GEnie des Procédés
Environnement
Agroalimentaire

GEPEA

UMR-CNRS 6144

UNIVERSITÉ DE NANTES

ECOLE DES MINES DE NANTES

Workshop – Fondation Tuck & Total

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Biochemical transformation – Biological use of CO_2

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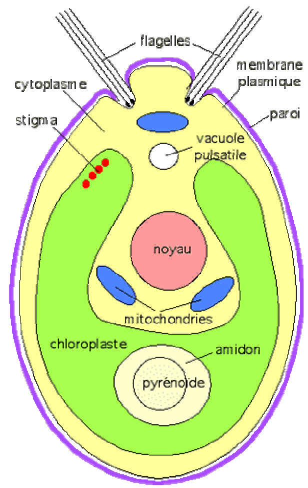
Photosynthesis

$$CO_2 + 0.512H_2O + 0.0063MgSO_4 + 0.181NH_4Cl + 0.0213K_2HPO_4 \longrightarrow CH_{1.77}O_{0.472}N_{0.181}S_{0.063}P_{0.0213} + 1.0752O_2 + 0.0063Mg + 0.181Cl + 0.0426K$$

1 kg CO_2 ——> 0.6 kg biomass

Photosynthesis: chloroplastes

Light absorption: pigments = Chlorophyll + (phycobiliproteins - carotenoïds)



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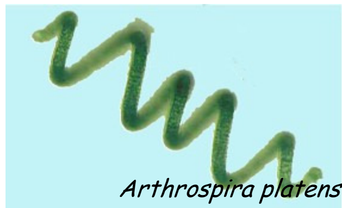
Photosynthesis

Photosynthetic microorganisms: **microalgae**, **cyanobacteria** and some **bacteria**.

Animal kingdom

Vegetal kingdom



Photosynthesis growth: **mineral media without organic substrat (photoautotroph organism), by absorption of inorganic carbone thanks to photonic energy**

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Photosynthesis

- Great diversity (>30 000 species)
- Various biochemical composition
- High growth rate

- High **protein concentration**
- **Carbohydrates**: starch, glucose, polysaccharides
- **Lipids**: fatty acids (w_3, w_6) – 1-70% dry matter
- **Vitamins** : A, B_1, B_2, B_6, B_{12}, C, E…
- **Pigments**: carotenoïds, phycobiliproteins

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Production technology

✓Lagoon, pond, raceways

Open solar photobioreactors

Advantages:
Simple conception
Extensive mass production
Low investment cost

Drawbacks:
No temperature control, evaporation, contamination
Réserved for specific strains (hardy to contamination, extremophiles) → *Skeletonema costatum (eutrophisation), Dunaliella salina*, *Spiruline)*

Major part of actual production
(5000 - 6000 tons per year of dry matter)

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Examples of open solar photobioreactors

***Skeletonema costatum* - Bouin** *(phot. Ifremer de O.Barbaroux)*

***Arthrospira platensis* California** *(22 hectares : projet Earthrise Farms -Fox)*

***Odontella aurita* - Bouin** *: société Innovalg (phot. Ifremer de O.Barbaroux)*

Haematococcus p . - Hawaï

β-carotène - Australia

(société Betatene)

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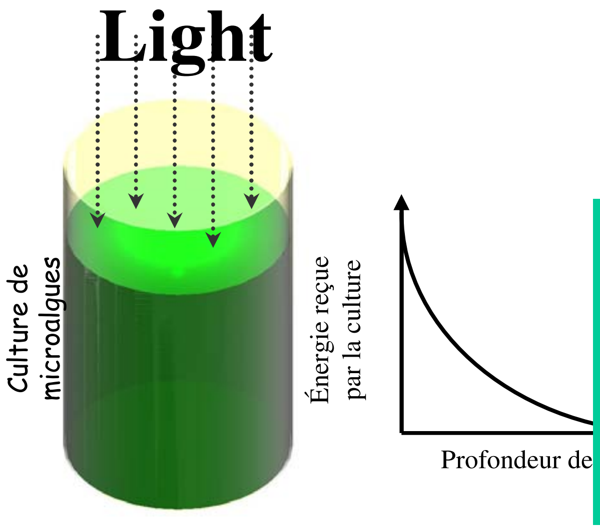
Principle of photobioreactors

Photosynthetic microorganisms (microalgae, cyanobacteria)

- Metabolism dependent on light

Development of <u>photobioreactors</u>



Light attenuation in the culture
→Heterogeneous distribution
→Not a classic substrate

Photobioreactors based on specific geometries (High S/V)

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Principle of photobioreactors

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Classification:

- Artificial or solar light
- Closed or open systems
- Cylindrical tank, plan systems, tubular reactors
- Free or immobilised cells
- Mechanical agitation or airlift

Dependent on the applications

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Closed solar photobioreactors

✓**Tubular or plan systems - « airlift »**

•**Not well developed technology**: few industrial examples with respect to open systems
•**Need to improve the performance to be cost-effective**: control of culture conditions at large-scale production, use of solar flux, energetic consumption, management of the input-output.

⇨ **Intensification could be possible, contrary to open pounds.**

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Closed solar photobioreactors

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Culture of *Chlorella vulgaris* in greenhouse of 2000 m² (500 kms of glass tube, volume of 700 m³).

Système commercialisé par la société B. Braun Biotech International GmbH (BBI).

Same system of 5000 l for CO_2 fixation (Germany)

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Closed solar photobioreactors

Culture of *Haematococcus pluvialis* for the production of astaxanthine (20000 l on a 100 m² area - **société MeraPharmaceuticals - Hawaii).**

Culture of *Porphyridium purpureum* (tube of 80 m long - 5.3 cm in diameter, volume 200l. Circulation by 4m high-airlift

Artificial light photobioreactors

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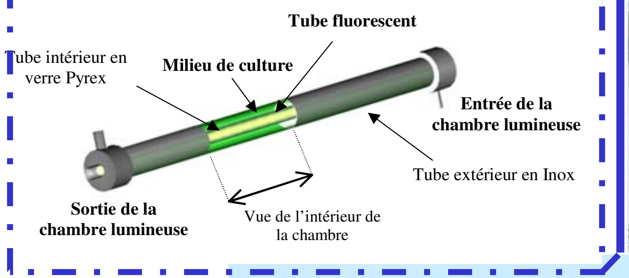
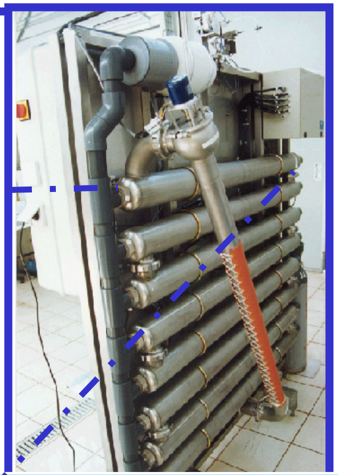
Scobalite tanks for aquaculture

Plan reactor for *chlorella* (500 l)

Photobioreactor LAMP of 100 l (Ifremer)





Tubular system of 20 l with fluorescents tubes (PBR 20 : Braun Biotech International GmbH (BBI).

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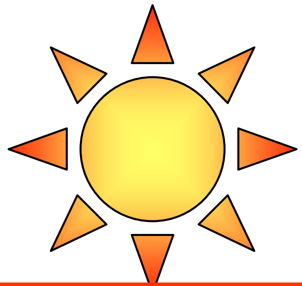
Production of biohydrogen (ANR PhotobioH_2, Solar H_2)

Photosynthesis

solar light + water + CO_2 → H_2

Complex physiologic mecanisms



Sun
(visible spectra)

Photosynthesis yield
+ conversion reaction
(min 4 photons by H2)

Theoretical yield of bioconversion photons => H_2

10%

Combustion energy of H2/ Incident solar energy

France: energy need = 1/1000 incident solar energy
Yield of 10% → 1% of the surface !

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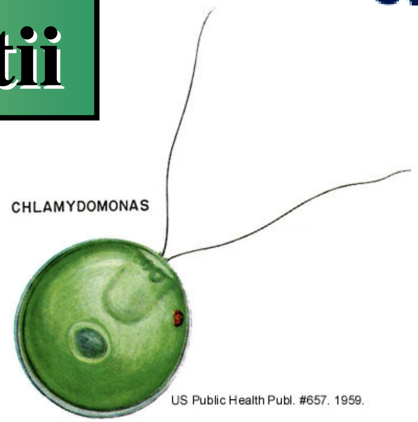
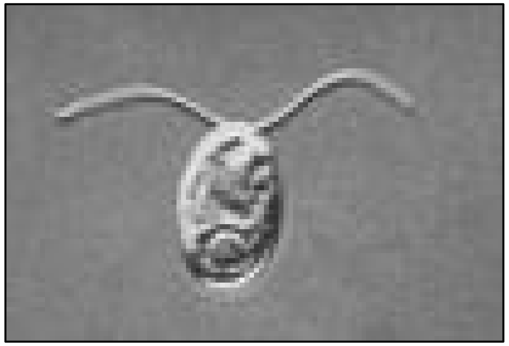
Chlamydomonas reinhardtii



. Unicellular green microalgae; bi flagellate;

Model microrganism: easy culture; well-studied photosynthesis

. Hydrogenase with high activity



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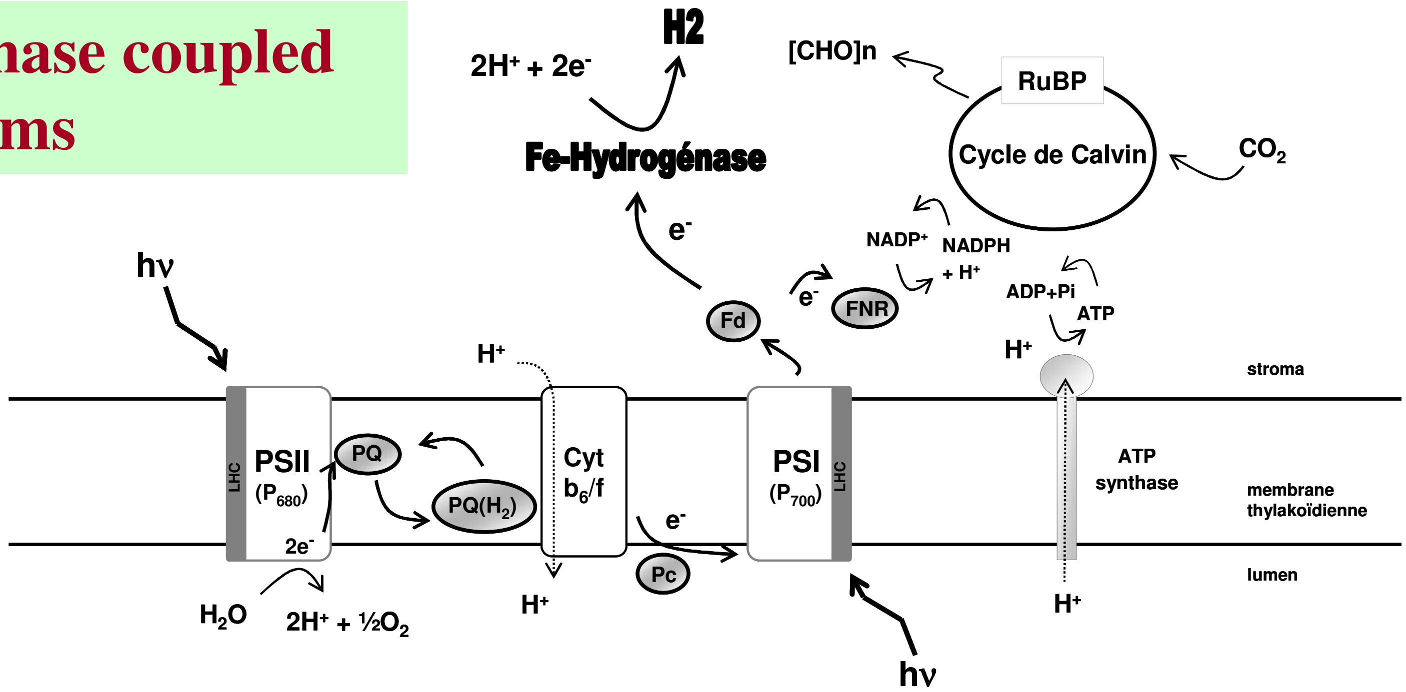
H_2 metabolism in *Chlamydomonas reinhardtii*

Fe - hydrogenase coupled to photosystems



Non permanent release of H_2 (protection mecanism)

Main limiting factor: O_2 sensibility of hydrogenase

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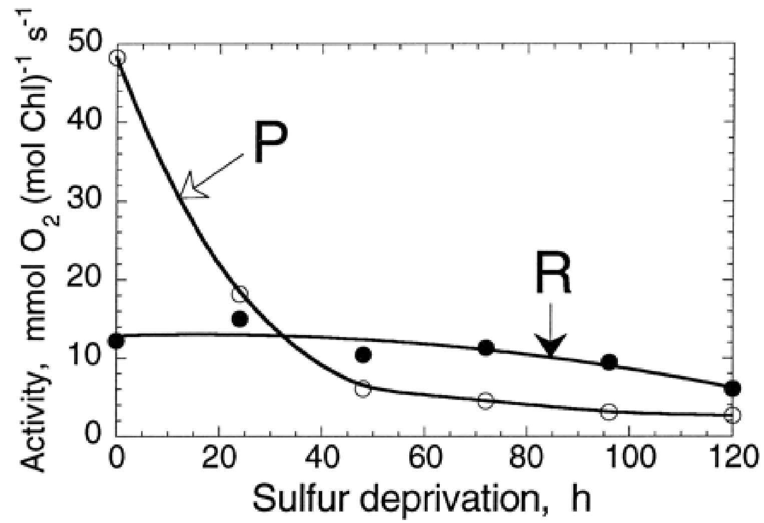
S-deprivation protocol (Melis et al.)

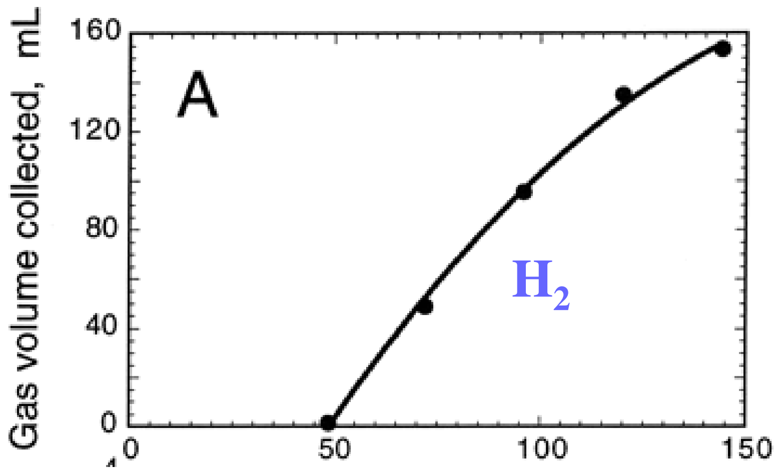
- Progressive decrease of photosynthetic activity

- Constant respiration

→Anoxia → Hydrogenase

H_2 production





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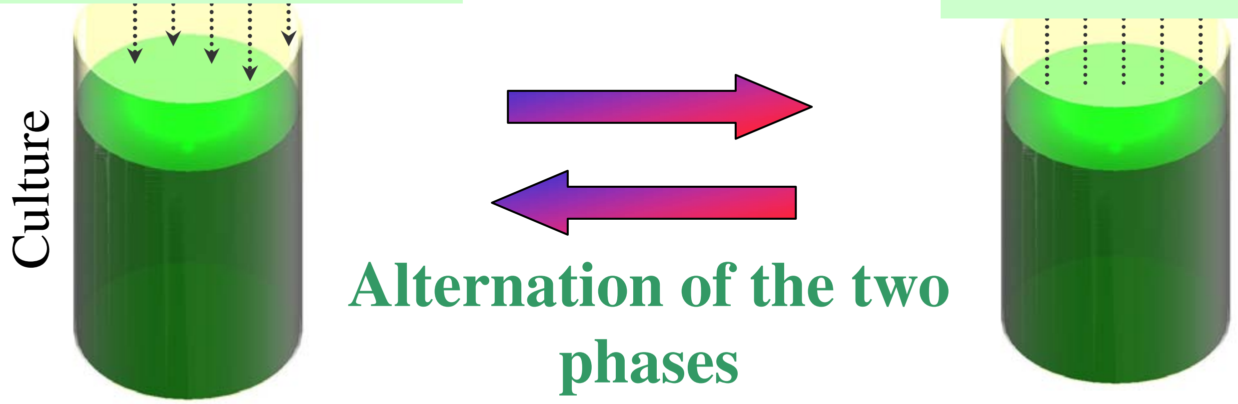
Two-step process

Phase 1: Biomass Production

Phase 2: Hydrogen production

Light + water
+ CO_2 + nutriments

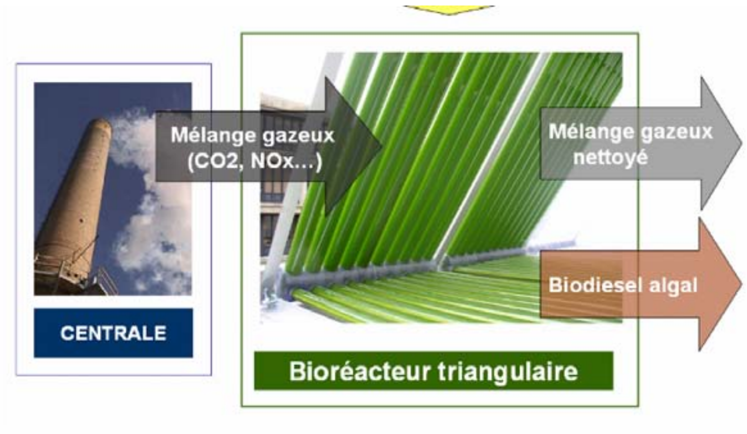
H_2 release

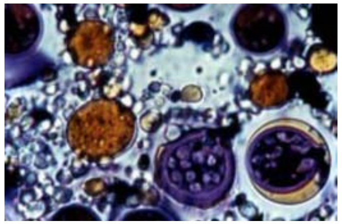


→Growth
(accumulation of cell reserves)

→Anaerobic condition
(consumption of cell reserves)

Fatty acids production (ANR Shamash)





• some microalgae: 60-80% of dry weight

Non permanent Accumulation

•Remarque: *Botryococcus braunii* metabolises hydrocarbars

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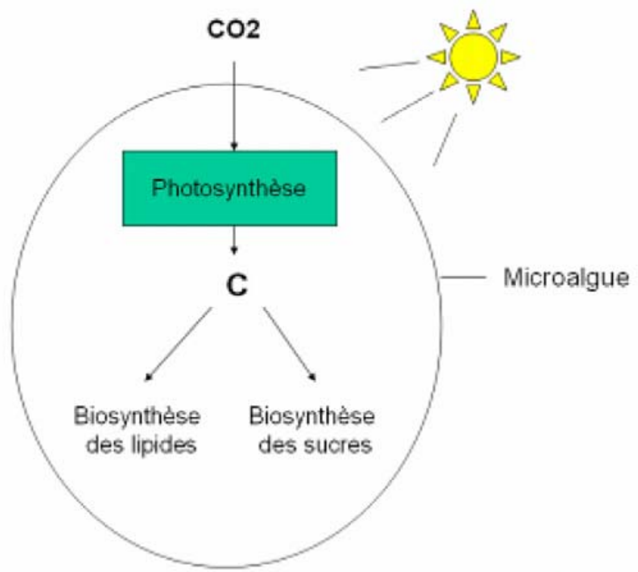
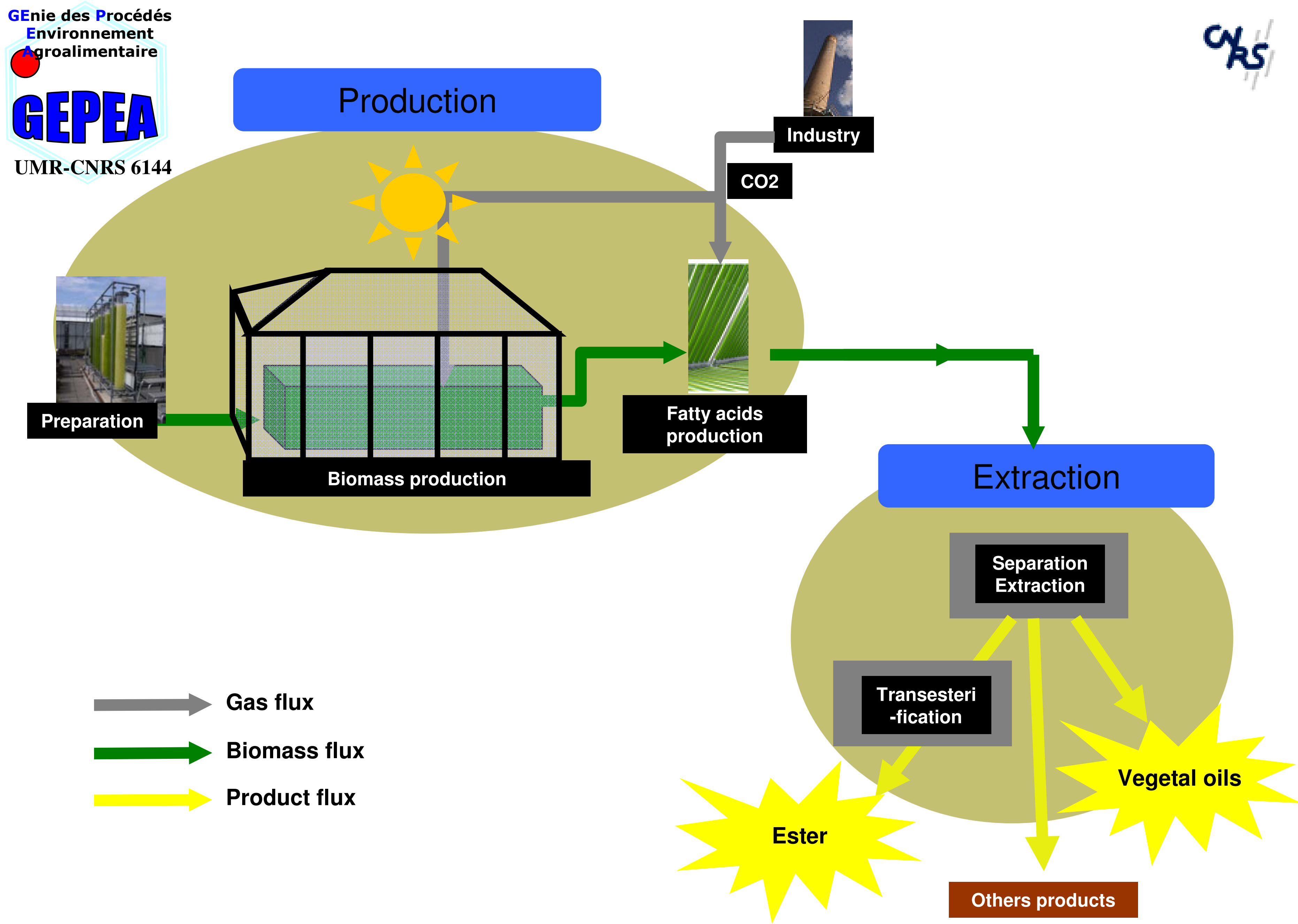
Fatty acids production



Biosynthèse des lipides et des sucres par les microalgues

Bioproduction stimulated by:

- $-N_2$ or silica deprivation
- -High ligh intensity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Production
Industry
CO2
Preparation
Biomass production
Fatty acids
production
Extraction
Separation
Extraction
Transesteri
-fication
Vegetal oils
Ester
Others products
Gas flux
Biomass flux
Product flux

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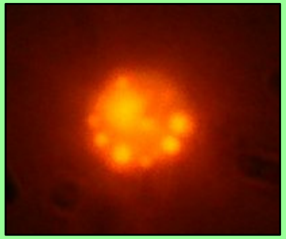
Neochloris oleoabundans as a case study

Investigation of the relation between photobioreactor operating parameters and resulting productivities

Neochloris oleoabundans: freshwater green microalga



Fluorescence microscope visualisation of TAGs globules (NileRed stain)

Easy to cultivate, naturally enriched in lipids, accumulates TAGs in nitrogen starvation

Chlamydomonas reinhardtii : freshwater green microalga

Highly documented, interesting for bioenergy application (high growth rate, able to produce H2, accumulates starch in mineral starvation)

Modelling light-limited growth in photobioreactors

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Maximum biomass production obtained **without mineral limitation → light-limited growth**

Mass balance

(1) $$\frac{dX}{dt} = r_x - DX$$

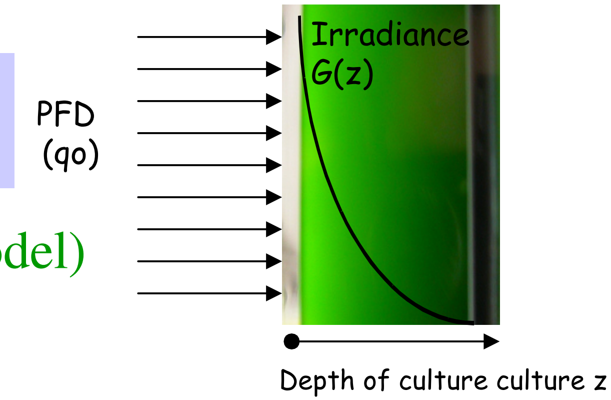
Key-term : rx → function of **light received** G (limited-growth)

Radiative transfer modelling

Light availability is a function of light absorption and scaterring by cells → **irradiance G**

(2) $$\frac{G(z)}{q_o} = 2\frac{(1+\alpha)\exp(-\delta(z-L)) - (1-\alpha)\exp(\delta(z-L))}{(1+\alpha)^2\exp(\delta L) - (1-\alpha)^2\exp(-\delta L)}$$

(Two-flux model)



Kinetic model of photosynthetic growth

Biomass growth (rx) can be deduced G(z)

(3) $$r_X = (\mu_{max}\frac{G(z)}{K_I + G(z)} - \mu_s)X$$