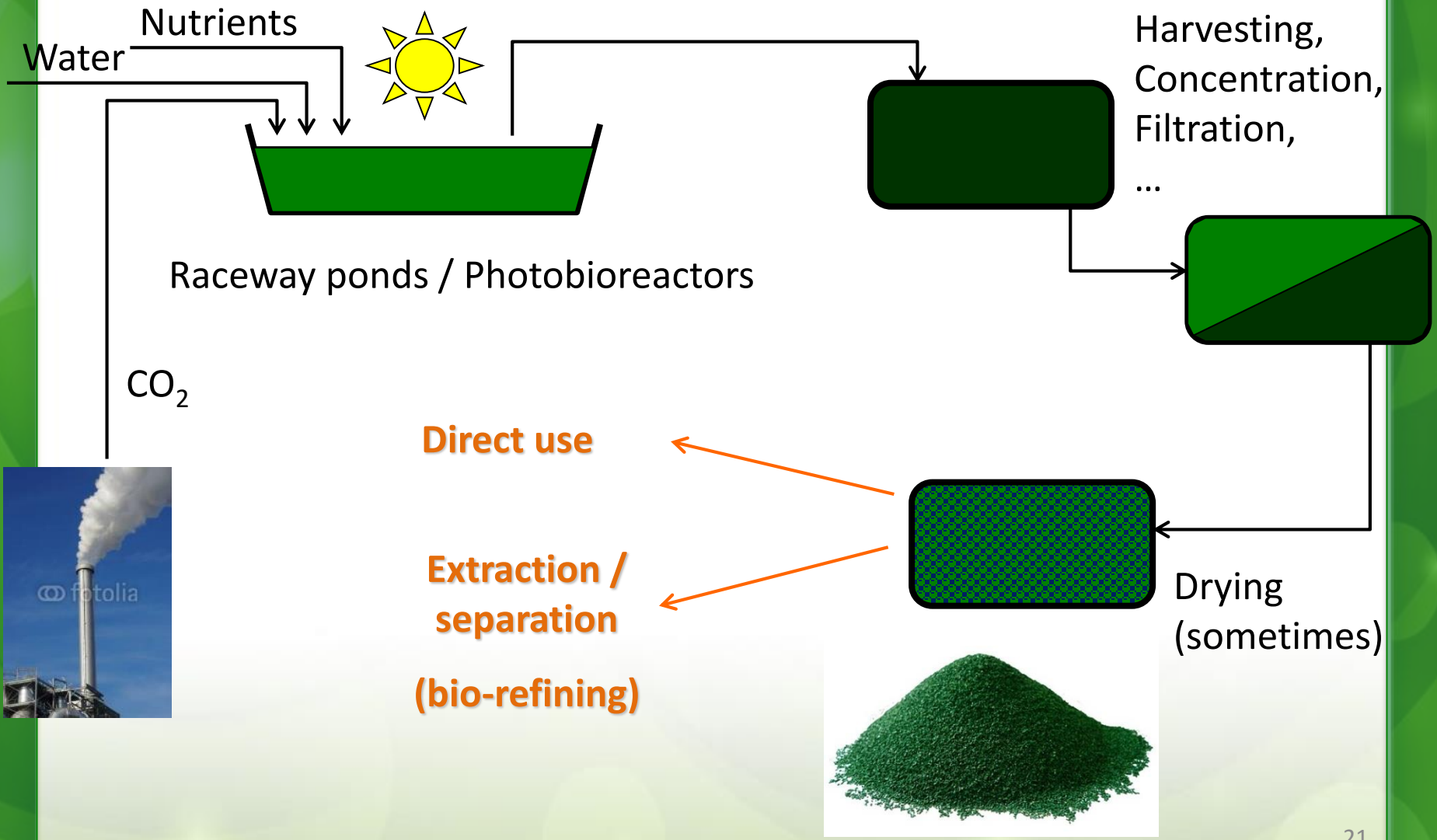
Industrial surface

CO_2

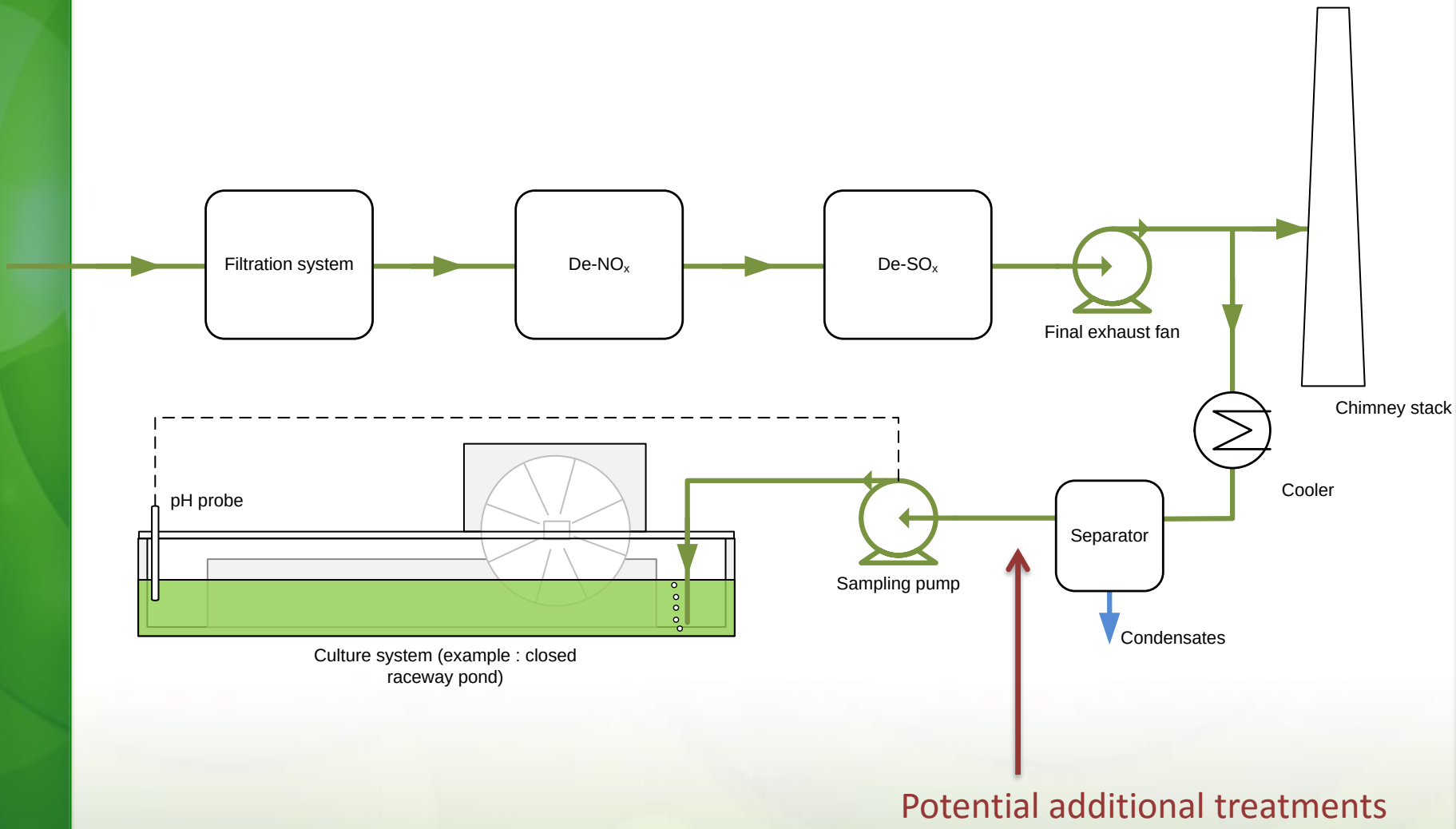
Minerals NO_x Water

Circular economy : waste of industry are resources of other

General concept



General concept



General concept

- **Profits for industrial emitter of CO_2** :
  - valorisation of unused waste (costly waste in future)
  - creation of a new value (from produced microalgae)
  - reduction of CO_2 emissions (depends on size of emitter)
  - also possible valorisation of fatal heat, unused area, etc…
- **Profits for microalgae sector** :
  - significant decrease of production costs (CO_2, heat, area)
  - reduction of environmental impact of microalgae production
  - development of microalgae sector
- **Main issue : market and customers acceptability of such microalgae ?**

Impacts of "pollutants" on microalgae cells development

- Pollutants : NO_x, SO_x, CO, hydracids, metal elements, organic compounds, …
- usually, few scientific articles about impact of a large mix of pollutants on microalgae
- No major effect expected at these concentrations (low SO_x)
- NO_x and SO_x : potentials sources of N and S for microalgae
- Main issue : impact of **large mix** of pollutants on cell development ?
- Metal elements : adsorption of metal elements on cells surface → sometimes, absorption metal elements in cells and potential cellular stress

Example of projects

- Summary of projects in the world for years 2000 – 2010

Project/Company	Location	Flue gas	Photobioreactor	Size	Strain	Results	Status
Pond Biofuels/St Mary	Ontario, Canada	cement plant	?	pilot scale 25 m^3	*local strain*		on going since 2009
A4f/Galp/Secil	Portugal	cement plant	tubular horizontal	10000 m^2	*local strain Chlorella*		on going since 2009
BioFuelSystems/Cemex	Spain	cement plant	tubular vertical	100 m^2	*marine*	impossible	on going since 2010
Lafarge	Austria	cement plant	tubular vertical	lab scale	*Chlorella from Portugal*	no difference between CO_2 / fg	stopped
Lafarge	France	cement plant	closed	pilot scale			2010
AST/Italcementi	France	cement plant	tubular vertical / inclined flat	lab scale	*Chlorella & Spirulina*	10 g/m^2/d	2011 - 2015
Seambiotic	Askhelon, Israël	coal power plant	raceway	3000 m^2	*Nannochloropsis*	20 g/m^2/d	2004 / 2013
ENI	Gela, Italy	refinery	raceway	10000 m^2	*Tetraselmis*	20 g/m^2/d	2008 / 2011
Subitec/Eon	Bremen/Hamburg Germany	natural gaz	flat panel	1,44 m^3	*marine*	15 g/m^2/d	on going since 2008
Subitec/Vattenfall	Senftenberg, Germany	coal power plant	flat panel	2,16 m^3			2010 / 2015
Novagreen/RWE	Bergheim, Germany	coal power plant	plastic bags under GH	600 m^2	*Nannochloropsis*	1,6 g/m^2/d	2010 / 2012
Ingrepro/Akzo Nobel	Delfzijl, Netherlands	power plant	2 open raceway	200 m^2	*Chlorella vulgaris*		2008 / 2012
Cyanotech	Hawaï, USA	Diesel generator	raceway	12000 m^2	*Spirulina*	10 g/m^2/d	1997 / 2010
Salinalgue/Compagnie du v	Gruissan , France	Air Liquide	raceway	10000 m^2	*Dunaliella salina*		2010 / 2014
Linnaeus University/ HeidelbergCement	Degerhamm, Suède	cement plant	closed	pilot scale	*local strain*		on going since 2014
Setec Environnement/ Syctom	Saint Ouen, France	waste incinerator		pilot scale (bioplastics,			2016 - 2021

Example of projects

Portugal

Cement group « Secil »

- Location : Pataias
- Operated by Algaeforfuture (A4f)
- 2009 – 2012 : R&D plateform

  0,1 ha and 20 m^3
- CO_2 from cement plant
- Since 2012 : industrial plant

  1 ha and 1300 m^3
- For Feed & Food

Example of projects

Spain

Cement group « Cemex »

- Location : Alicante
- Operated by BFS
- 2010 – 2015
- CO_2 from cement plant (300 m)
- For energy (“biopetroleum”), Feed & Food

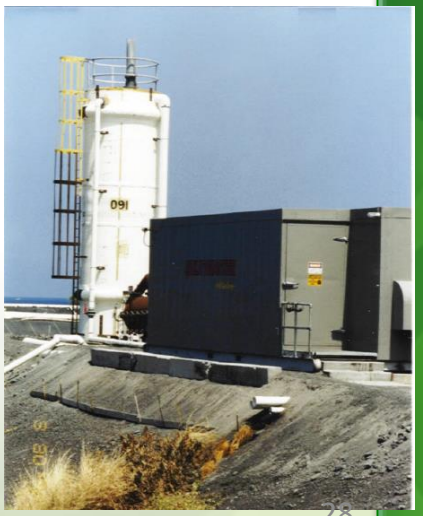
Example of projects

Hawaï - USA

Microalgae producer « Cyanotech »

- Location : Kailua-Kona – Hawaï island
- 1997 – 2010
- CO_2 from electricity generator (patented process)
- Production of *Spirulina* and *Haematococcus pluvialis*

Cyanotech



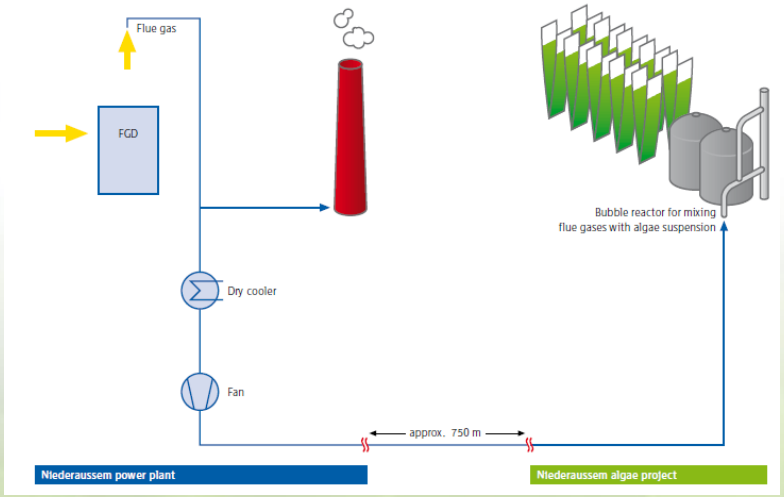
Example of projects

Germany

Power group « RWE »

- Location : BERGHEIM -NIEDERAUSSEM
- 2008 - 2012
- CO_2 from coal power plant
- Production of *Nannochloropsis*

RWE



Example of projects

Israël

Israël Electricity Corporation & Seambiotic

- Location : Ashkelon
- 2004 - 2013
- CO_2 from coal power plant
- Production of *Nannochloropsis* and PolyUnsaturated Fatty Acids

Seambiotic

Additional Flue Gas Desulphurisation system (FGD) : SO_x < 100 mg/Nm³

Example of projects

Israël

Israël Electricity Corporation & Seambiotic

Pilot tests within cement plant

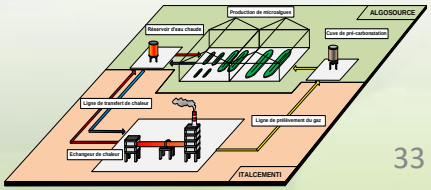
Long partnership since 2008 :

- Gargenville cement plant (France)
- AlgoSource Technologies (AST)
- GEPEA lab.

Pilot tests within cement plant

Goals of project

- Development and operation of sample line of cement plant flue gas
- Development and operation of pilot tests platform of microalgae culture within cement plant
- **Implementation of microalgae culture (artificial and natural light) fed by pure CO_2 (reference) and by cement plant flue gas**
- Tests of several microalgae strains
- Preparation of demonstrator project called "**CIMENTALGUE**" supported by French state (ADEME : national agency about energy and environment)



Pilot tests within cement plant

Gargenville cement plant (near Paris)

Pilot tests within cement plant

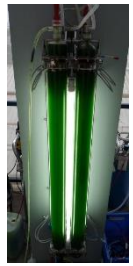
Test plateform

Pilot tests within cement plant

Samples line

Tests plateform

Pilot tests within cement plant

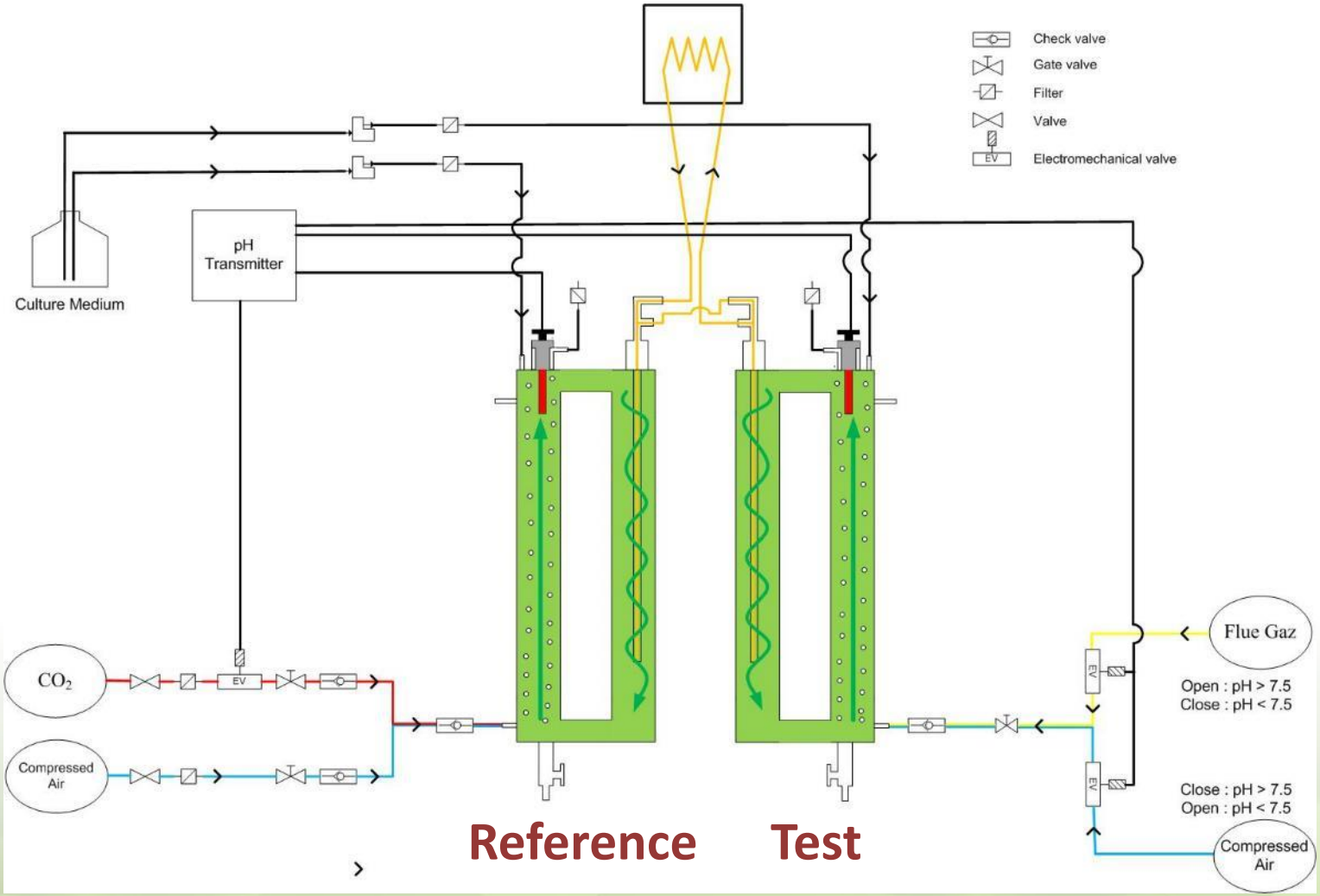


- **Culture with tubular photobioreactors (PBR)**

- Two culture modes : Batch and Continuous (artificial light)
- Reference reactor fed by pure CO_2
- Test reactor fed by cement plant flue gas
- Numerous experiments implementing several microalgae strains – addition of CO_2 or cement plant flue gas depends on pH value of each photobioreactor measured continuously (pH regulation)

Pilot tests within cement plant

- **Culture with tubular photobioreactors (PBR)**



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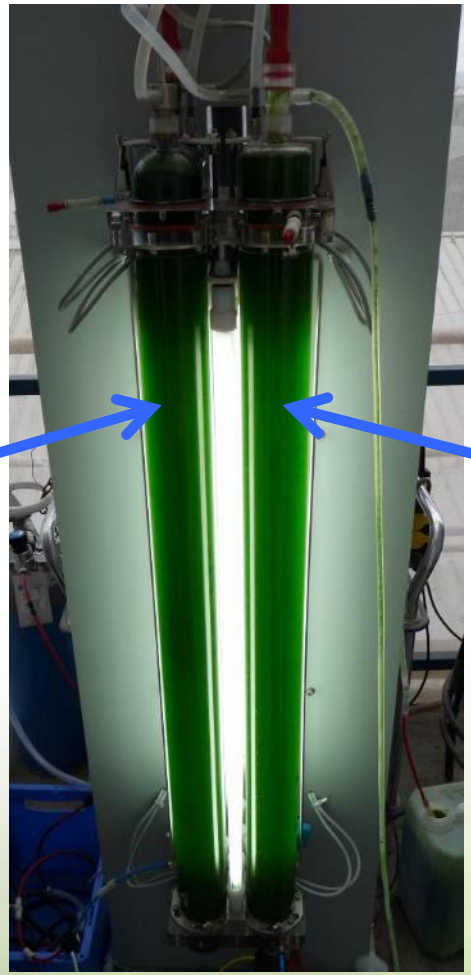
Pilot tests within cement plant

- **Culture with tubular photobioreactors (PBR)**



CO_2 pur

Gaz

Reference

Test

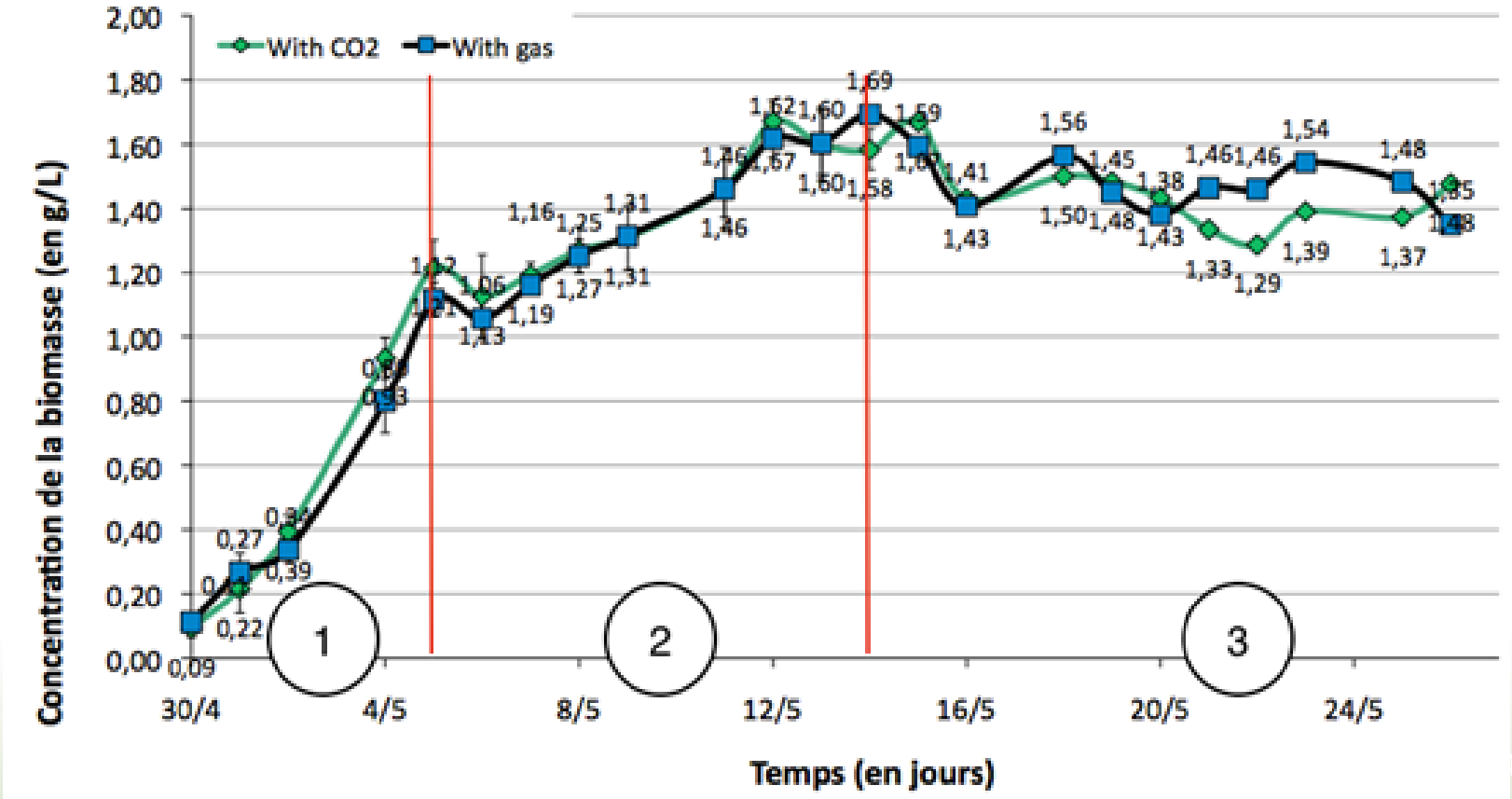
PBR tubulaires le 31/3/15

PBR tubulaires le 1/4/15

PBR tubulaires le 3/4/15

Pilot tests within cement plant

- **Culture with tubular photobioreactors (PBR)**



⇒ Similar productivities to the case with pure CO_2

Pilot tests within cement plant

- **Culture with flat photobioréacteurs (PBR)**

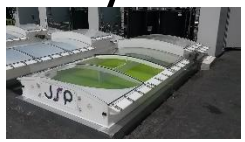
41

Average production : 5 – 10 g/m²/day

Main conclusions about Pilot tests within cement plant

- Yes, it is possible to use flue gas from cement plant as carbon source (CO_2)
- No difference between use of pure CO_2 and use of flue gas about microalgae development
- CO_2 is not a poison for microalgae : concentration of CO_2 is not important if you regulate pH of medium culture (injection of carbon source linked to pH)
- About quality of microalgae : in accordance with European food standards about heavy metals
- Same conclusions with several tested strains
- Flue gas involve water : management of condensate ?

Main points about CO_2 capture by microalgae

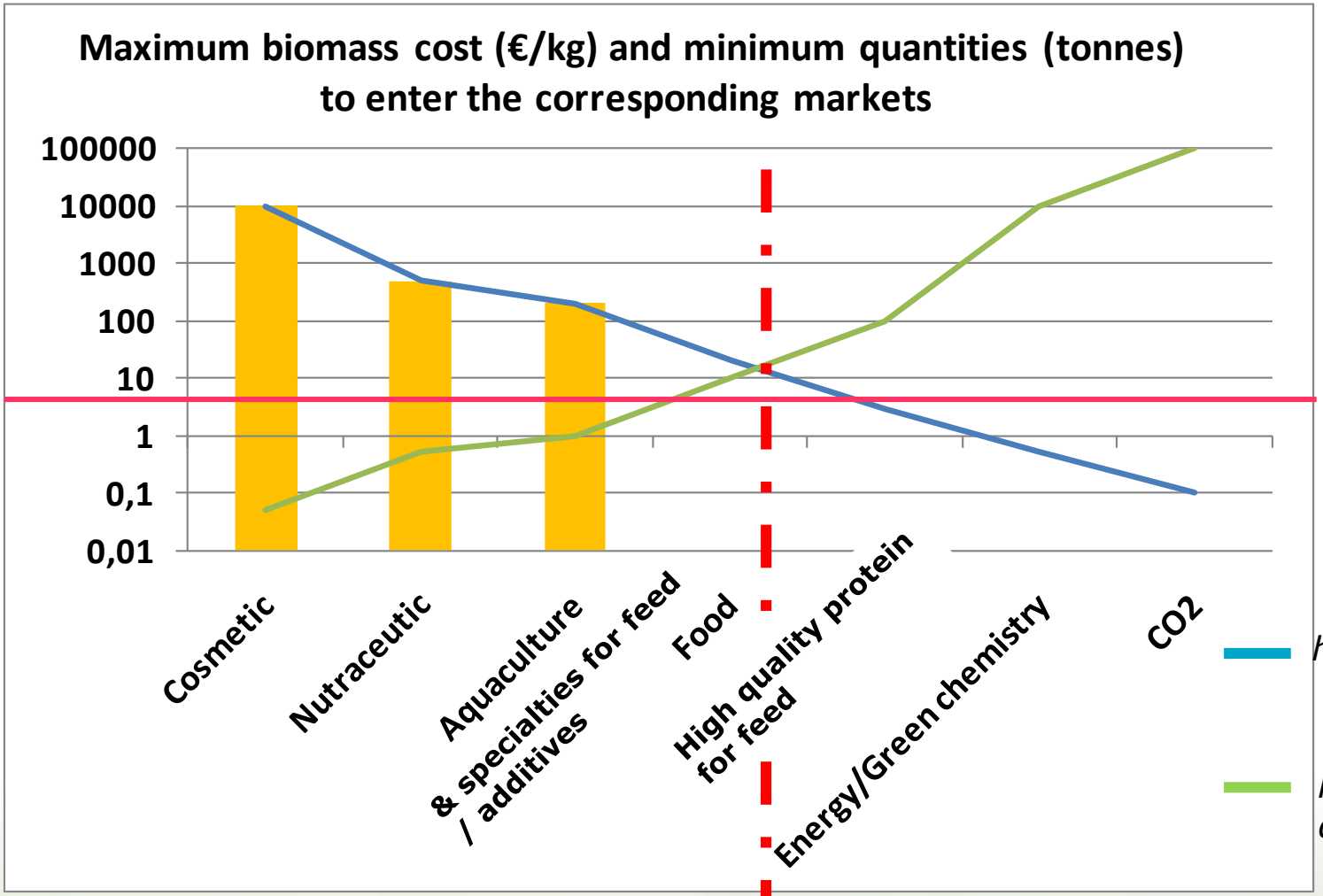



- Implementation of **closed** culture systems : closed raceway ponds or photobioreactors
- Control of temperature $\Rightarrow$ increase of CO_2 capture
- Possible also recycling of **fatal heat**
- No CO_2 chemical capture step (no separation step between $CO_2/O_2/N_2$)
- Potential additional filtration and FDG : depends cement plants
- Production of **1 kg** of dry biomass requires **1,85 kg of CO_2**
- Capture of **40 t – 50 t CO_2/ha/year**
- Require land and water (current development about culture medium recycling)

Agenda

- AlgoSource
- CO_2 capture by microalgae
- **Microalgae and after ?**

Future of microalgae



Existing opportunities ⟷ **The future to Shape**

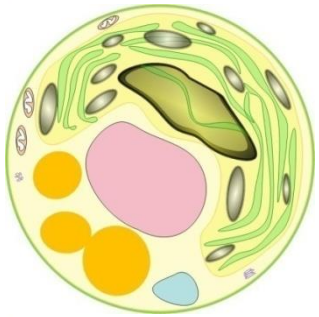
Future of microalgae

Direct use or Algo-refining

- **Food supplements** : proteins; anti-oxidants; pigments and food coloring; dietary additives; PUFA (DHA, EPA); health promoting molecules (anti-cancer; skin protection; strengthening natural defences)
- **Cosmetics and pharmaceuticals** : lipids for cosmetics, exo-polysaccharides for medical application : anticoagulant, cell therapy, tissue engineering, antiviral activity, etc…
- **Feed for animals, pets, aquaculture (fish, crustaceans, molluscs)** : pigments; proteins; lipids (<u>in order to replace fishmeal</u>)
- **Specific materials** : molecules for soap/surfactant and plastics, lipids for bio-bitumen
- **ENERGY** : lipids for bio-fuels; carbo-hydrates for bio-ethanol

What is Algo-refining ?

Algorefining is the way to optimize the production of products and the value of the microalgae biomass : separation of compounds in microalgae cells



Carbohydrates :
EPS

Lipids :
TAG, AGPI

Metabolites of interest

Cellular wall Protein…

+ extracted medium with high value…

Extraction and market development

Algo-refining generic processes

Harvesting

Exo metabolites

Product 1

Fresh Biomass

Extraction 1

Product 2

Extraction 2

Microalgal oil

Product 3

Additional treatment

Product 4

Structural molecule

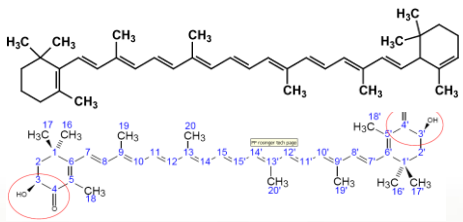
Final residue

Product 5

Value of molecules from microalgae

Price to sell the extracts after algo-refining

- TriAcylGlycerides (TAGs) : 0,6 €/kg (for bio-diesel)
- PolyUnsaturatedFattyAcids (PUFAs ω3 – ω6 –ω9) : 100 €/kg
- ExoPolySaccharides (EPS) : +1000 €/kg
- Proteins high grade : 1000 €/kg
- Pigments :
  - Phycocyanine : +1000 €/kg
  - β-carotene : +1000 €/kg
  - Astaxanthine : +10000 €/kg
  - PhycoErythrine : > 100 €/mg



- Vitamins : E : +100 €/kg
- …

AlgoSource and microalgae

Through partnerships, AlgoSource studies large scale markets :

- Animal feed with SOFIPROTEOL; ADDISEO; COOPERL;

- Feed for aquaculture with SUPRABIO European project

- Materials : bio-bitumen with « AlgoRoute » project (patent)

- Energy and co-products : Shamash, Diesalg, BIOFAT

Thanks for your attention !

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