*Dipartimento di Biotecnologie Agrarie*
*Università degli Studi di Firenze*

# Le microalghe: Mercato e tecnologie

*Mario R. Tredici*

**Near horizontal tubular reactor (1990)**

| Prodotto o processo | Specie e quantità | Sistema di coltura | Stadio |
|---|---|---|---|
| Integratori alimentari<br>Mangimi | *Arthrospira (3000 t)*<br>*Chlorella (2000 t)*<br>*Dunaliella (1200 t)*<br>*Aphanizomenon (500 t)*<br>*Haematococcus (300 t)* | Lagune, vasche raceway | Commerciale |
| Pigmenti (carotenoidi, ficobiliproteine) | *Dunaliella*<br>*Arthrospira*<br>*Haematococcus* | Lagune, vasche raceway | Commerciale |
| Acidi grassi ω 3 (DHA) | *Schyzochitrium (10 t olio)*<br>*Crypthecodiniun (240 t olio)* | fermentatori<br>(10-100 $m^3$) | Commerciale |
| Traccianti fluorescenti<br>Molecole marcate,<br>Enzimi di restrizione | *Arthrospira*<br>*Anabaena*<br>*Anacystis* | fermentatori e fotobioreattori axenici | Commerciale |
| Trattamenti acque di scarico | *Scenedesmus*, colture miste | Vasche raceway | Commerciale |
| Biomassa per acquacoltura | Varie specie (1000 t) | Sacchi, cilindri, vasche, fotobioreattori | Commerciale |
| Polisaccaridi | | | Ricerca |
| Biofertilizzanti | | | Ricerca |
| Molecole bioattive (farmaci, biopesticidi, probiotici) | | | Ricerca |
| Biosensori e sun-screens | | | Ricerca |
| Bioremediation (xenobiotici, metalli pesanti, ecc.) | | | Ricerca |
| Biofissazione $CO_2$ | | | Ricerca |
| Energia (biodiesel, $H_2$) | | | Ricerca |

**Applicazioni commerciali delle microalghe (2006)**

↓

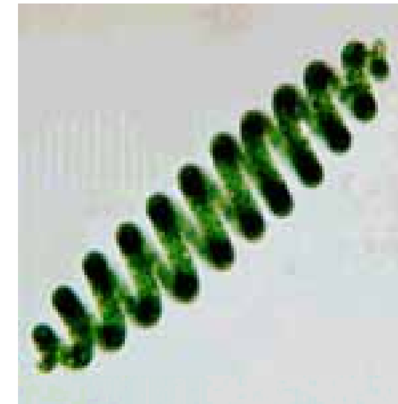
**8-9000 t** per un valore di 1.200.000.000 €

## *Raccolta di Arthrospira platensis (*Kanembu, Ciad)

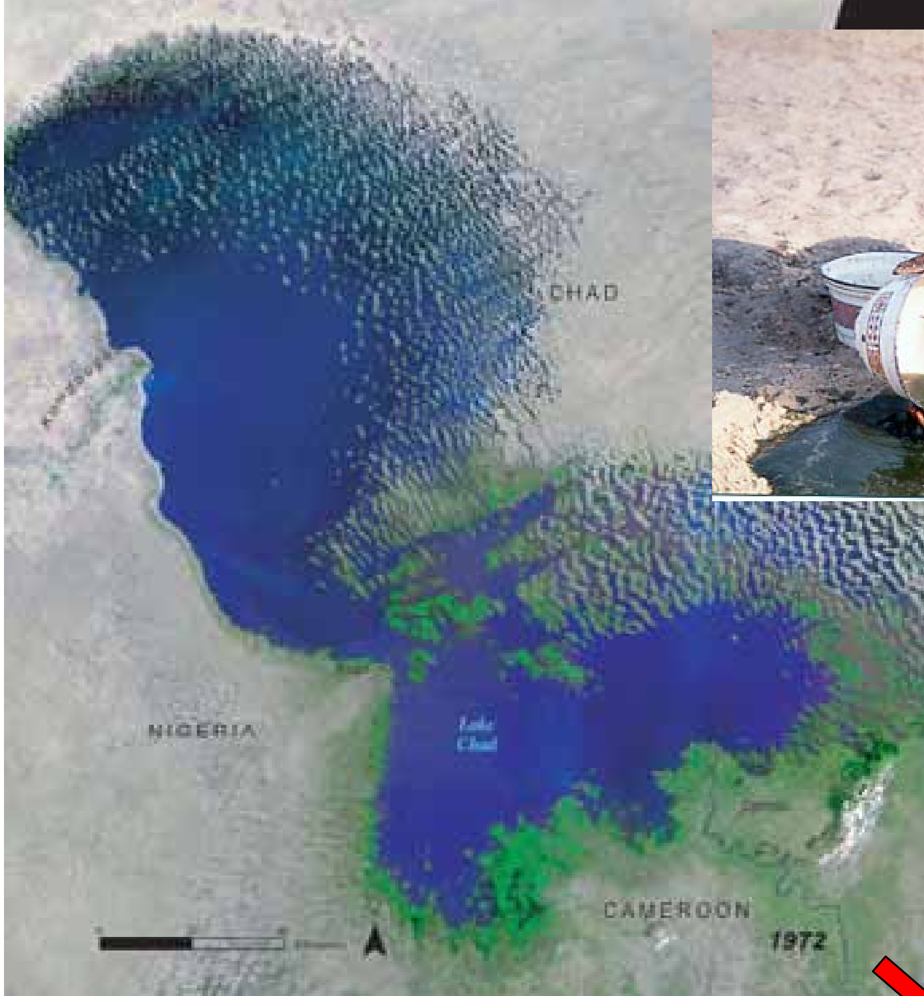
**Lago Kossorom (Chad, Africa)**

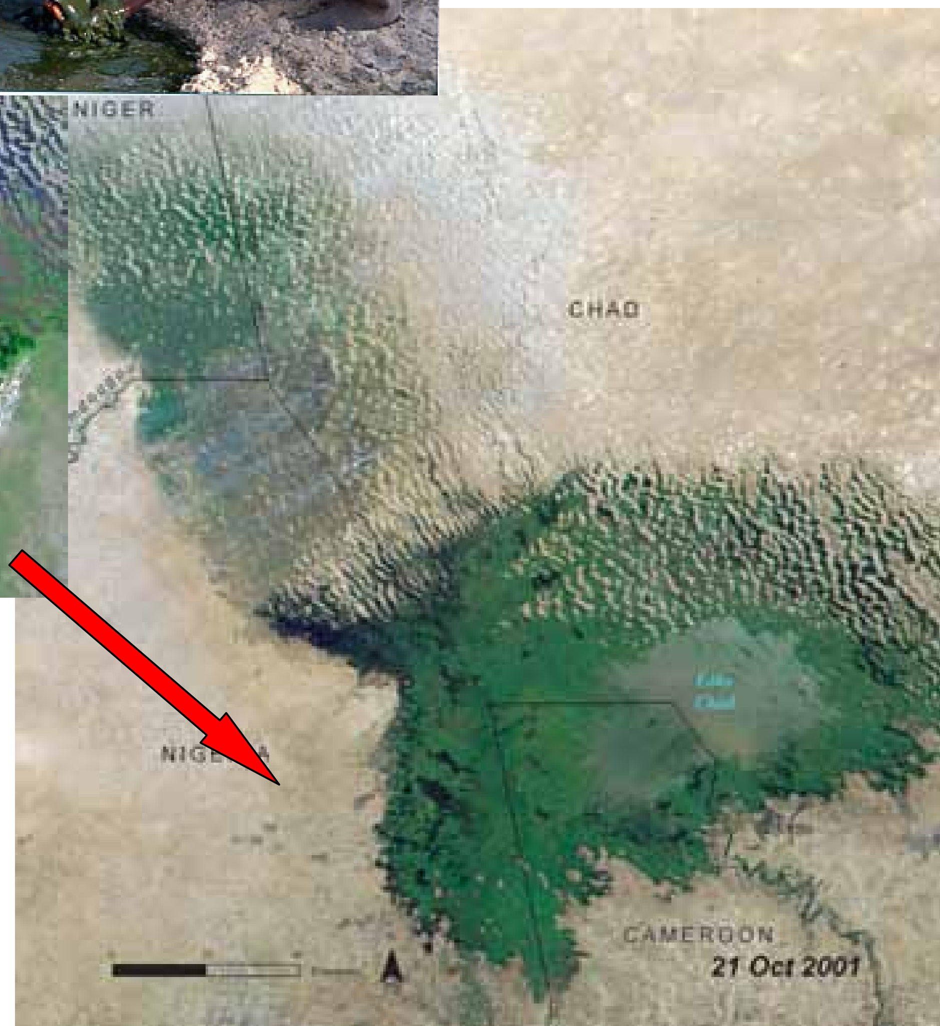
**(Abdulqader, Barsanti, Tredici, 2000)**

Lago Kossorom
(Ciad, Africa)



**(Abdulqader, Barsanti, Tredici, JAP 2000)**



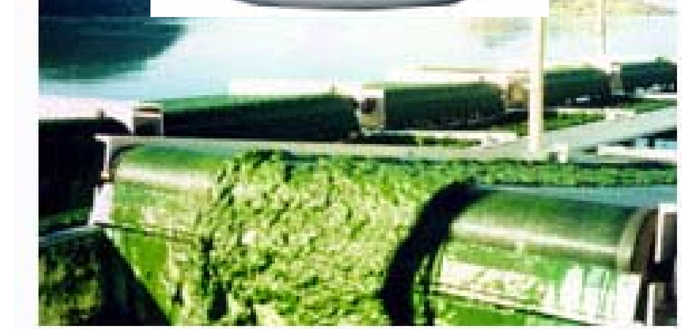




Lago Ciad (Africa)

# Klamath Lake (Oregon, USA)



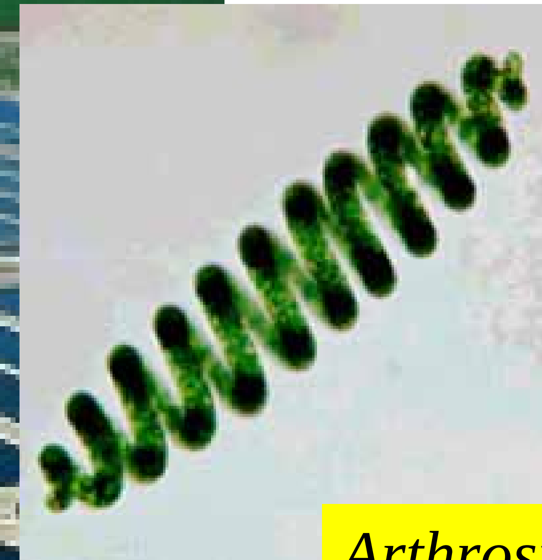


*Aphanizomenon flos-aquae*

**Colture massive di**
***Arthrospira platensis*** **in**
**“raceway ponds”**

Earthrise Farms (California)



*Arthrospira platensis*

Integratore
alimentare



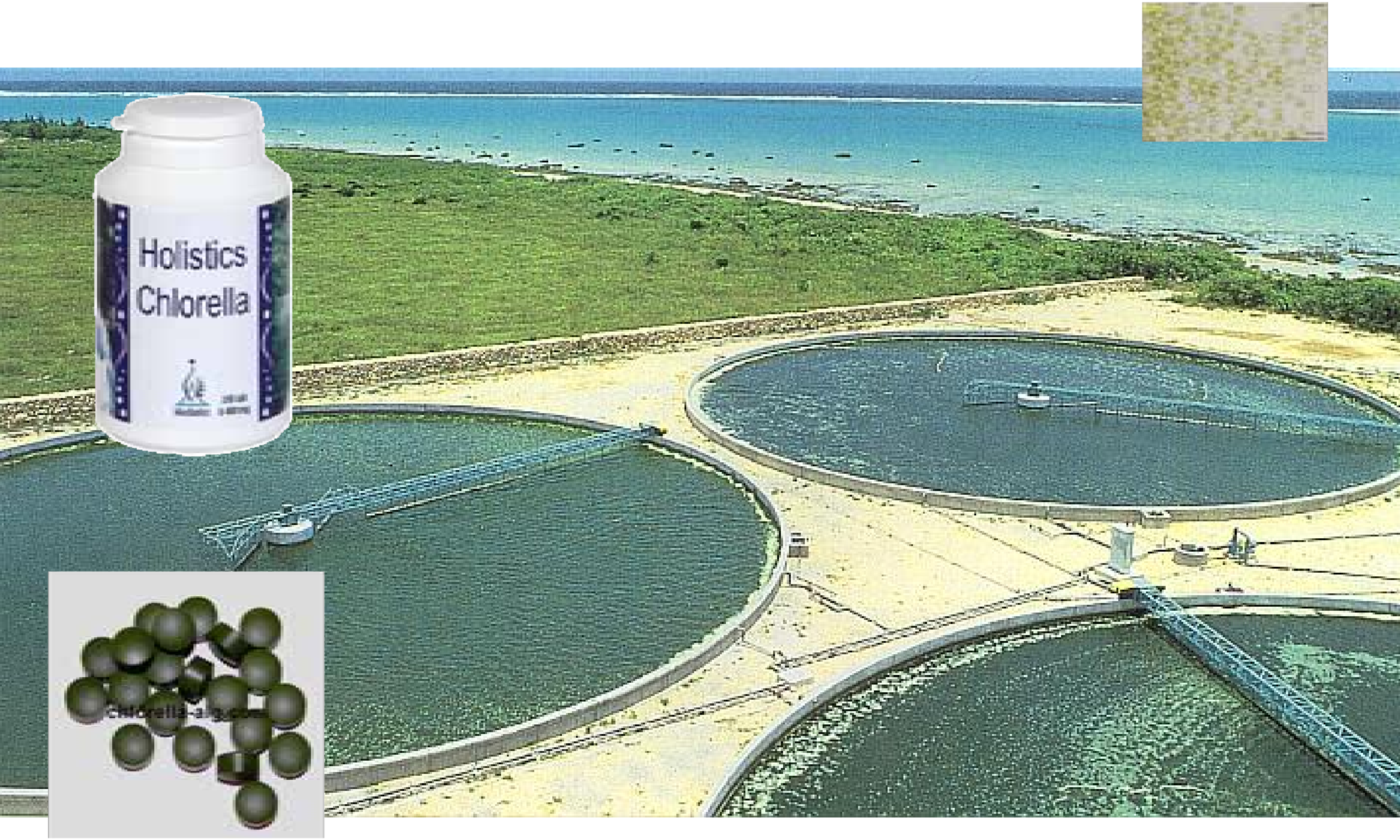
CYANOTECH

## CYANOTECH PRODUCTS

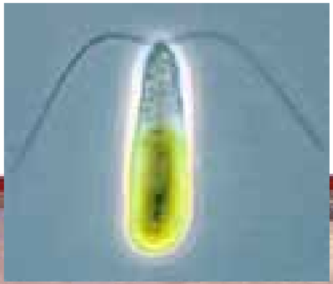
*Arthrospira platensis*
Spirulina
Pacifica®
**Health and Natural Foods**
Phycobiliproteins
**Fluorescent pigments used for medical diagnostics.**

*Haematococcus pluvialis*
NatuRose®
**Natural Astaxanthin Aquaculture/Animal Feed/Pigments**
BioAstin®
**Natural Astaxanthin Human Dietary Supplement**

# *Chlorella* (Japan)



Coltura estensiva di *Dunaliella salina*
(Cognis Nutrition and Health, Hutt Lagoon, Australia)

Martek

Martek Biosciences Corporation
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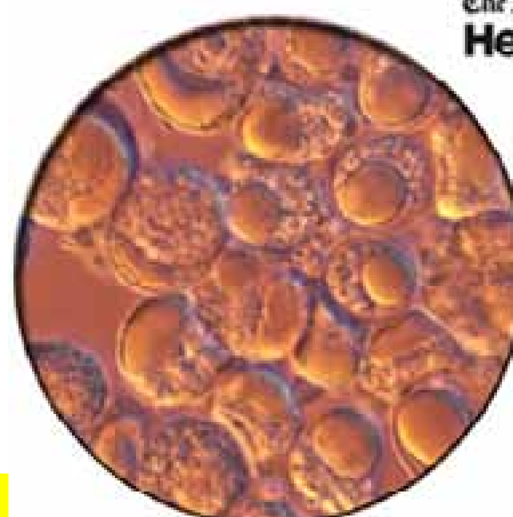
Neuromins®
vegetable source DHA

DHA NEWS

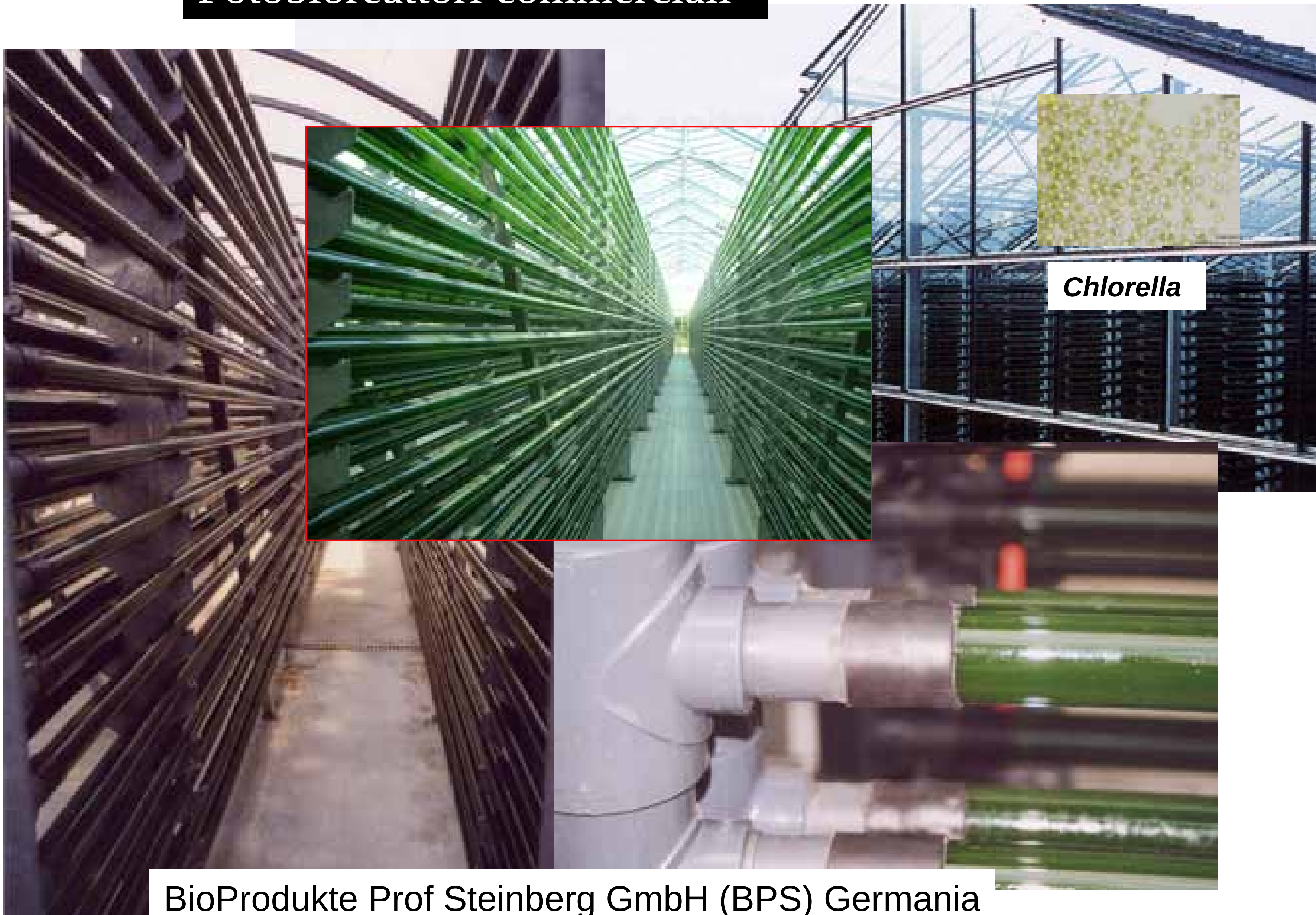
Medwatch examines over-the-counter products. (Gold Circle Farms DHA Omega-3 Cage Free Eggs)
by: Shari Rudavsky

The Miami Herald
Herald.com



***Crypthecodinium cohnii* e *Schizochytrium coltivati* in fermentatori per oli ricchi in DHA**

# Fotobioreattori commerciali



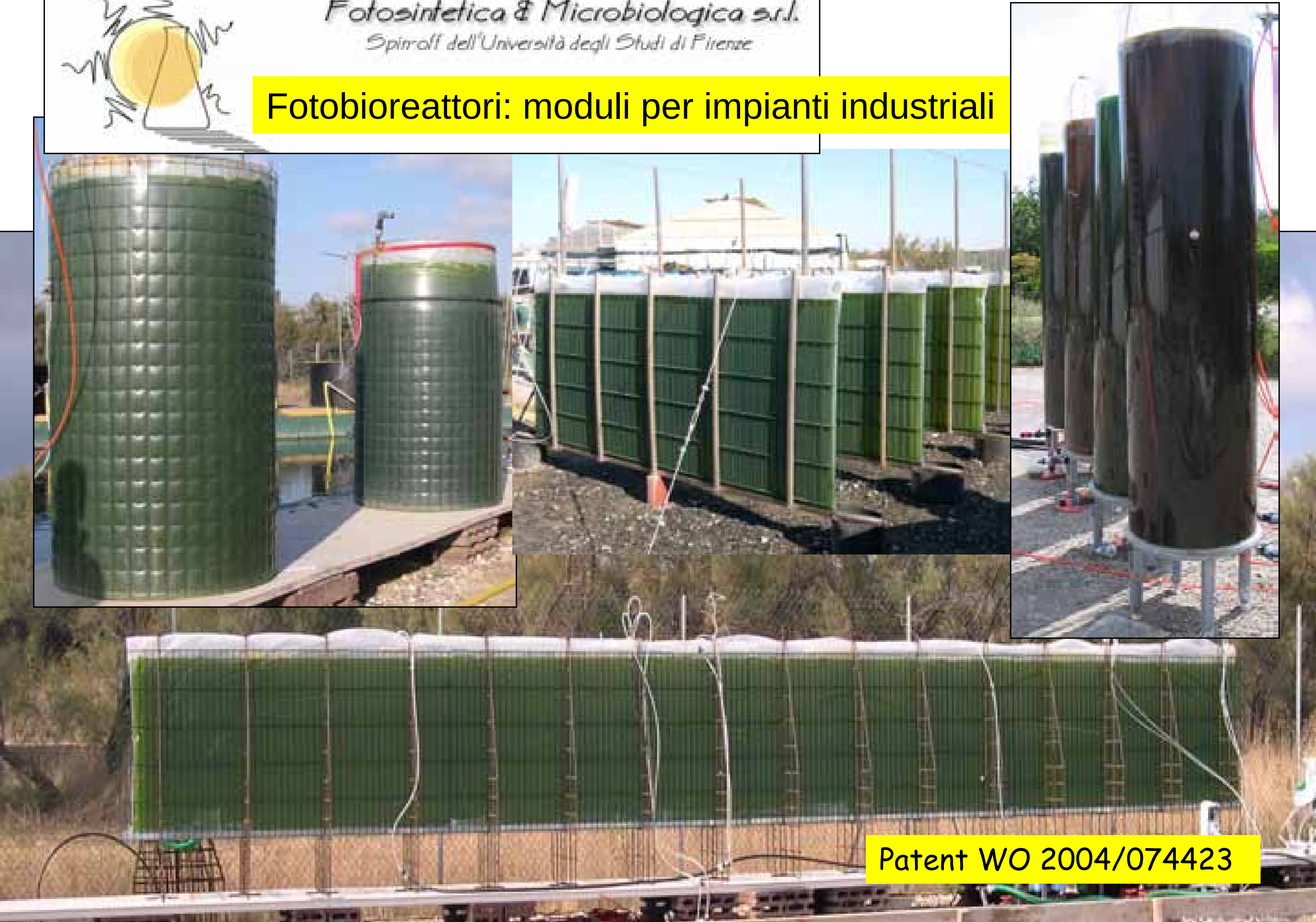

BioProdukte Prof Steinberg GmbH (BPS) Germania

# Fotobioreattori commerciali


***Haematococcus pluvialis***

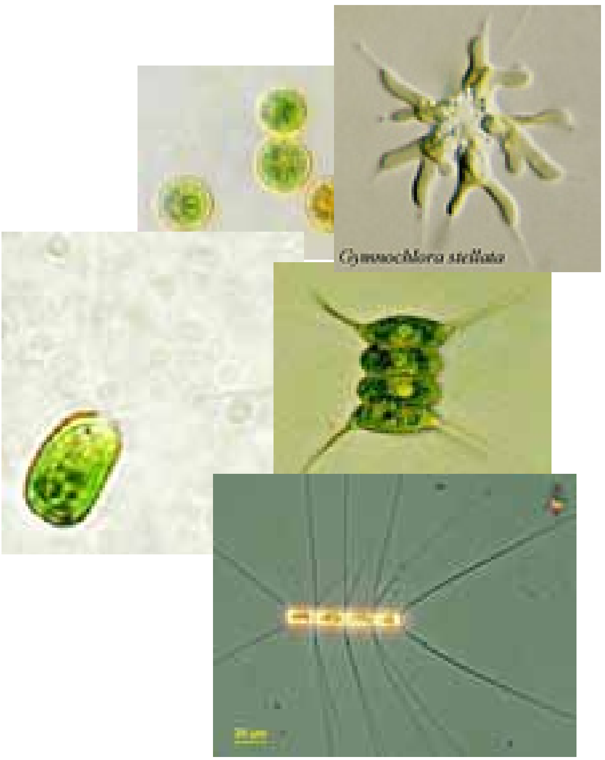
Fotosintetica & Microbiologica s.r.l.
Spin-off dell'Università degli Studi di Firenze

# Fotobioreattori: moduli per impianti industriali



Patent WO 2004/074423

# Energia dalle microalghe?




?


$H_2$

# Iniziative commerciali su biodiesel da microalghe (2006-2007)

| Company | Location | Web | Links |
|---|---|---|---|
| **Algatech** | Israel | | |
| **Algoil** | Bamgalore, India | | |
| **AlgaeFuels (Owned by Bioking)** | Netherlands | www.algaefuels.org | |
| **Aquaflow Bionomic Corporation** | New Zealand | www.bio-diesel.co.nz | |
| **Biofuel Systems (BSF)** | Spain. | | |
| **De Beer's Fuels BPK** | South Africa | | GFT Technology |
| **Ecogenics Research Center** | Tennessee, USA | www.ecogenicsresearchcenter.org | |
| **Energetix (Victor Morgan Group)** | Victoria,Australia | | GFT technology. |
| **Enhanced Biofuels & Technologies** | | | Ponds and PBR through GreenFuel |
| **Energy Farms** | Texas, USA | www.nanoforcetechnologies.com | owned by Nanoforce Inc. |
| **GreenFuel Technologies Corp.** | Massachusetts, USA | www.greenfuelonline.com | MIT |
| **GreenShift Industrial Design Corporation** | New York, USA | www.greenshift.com | through Veridiun and Ohio University |
| **Green Star Products and De Beers Fuel Limited** | South Africa | | GFT Technology |
| **GS Clean Tech** | New York, USA | www.gs-cleantech.com | GreenShift Corp. & Veridium Corp. &Ohio State University |
| **Kwikpower Int. Advanced Biofuels Technologies** | Gibraltar, UK | www.kwikpower.com | |
| **Infinifuel Corporation** | Nevada, USA | www.infinifuel.com | |
| **Needful Provision, Inc** | Oklaoma USA | www.needfulprovision.com | |
| **PetroAlgae. LLC (XL Tech Group, Inc.)** | Florida, USA | www.xltg.com/html/activity/PetroAlgae.asp | Arizona State University |
| **PetroSun Drilling Inc. (with Algae Biofuels)** | Arizona, USA | www.petrosun.us<br>www.petrosuninc.com | |
| **Solazyme, Inc.** | California, USA | www.solazyme.com | |
| **Solix Biofuels, Inc. (Sun Source Industries)** | Colorado, USA | www.solixbiofuels.com | Colorado State University |
| **Sun Source Industries** | Colorado, USA | www.cobioscience.com | Solix Biofuels, Inc. |
| **Valcent Products, Inc** | Vancouver, Canada | www.valcent.net | |
| **Veridium Corp.** | New York, USA | www.veridium.com | |
| **XL Tech Group Inc.** | Florida, USA | www.xltechgroup.com | www.xltechgroup.com |


# Nasce nel Salento un progetto innovativo capace di rivoluzionare la produzione. Una azienda locale, la EnergEco, lo ha proposta ai comuni dell'Area sistema

di Alberto Nutricati, dalla Gazzetta del Mezzogiorno del 16/03//2006

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L'autonomia energetica è la sfida su cui si gioca il futuro economico dell'intero Paese. Le ripetute crisi energetiche rischiano di paralizzare l'Italia, come già avvenne con il black-out del 2003. Le strade intraprese per riscattare l'Italia dalla dipendenza energetica sono molteplici e vanno dal risparmio energetico allo sfruttamento di fonti rinnovabili. Casarano ed il Salento, per le condizioni di cui godono, non avrebbero problemi a vincere questa sfida. Un progetto innovativo, unico per dimensioni e per ricadute sul territorio, è quello elaborato dall'azienda casaranese EnergEco e del quale sono stati informati tutti i comuni dell'Area Sistema. Il progetto, che sarà realizzato grazie ad una cordata di imprenditori in gran parte provenienti dal Tac, **prevede per il 2006 la realizzazione in territorio salentino di un impianto da 3milioni kWh**. Si tratta di sfruttare l'energia solare, non attraverso i classici pannelli termici e fotovoltaici, bensì per mezzo di sistemi di bioconversione. Tali sistemi richiedono biomassa ad alta efficienza fotosintetica **(microalga Chlorella).** La biomassa viene convertita in biogas, che a sua volta alimenta i generatori elettrici. I veri protagonisti di questo processo sono, però, gli agricoltori, che potranno produrre in loco la biomassa, sia per autoalimentare i propri impianti, risparmiando sui costi di distribuzione, sia rivendendo a prezzi vantaggiosissimi l'energia in eccesso all'Enel. L'EnergEco stima che un impianto tipo realizzato su un ettaro di superficie produca circa 52mila euro netti annui. Insomma, una vera e propria «industria agro-elettrica» Ma che impatto avrebbe il progetto qualora venisse realizzato su larga scala? La popolazione dell'Area Sistema ammonta a circa 107mila abitanti, con un consumo pro-capite annuo di poco superiore ai 1000 kWh. La superficie da destinare alla produzione energetica dovrebbe essere pari a 647 ettari, per un investimento di 51,8 milioni di euro. Stando ai calcoli dell'azienda che ha elaborato il «Progetto autosufficienza», il fatturato lordo annuo realizzabile sarebbe di 50,7 milioni di euro ed il numero di occupati, direttamente o attraverso indotto, di 950 unità. Queste le cifre di un progetto che promette di coniugare equilibrio territoriale, realizzazione totale in Italia, sicurezza ed inquinamento zero. Una «rivoluzione verde», dunque, che intende dimostrare come si possa autoprodurre, attraverso l'agricoltura, tutta l'energia elettrica di cui si ha bisogno, senza ricorrere a scelte pericolose e, alla lunga, controproducenti. Del resto, in un Salento stereotipamente legato all'idea di «sule, mare e jentu», la salvezza non poteva che venire proprio da uno di questi elementi.

# Photobioreactors and the biodiesel dream

## Oil Yield

**[Cultivating Algae for Liquid Fuel Production](http://oakhavenpc.org/cultivating_algae.htm)**

**(*http://oakhavenpc.org/cultivating_algae.htm*)**

**Gallons of Oil per Acre per Year**

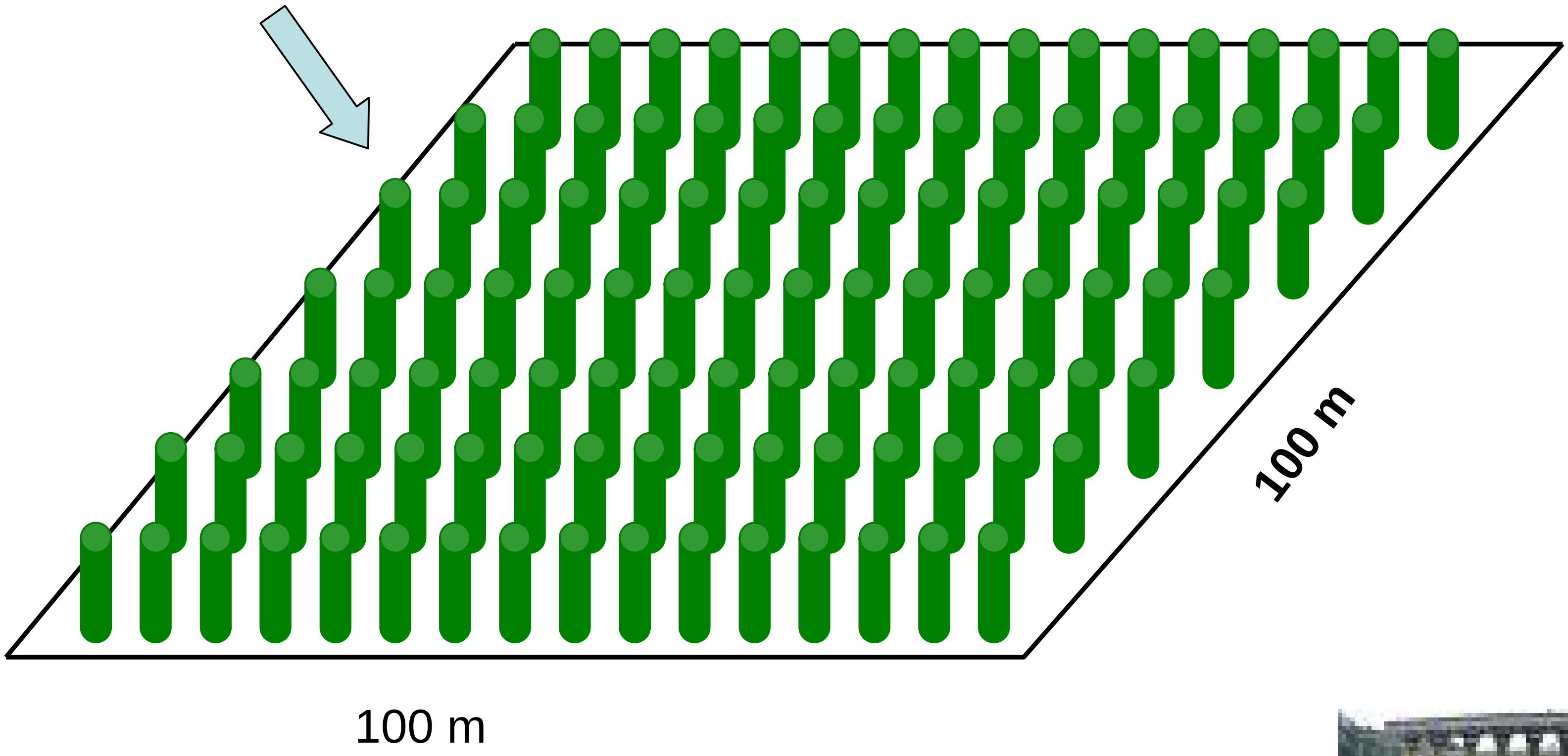
| | | |
|---|---|---|
| Corn | → | 18 |
| Soybeans | → | 48 |
| Sunflower | → | 102 |
| Rapeseed | → | 127 |
| Oil Palm | → | 635 |
| **Microalgae** | → | **5.000-20.000** |

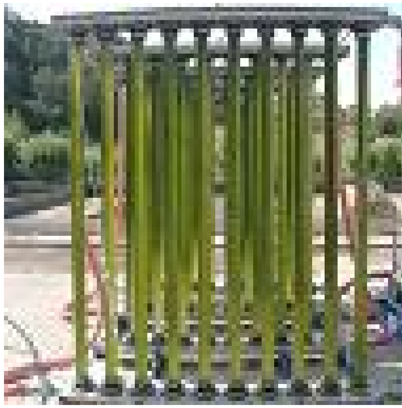
**50.000-200.000 L oil per ha and year**

???????????

## Selling dreams

**A company is offering turnkey large-scale photobioreactor plants**



- A 1ha plant is made with **1250** reactors
- Unit: a vertical tubular bioreactor 12-m-high and 0.9-m in diameter (7.630 L)
- Area coverage is ~ 8%

# A 1-ha plant made of 1250 reactors


**Price:** **6.000.000 €**

**Productivity**: **50 t of biomass per day** (of which 22.5 t can be oil)

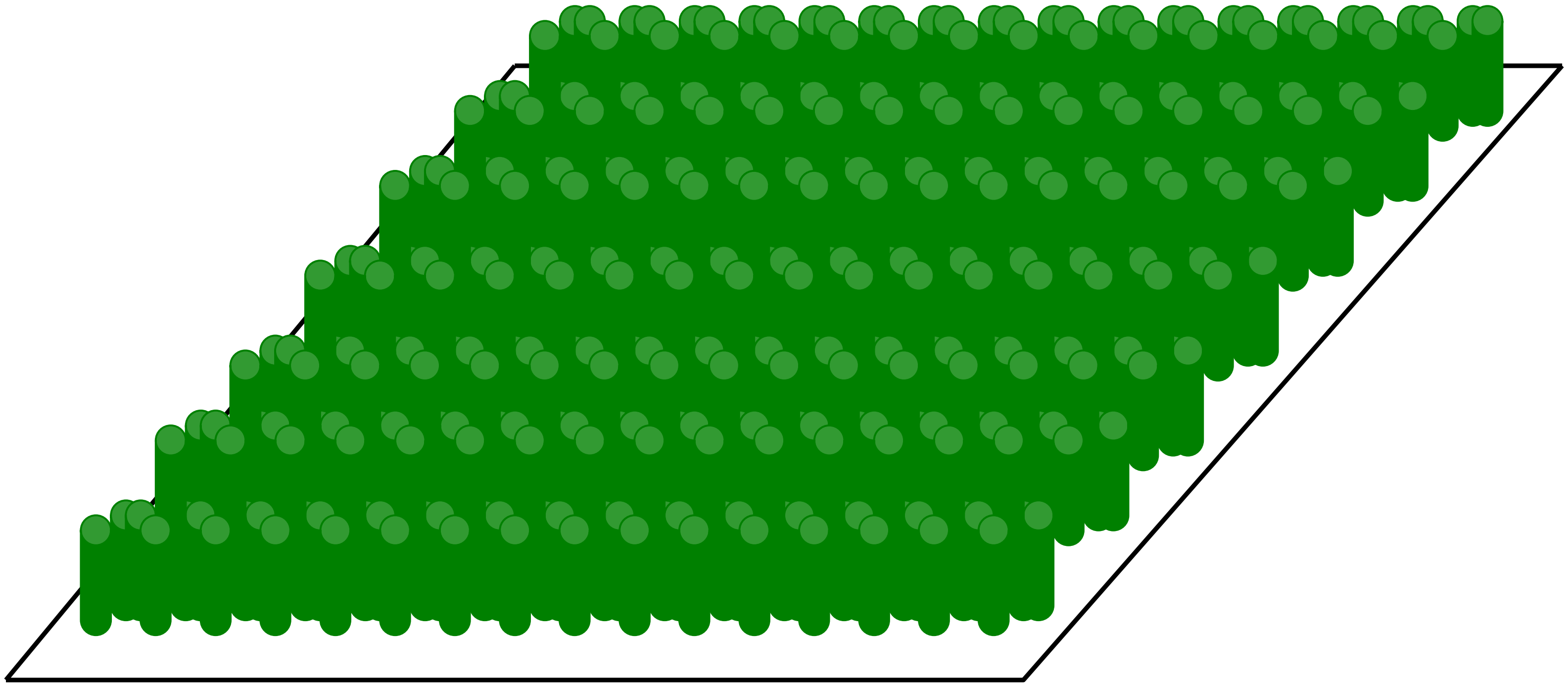
**Income per day**:

| | |
|---|---|
| 22.500 L biodiesel (at 0.65 €/L) | 14,625 € |
| 27,500 kg press cake (at 1.5 €/Kg) | 41,250 € |
| TOTAL | 55,875 € |

**TOTAL income per year** (365 days at 50 t/d) ⇨ **20,394,375.00 €**

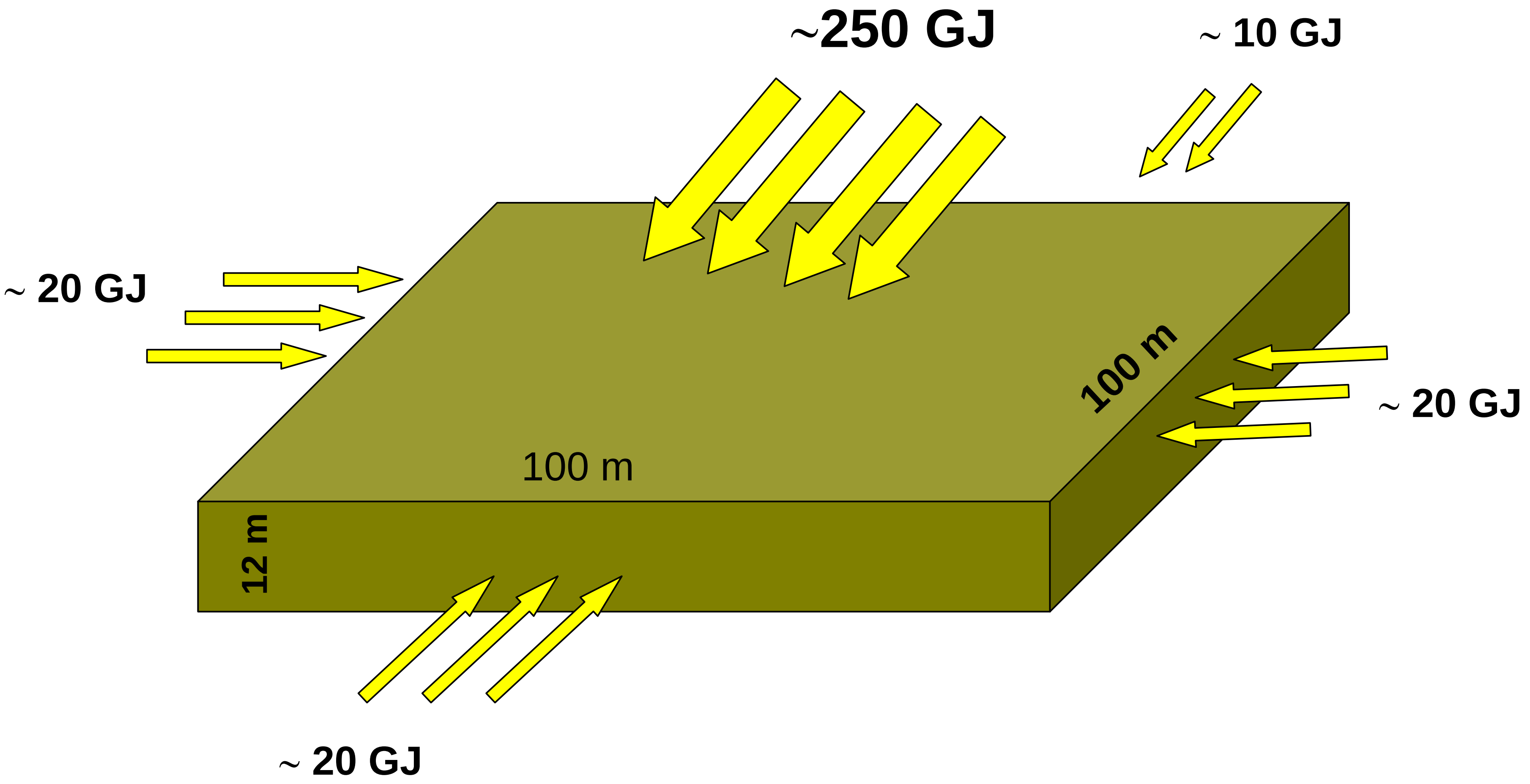
Is this productivity ⇨ 5.2 g $L^{-1}$ $d^{-1}$ achievable in a 0.9 m diameter vertical column?

A large number of columns completely covering the ground (1 ha)



How much light is falling on the whole plant?

**Solar energy impinging on a 1-ha plant in a sunny summer day (25 MJ $m^{-2}$)**




TOTAL → ~ 320 GJ per day

Solar energy impinging on a 1-ha reactor in a sunny summer day (25 MJ $m^{-2}$)

**320 GJ per day**

**If** productivity is **50 ton** dry biomass/day → **~ 1250 GJ (at 25 Kj/g)**

**PE** = 1250/320 = **390%**

**?**

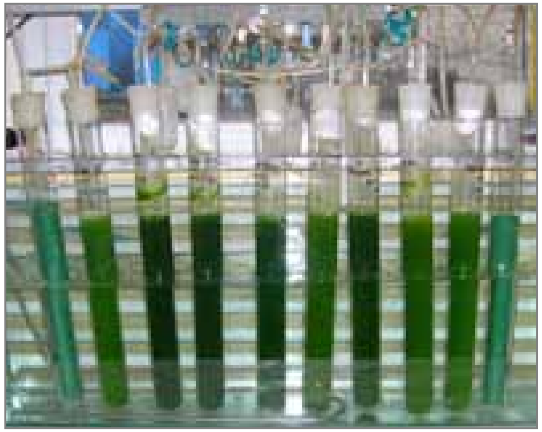
1° errore

Da prove in laboratorio

si estrapolano le prestazioni di impianti di migliaia di ettari

2° errore

**Si estrapolano i tassi di crescita all'aperto da quelli di laboratorio e si confonde il tasso di crescita (μ) con la produttività (μX)**

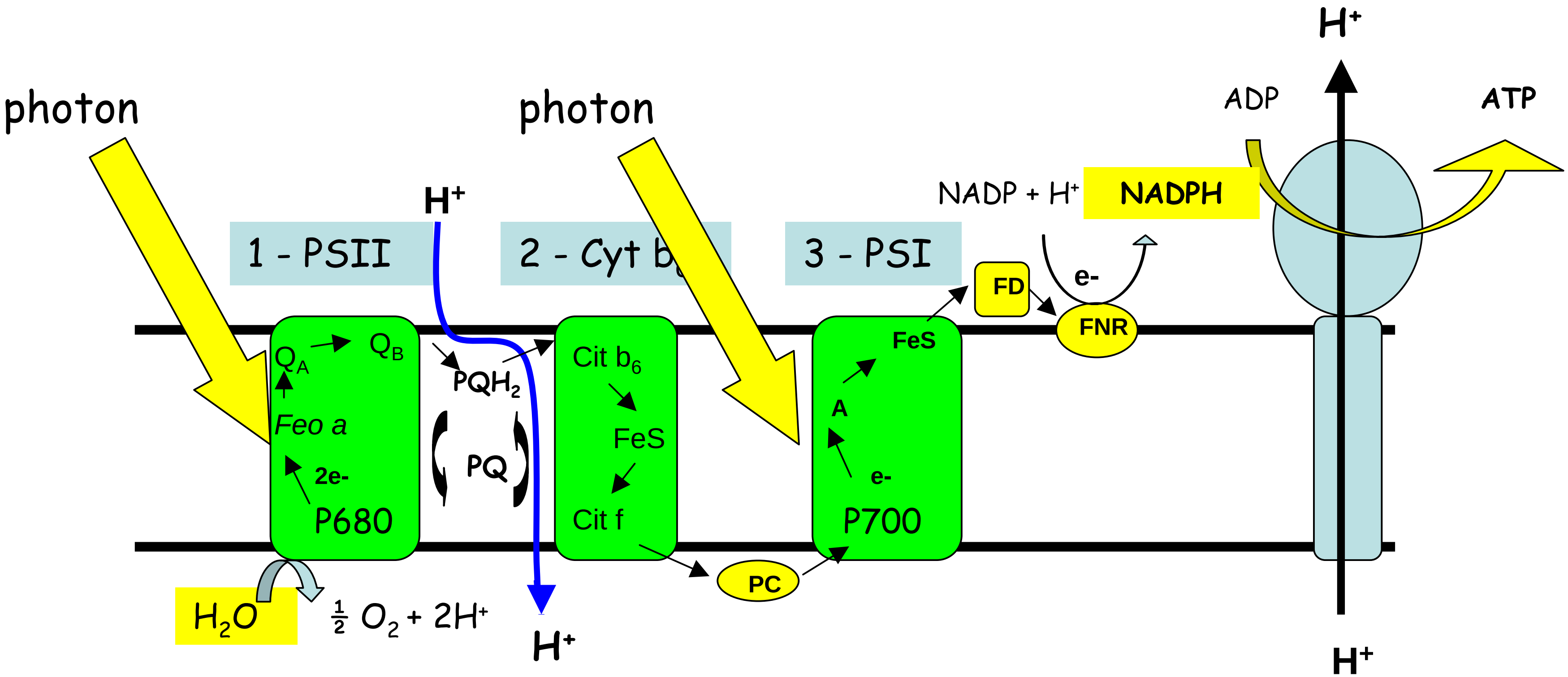


μ elevato

μ basso

**3° errore**: non si rispetta il biochimismo della fotosintesi ossigenica

$2\ NADPH + 3\ ATP + CO_2 \rightarrow$ Carbohydrate




Photosynthetic membrane

not less than 10 mol photons are required for the formation of the two moles of NADPH necessary, together with 3 moles of ATP, to reduce one mole of CO2 to the level of carbohydrate

Since:

1. 10 photons are required to fix one molecule of $CO_2$
2. one mole of fixed $CO_2$ is equivalent to 475 KJ
3. PAR photons have an average energy content of 217 KJ per mole

Thus:

the maximum theoretical efficiency of conversion of PAR into the chemical energy of biomass is → 475 KJ / 2170 KJ = **22%**

and since sunlight has only 45 % of PAR

under natural illumination maximum PE is 22% of 45%

→ **10%**

# Rese (reali) di colture algali

Le migliori a breve termine: 50 g $m^{-2}$ $d^{-1}$ → **170 t $ha^{-1}$ $anno^{-1}$**

Le migliori a lungo termine: 30 g $m^{-2}$ $d^{-1}$ → **100 t $ha^{-1}$ $anno^{-1}$**

Le migliori in impianti industriali: 15 g $m^{-2}$ $d^{-1}$ → **50 t $ha^{-1}$ $anno^{-1}$**

**Obiettivo in biomassa** → **80 t $ha^{-1}$ $anno^{-1}$**

**Obiettivo (ambizioso) in olio** → **25-30 t $ha^{-1}$ $anno^{-1}$**

Biodiesel dalle microalghe


**Che c'è di vero?**

# Biocarburanti da colture di microalghe: i vantaggi

1. non necessitano di terreni fertili;
2. non richiedono acqua dolce;
3. possono essere abbinate al trattamento di acque reflue;
4. si può utilizzare $CO_2$ da fumi di combustione o fermentazione;
5. la biomassa residua può trovare applicazione come fertilizzante o mangime;
6. non rilascia sostanze contaminanti. Non fa uso di pesticidi
7. non necessita di organismi geneticamente modificati
8. *nei nostri climi producono 10-20 volte di più delle colture tradizionali*

# Ricerche svolte a Firenze

Dipartimento di Biotecnologie Agrarie

F&M Srl

## Lipid production from microalgae: strain selection, induction of lipid synthesis and outdoor cultivation in pilot photobioreactors

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**keywords**: biofuel, *Nannochloropsis* sp ZM, alveolar panel, "green wall" panels

The high yields attained per unit area make microalgae one of the most promising sources of biofuels. Besides, microalgae cultivation does not compete for fertile soil and requires much less water than oilseed crops. With the increasing interest in biodiesel, many are looking at microalgae as a new source of oil. The average lipid content of microalgae biomass varies between 1 and 40%, but under certain conditions (e.g. nutrient limitation) microalgae can be induced to produce as much as 60% of their biomass as extractable triacylglycerols. However, despite their potential, microalgae have been rarely assessed as oil producers.

**Figure 1**
Photobioreactors used for cultivation of lipid-rich microalgae.
Left: 20-L alveolar panel under artificial light.
Right: 500-L Green Wall Panel (patent WO 2004/074423 A2)

In this work, thirty one microalgal strains were tested for their growth characteristics (light limited productivity, cell fragility, sedimentation rate) and lipid content. Four strains (two marine and two freshwater), selected because of their better perfomance, were cultivated under nitrogen starvation. One of them, *Nannochloropsis* sp. ZM, attained 60% lipid content after 4 days of nitrogen shortage, and was used to study lipid induction in a 20-L alveolar panel (Fig. 1, left) under high irradiance and nutrient deficiency. Fatty acid content was increased by both nitrogen and phosphorus starvation (up to more than 50% of the dry weight). *Nannochloropsis* sp. ZM was then grown outdoors in 110- and 500-L polyethylene "green wall" panels (Fig. 1, right) to evaluate its lipid production potential under natural conditions in nitrogen-sufficient, nitrogen-deficient and nitrogen-limited media. Since the pilot plant was arranged so as to simulate a full-scale system (Tredici, 2004), the areal lipid productivity could be calculated. The experiments showed that this marine microalga has a potential for producing more than 15 tons of lipid per ha per year in the Mediterranean basin, and of more than 30 tons of lipid per ha per year in sunny tropical areas.

# Biomass and lipid production by 31 microalgal strains

| Microalgae | Biomass productivity (mg L$^{-1}$ day$^{-1}$) | Lipid content (% biomass) | Lipid productivity (mg L$^{-1}$ day$^{-1}$) |
|---|---|---|---|
| *Porphyridium cruentum* | 613.3 ± 77.8 | 9.4 ± 0.2 | 57.5 ± 7.3 |
| *Tetraselmis suecica* OR | 448.0 ± 0.0 | 8.4 ± 0.3 | 37.5 ± 0.0 |
| *Tetraselmis* sp. LW | 414.0 ± 11.3 | 14.9 ± 0.1 | 61.8 ± 1.7 |
| *Tetraselmis suecica* CV | 383.6 ± 1.3 | 14.9 ± 0.1 | 57.3 ± 0.2 |
| *Chlorococcum* sp. UMACC 112 | 380.0 ± 2.6 | 19.5 ± 0.7 | 74.2 ± 0.5 |
| *Scenedesmus* sp. DM | 348.2 ± 2.6 | 21.8 ± 0.6 | 75.8 ± 0.6 |
| *Phaeodactylum tricornutum* | 335.0 ± 31.1 | 19.2 ± 0.4 | 64.3 ± 6.0 |
| *Chlorella sorokiniana* | 315.5 ± 10.3 | 19.8 ± 0.7 | 62.3 ± 2.0 |
| *Chlorella* sp. AMI2 | 307.3 ± 7.7 | 19.2 ± 0.4 | 59.0 ± 1.5 |
| *Scenedesmus* sp. cvc3 | 283.6 ± 5.1 | 20.6 ± 0.8 | 58.4 ± 1.1 |
| *Nannochloropsis* sp. RM | 278.2 ± 0.0 | 31.0 ± 0.5 | 86.3 ± 0.0 |
| *Ellipsoidium* sp. LW 277/01 | 275.5 ± 21.9 | 22.5 ± 0.8 | 62.1 ± 4.9 |
| *Chlorella vulgaris* UTEX 1200 | 274.5 ± 21.9 | 19.4 ± 0.9 | 53.2 ± 4.2 |
| *Nannochloropsis* sp. MRS | 270.0 ± 2.6 | 24.9 ± 0.7 | 67.2 ± 0.6 |
| *Scenedesmus quadricauda* | 260.0 ± 1.3 | 19.0 ± 0.5 | 49.3 ± 0.2 |
| *Monodus subterraneus* UTEX 151 | 257.3 ± 20.6 | 15.5 ± 0.5 | 39.9 ± 3.2 |
| *Isochrysis* (T-ISO) CS 177 | 252.5 ± 1.8 | 22.0 ± 1,6 | 55.4 ± 0.4 |
| *Nannochloropsis* sp. ZM | 241.8 ± 7.7 | 33.1 ± 1.7 | 79.9 ± 2.6 |
| *Pavlova salina* | 240.0 ± 7.1 | 31.1 ± 1.4 | 74.6 ± 2.2 |
| *Nannochloropsis* sp. MI | 237.3 ± 1.3 | 22.3 ± 0.5 | 52.8 ± 0.3 |
| *Ellipsoidium* sp. LW 70/01 | 235.5 ± 1.3 | 28.4 ± 0.4 | 67.0 ± 0.4 |
| *Nannochloropsis* sp. RP | 232.7 ± 25.7 | 37.0 ± 0.5 | 86.1 ± 9.5 |
| *Nannochloropsis* sp. CS 246 | 231.8 ± 1.3 | 30.4 ± 0.3 | 70.4 ± 0.4 |
| *Chlorella vulgaris* CCAP 211/11b | 231.8 ± 1.3 | 19.7 ± 0.3 | 45.7 ± 0.3 |
| *Pavlova lutheri* | 212.5 ± 10.6 | 37.1 ± 0.5 | 78.9 ± 3.9 |
| *Isochrysis* sp. MRS | 194.0 ± 5.7 | 28.7 ± 0.5 | 55.6 ± 1.6 |
| *Thalassiosira pseudonana* | 135.0 ± 5.3 | 22.0 ± 1.7 | 29.7 ± 1.2 |
| *Skeletonema* sp. CS 252 | 128.8 ± 5,0 | 32.9 ± 0.2 | 42.4 ± 1.6 |
| *Skeletonema* sp. CS 181 | 123.8 ± 3.5 | 21.1 ± 0.9 | 26.1 ± 0.8 |
| *Chaetoceros muelleri* | 92.0 ± 4.2 | 34.7 ± 0.2 | 32.0 ± 1.5 |
| *Chaetoceros calcitrans* | 62.0 ± 1.4 | 40.9 ± 0.1 | 25.3 ± 0.6 |

# Lipid production in bubbled tubes under

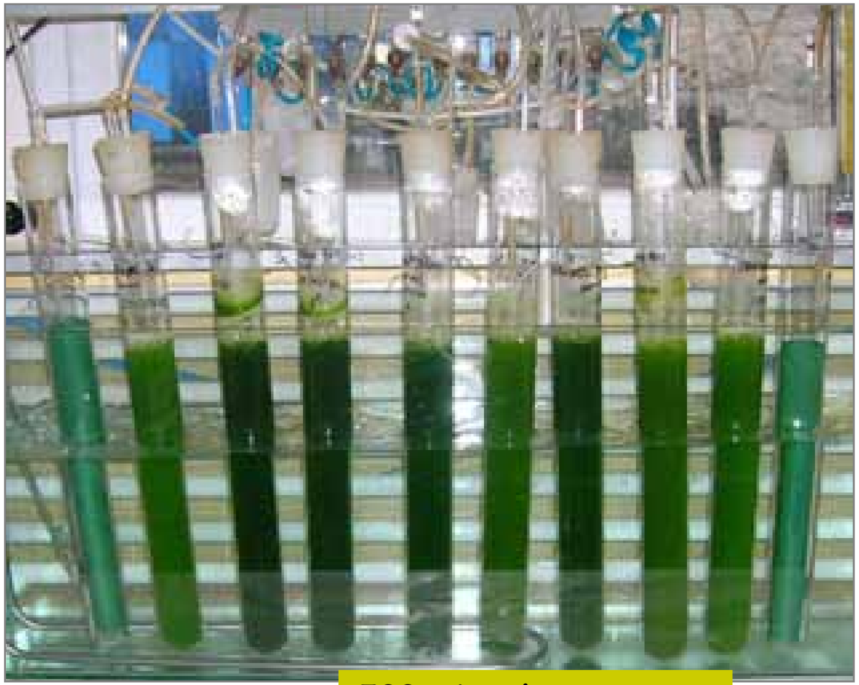
# NITROGEN STARVATION

***Freshwater species:***

- *Chlorella* sp. AMI2
- *Scenedesmus* sp. DM

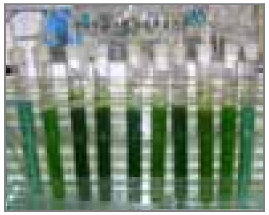
**Marine species:**

- *Tetraselmis suecica* OR
- *Nannochloropsis* sp. ZM

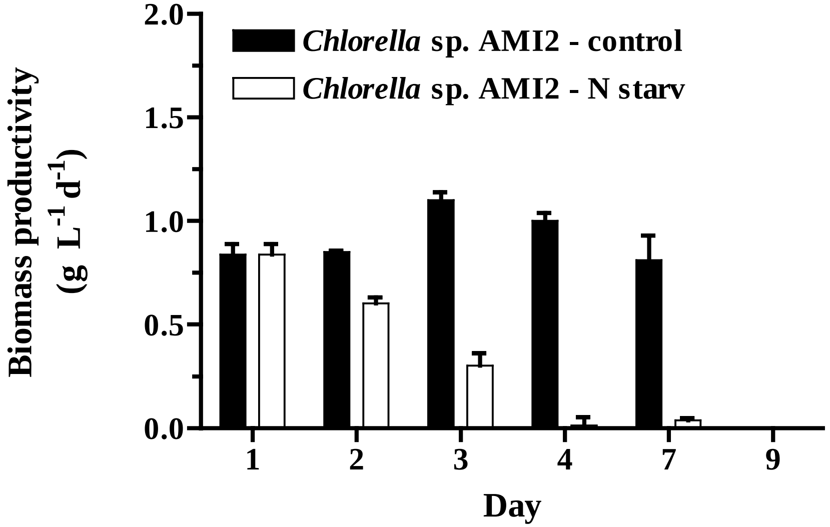


•500 mL cultures
•50% daily harvest rate
•N – sufficient medium
•N – free medium

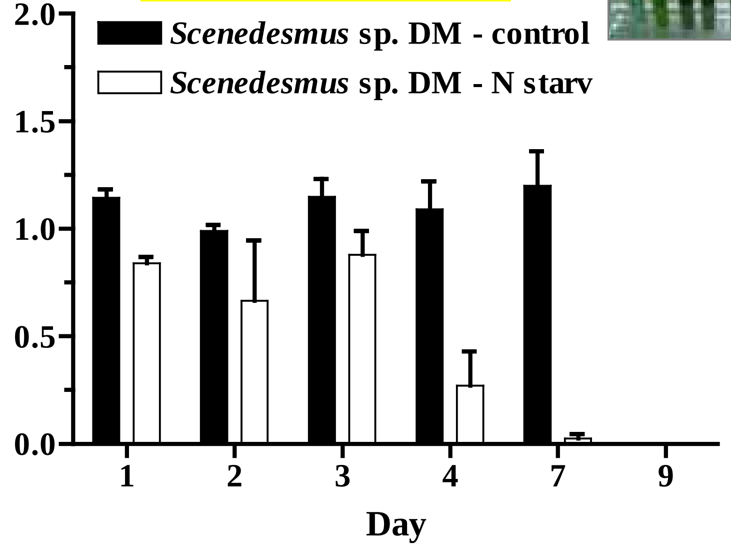
# Freshwater microalgae under NITROGEN STARVATION

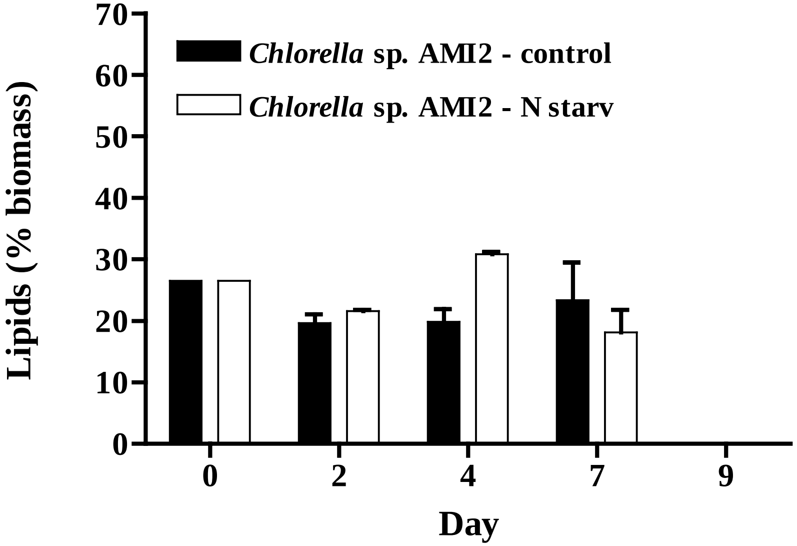


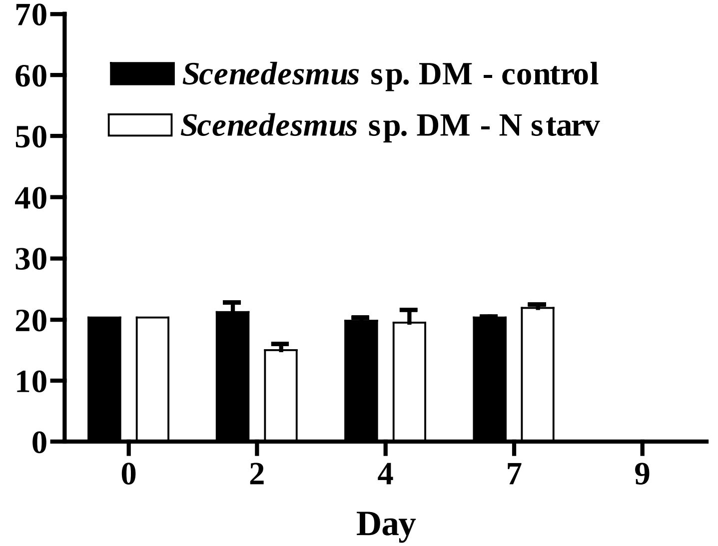
## *Chlorella*



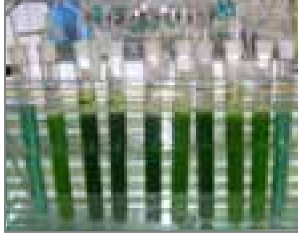

## *Scenedesmus*



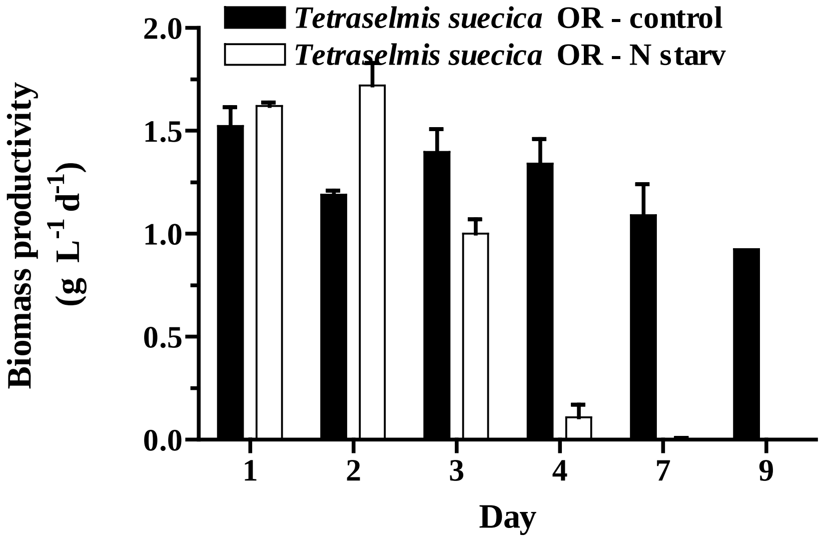



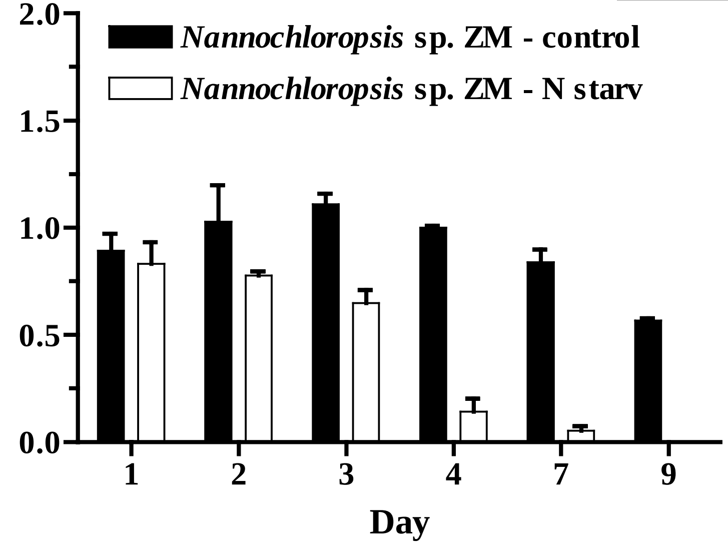
# Marine microalgae under NITROGEN STARVATION

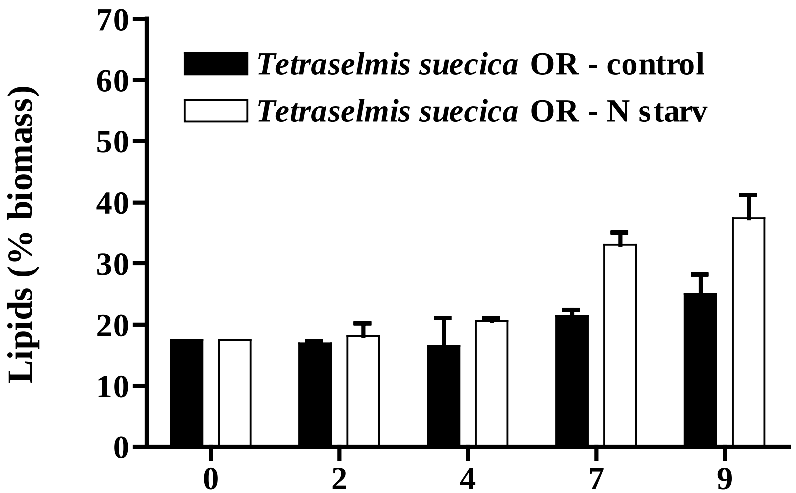


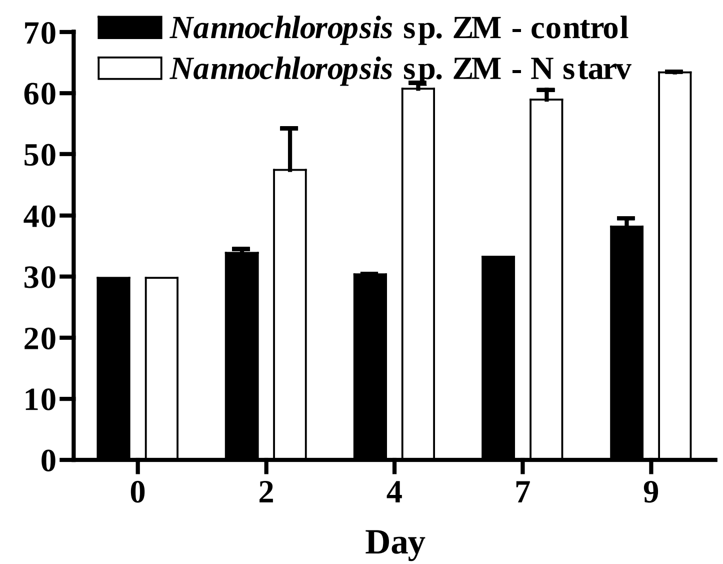
## *Tetraselmis*




## *Nannochloropsis*

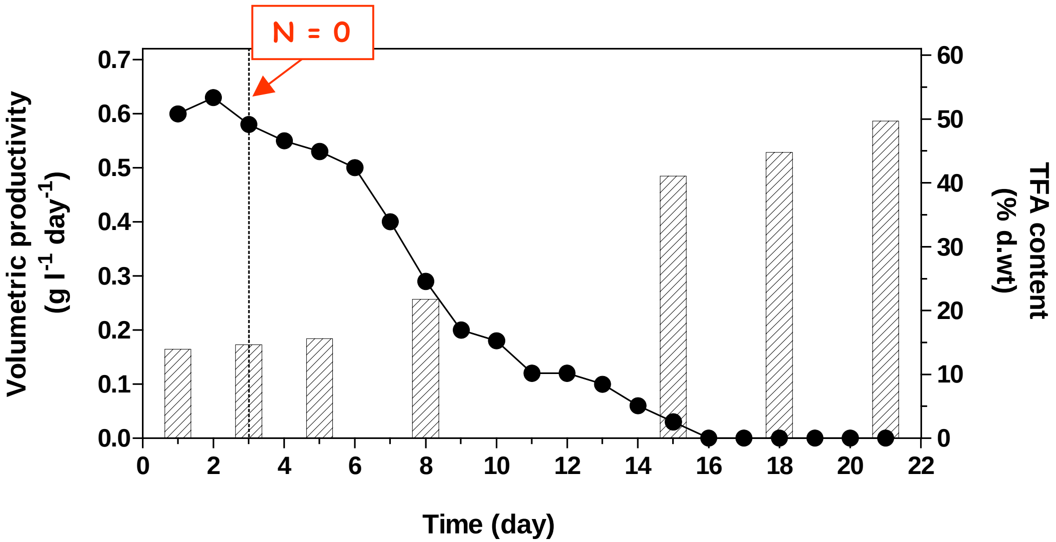


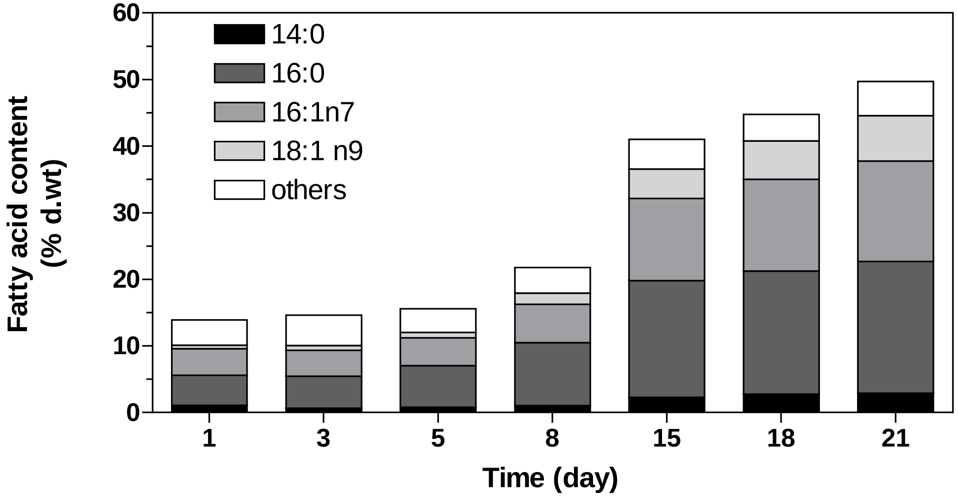



*Nannochloropsis* sp. ZM in alveolar panels with artificial illumination

Fatty acid accumulation under NITROGEN STARVATION

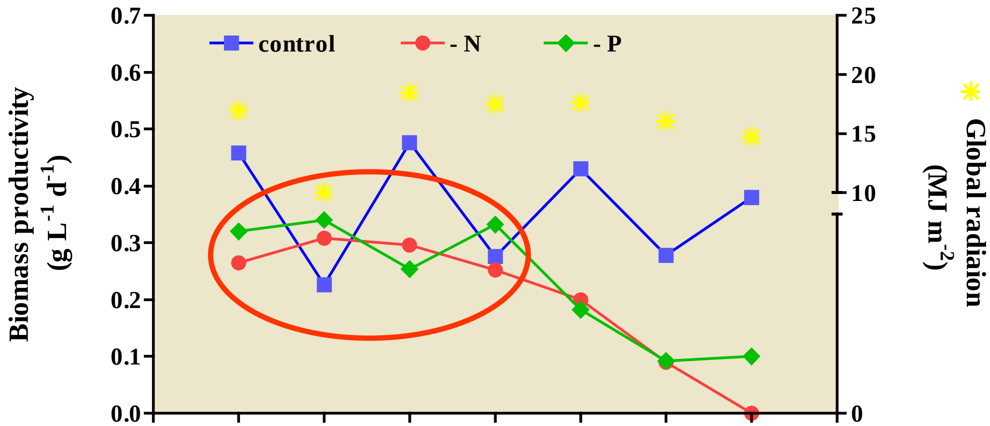



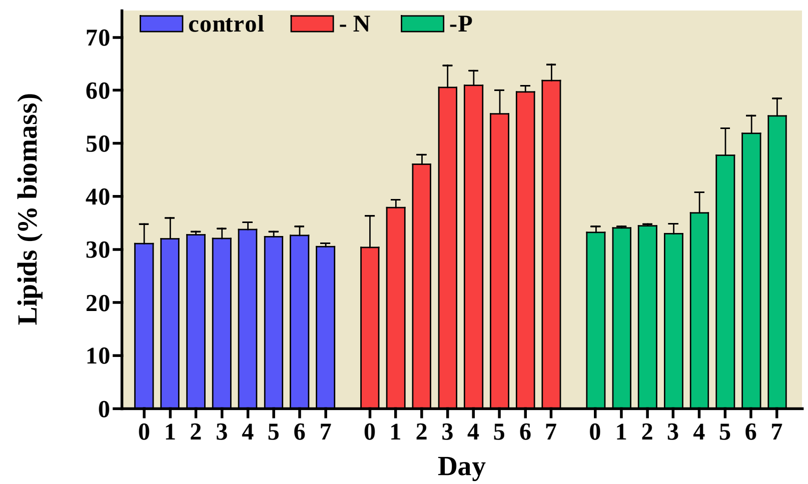



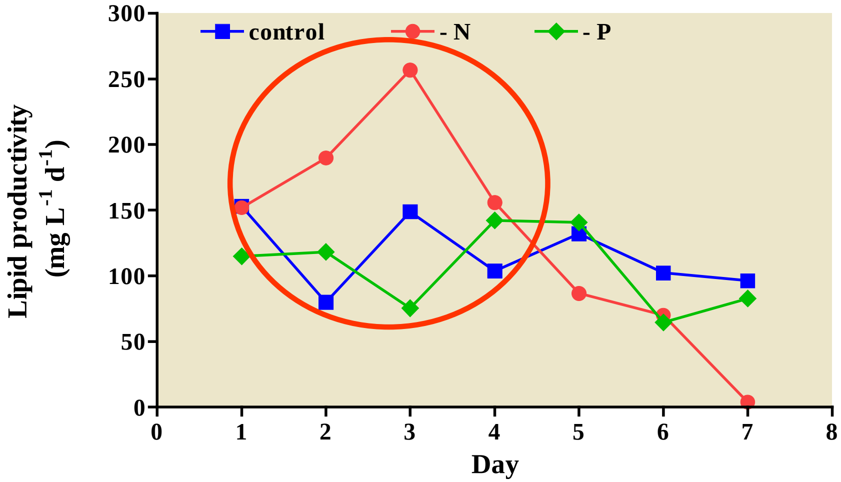
# Outdoor cultivation of *Nannochloropsis* sp. ZM in green-wall reactors

Influence of **NITROGEN & PHOSPHORUS** starvation/limitation on lipid productivity


# *Nannochloropsis* sp. ZM outdoor in green-wall reactor - **NITROGEN & PHOSPHORUS STARVATION**

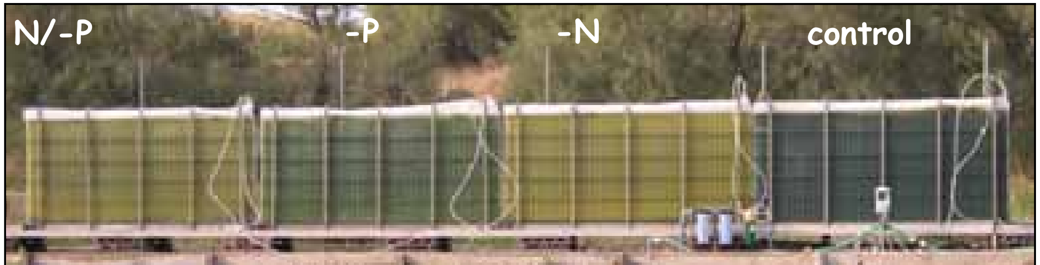



**Conclusion:**

**Nitrogen starvation in a growing *Nannochloropsis* culture causes a rapid increase of lipid content and leads to a significant increase of lipid productivity**

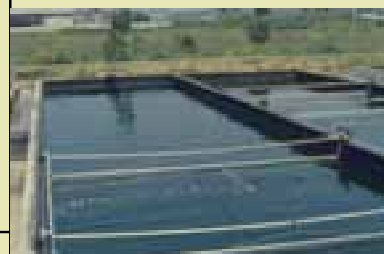


The pilot plant was arranged so as to simulate a full-scale system and the areal lipid productivity could be calculated

The experiments showed that *Nannochloropsis* has a potential for producing more than **20 tons of lipid per ha per year** in the Mediterranean basin and more than **30 tons of lipid per ha per year** in sunny tropical areas (20 MJ $m^{-2}$ $d^{-1}$)

# Open ponds vs. PBR: Productivity and energy output

(with the marine microalga *Tetraselmis* [1] )

| | **Pond**<br>**(Calabria, Italy, 1983)** | **Tubular reactors**<br>**(Tuscany and Lazio, Italy, 1998-2005)** | **GW reactor**<br>**(Tuscany, Italy, 2006)** |
|---|---|---|---|
| |  |  |  |
| **Productivity ($ton\ ha^{-1}\ y^{-1}$)** | **~50** | **57- 60** | **~ 70** |
| **Energy output ($GJ\ ha^{-1}\ y^{-1}$)** | **1150** | **1350** | **1600**<br>**~ 40%** |

(1) - biomass energy content: 23 $kJ\ g^{-1}$

# Open ponds vs PBR: energy consumption for mixing

| | Raceway pond[1] | Tubular reactor[2] | GW reactor [3] |
|---|---|---|---|
| GJ $ha^{-1}$ $y^{-1}$ | 6.5 | 180 | 670 |
| % of the energy in biomass | 0.5 | 14 | 42 |

(1) from Oswald, 1988

(2) from Burgess and Fernandez-Velasco, 2007 (0.05 m diameter tubes)

(3) according to Molina Grima et al. (2002)

# Energy cost of materials

| | Total embodied energy | |
|---|---|---|
| | (GJ $ha^{-1}$ $y^{-1}$) | % of the productivity |
|  | **1214** (10y lifespan) | **75%** |
|  | **110-120** HDPE membrane + dividers + paddle wheel (12 year lifespan) | **10%** |


| WG Reactor | N° pieces ha$^{-1}$ | Weight per piece (kg) | Material embodied energy (MJ kg$^{-1}$) | Material lifespan (yr) | Lifespan-weighed energy content (GJ ha$^{-1}$ y$^{-1}$) |
|---|---|---|---|---|---|
| Steel grids (0.7 m x 2 m) | 12,500 | 4.3 | 36 | 10 | 193.5 |
| 50-m-long LDPE culture chamber | 250 | 21 | 74 | 2 | 194.2 |
| Wood or cement basament (5m) | 2,500 | 35 | 13 | 7 | 162.5 |
| **TOTAL** | | | | | **550** |

embodied energy of the new GW

~ 35 % of productivity

Energy for mixing

~ 35 % of productivity

New GW design with lower embodied energy and lower energy requirement for mixing to increase the NER of the system.

# The Green Wall Panel

# Colture di microalghe:

## Una tecnologia di grande potenziale che richiede ancora R&D

Near horizontal tubular reactor (1990)

## Biocarburanti da microalghe: i punti deboli

1. l'elevato costo del sistema produttivo (fotobioreattore)

2. l'elevato costo del rimescolamento della coltura

3. il costo (energetico) della separazione della biomassa dal mezzo acquoso di coltura

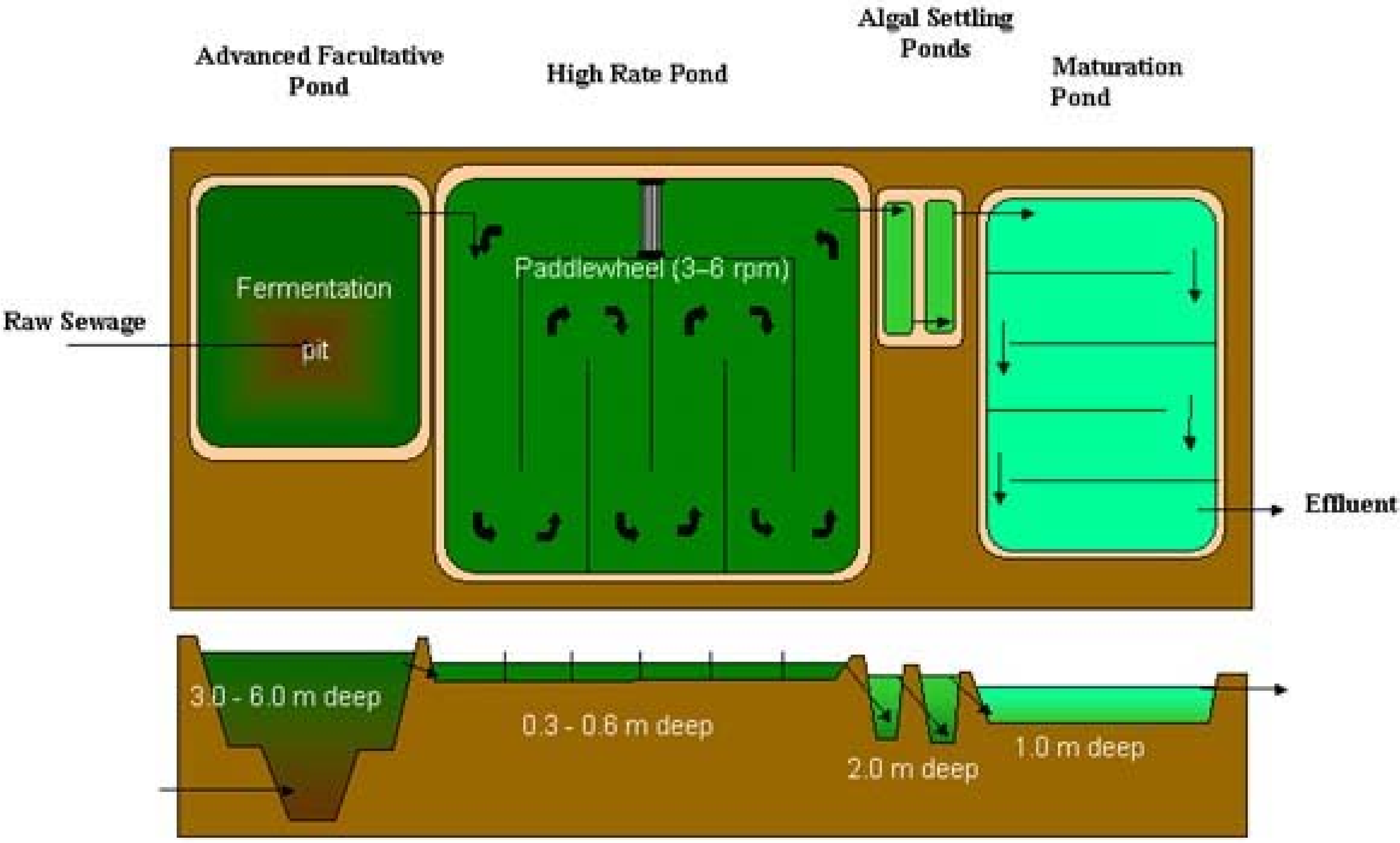
**Principale limitazione $\rightarrow$ Costo di produzione della biomassa: 3 – 30 €/Kg**

**Per energia < 0.3 €/Kg**

**?**

# Microalghe su acque reflue: Le HRAP


**Figura 11 - Vasche “raceway” per il trattamento di acque reflue**




**Schema di Advanced Integrated Wastewater Ponding System (adattato da sito web della NWA).**

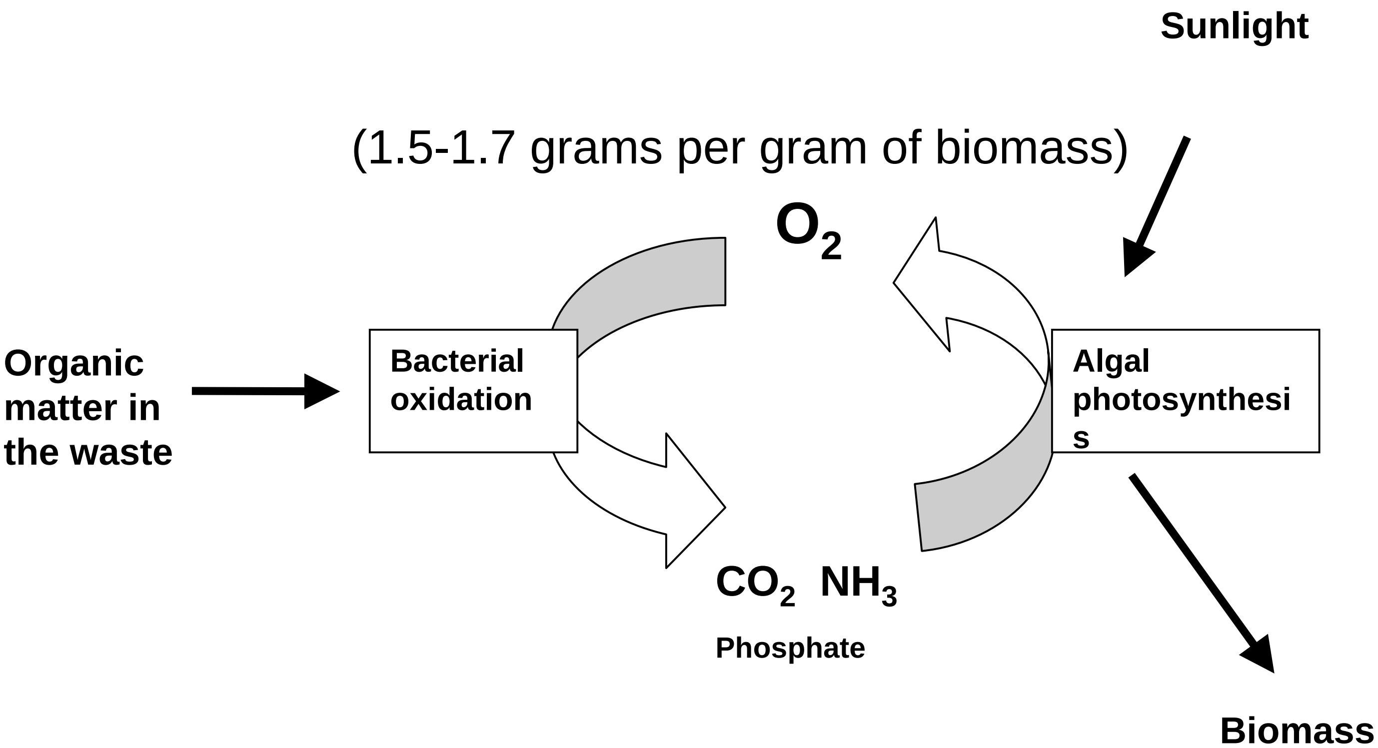



**Fig. 1 –Cycle for photosynthetic oxigenation**

- The typical pond design is that already described of a single or meandering raceway pond simply excavated in the earth with the bottom unlined or sealed with a plastic liner. **The energy input for well-designed paddlewheel-mixed HRAP is only about 5 KWh per hectare per day** (Oswald, 1988).

- The most difficult task will be **maintaining a selected microalgal species** in the culture: a necessary requisite to develop efficient harvesting and processing techniques, and when a specific use of the biomass (e.g. oil extraction) is pursued (Rodolfi et al., 2008).

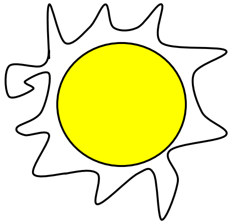
**Le emergenze del 21$^{mo}$ secolo:**

1. Cibo
2. Acqua
3. Clima
4. Energia


alluvioni
nuove specie
desertificazione
fusione ghiacci


Peak Oil
SURVIVAL GUIDE
Preparing For The
Coming Global Crisis
Africa
Food
Crisis

**Che fare?**

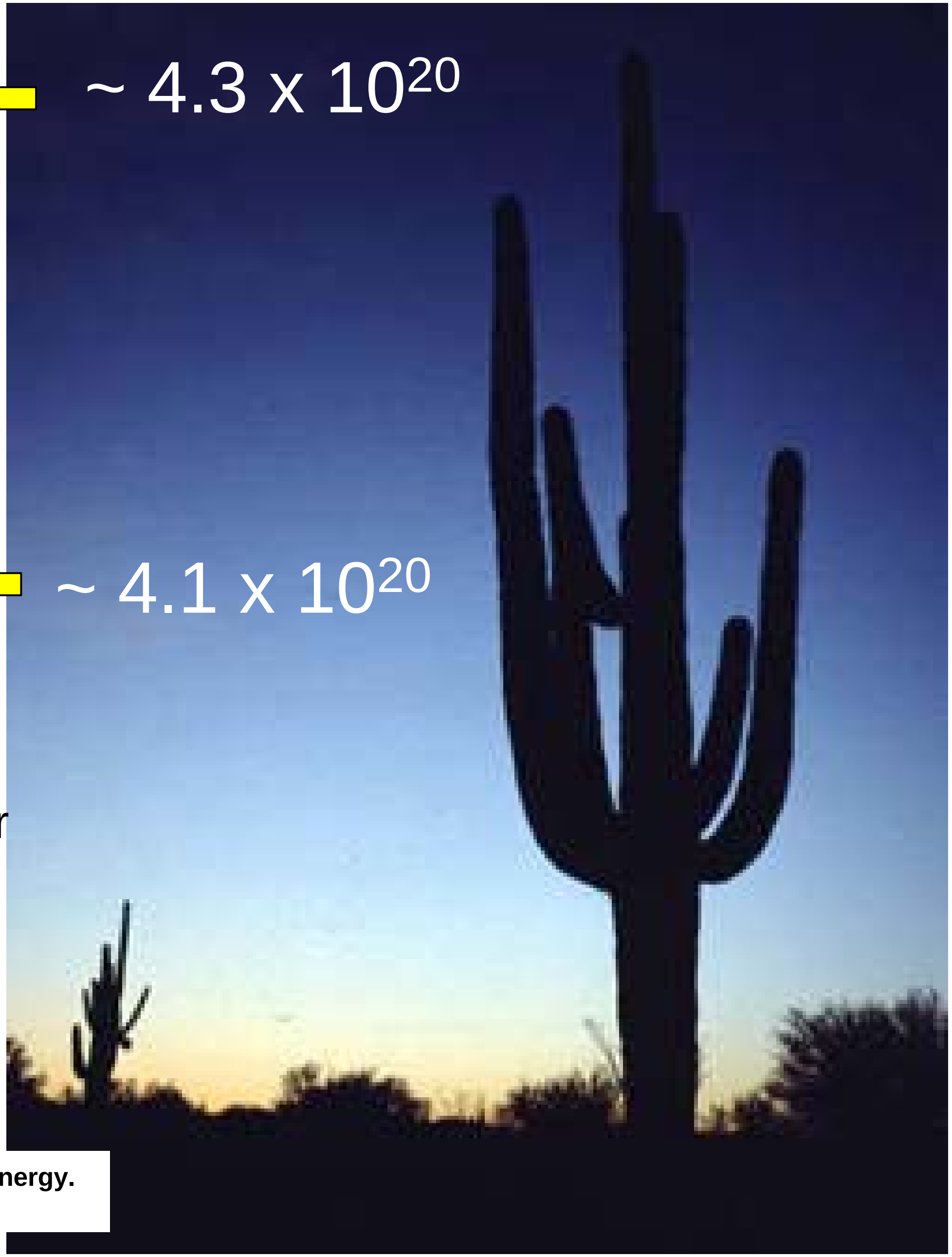


~ $4.3 \times 10^{20}$

energy (J) from the sun every hour

~ $4.1 \times 10^{20}$

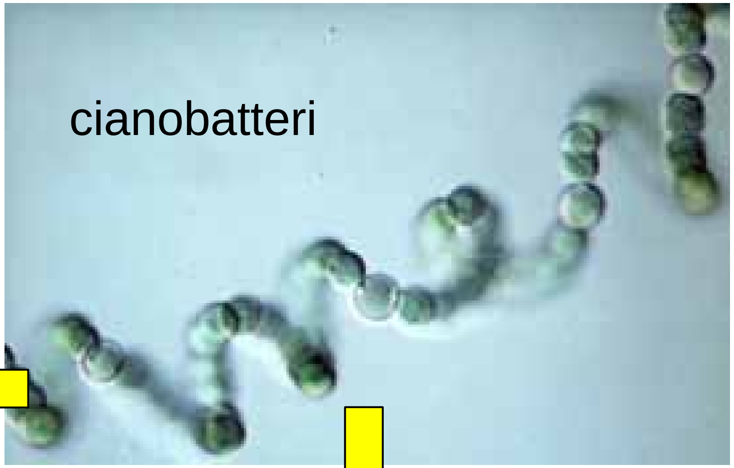
energy (J) consumed in the world per year



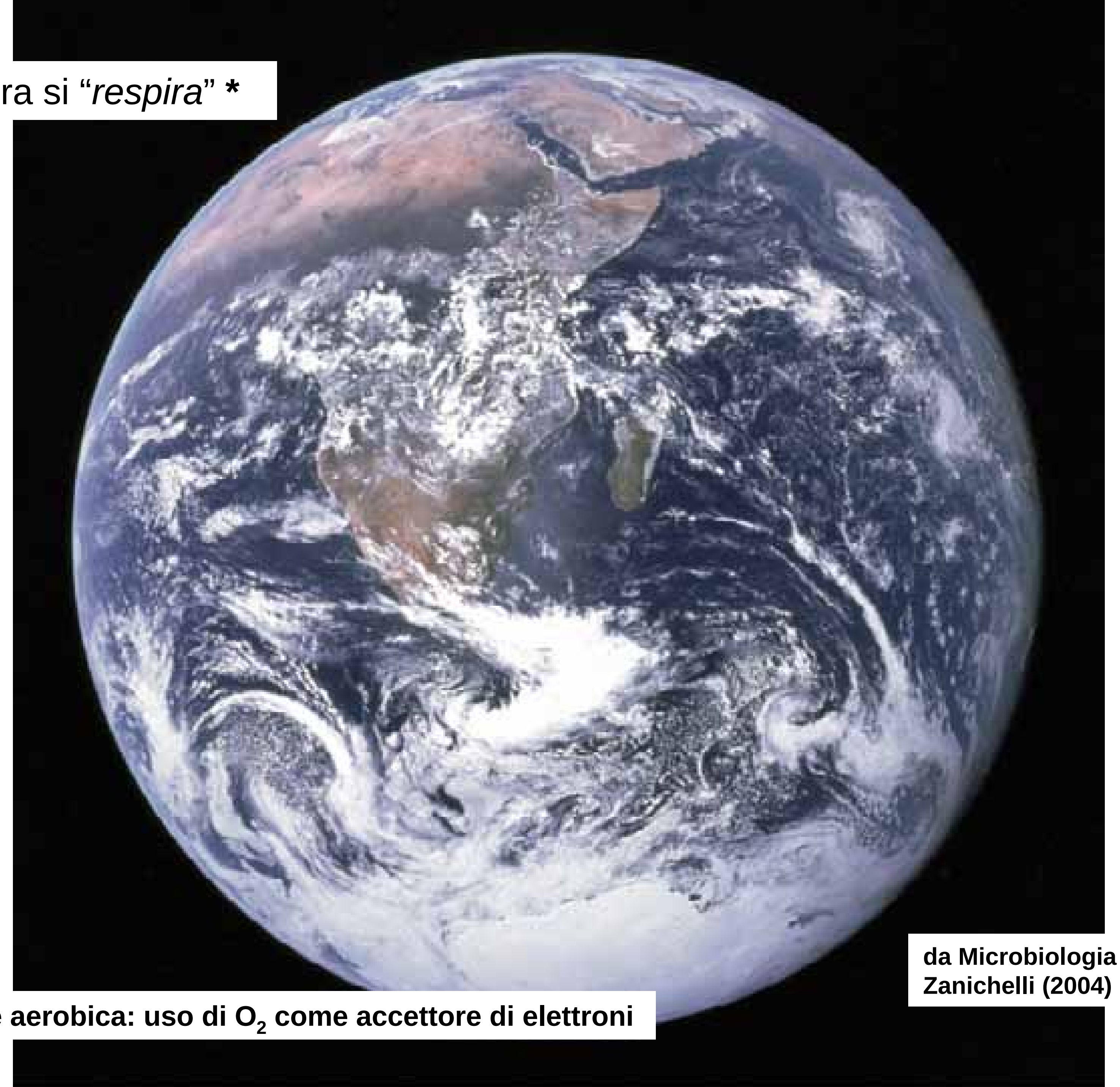
**Donohue T. and Cogdell R. Microorganisms and clean energy. Nature Reviews Microbiology 4, 800 (November 2006)**

# Fotosintesi ossigenica

$H_2O \rightarrow O_2 +$ **elettroni**




Sulla terra si “*respira*” *****

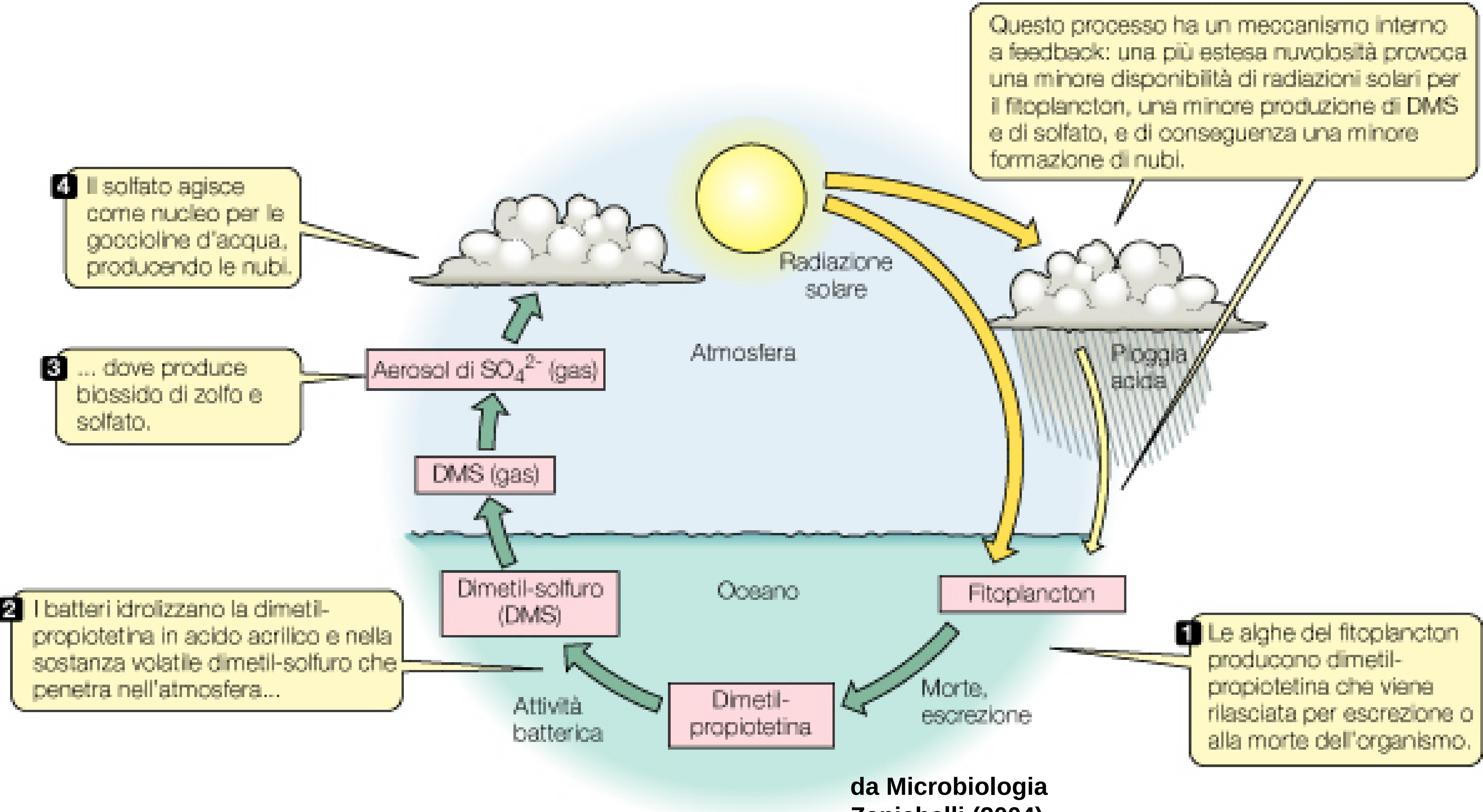


da Microbiologia
Zanichelli (2004)

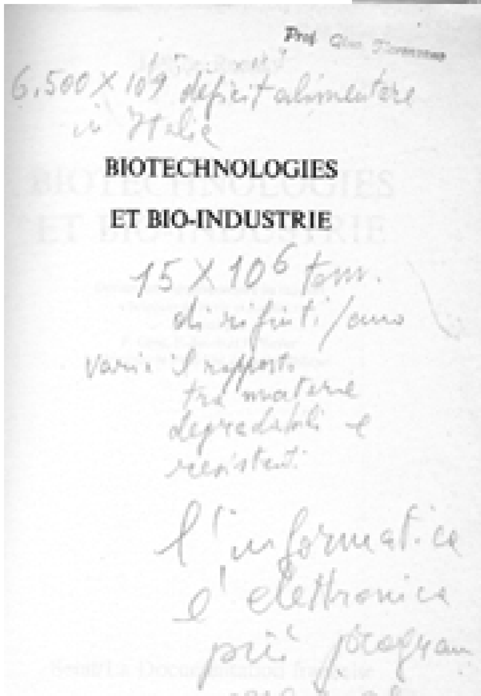
***Respirazione aerobica: uso di $O_2$ come accettore di elettroni**

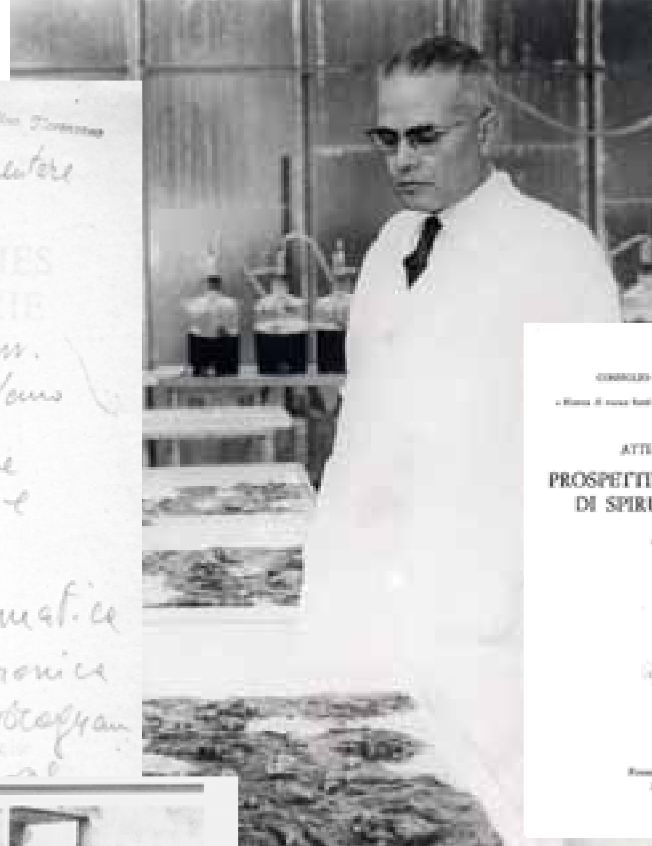
# Fotobioreattori

# Bloom algali e global change




**da Microbiologia Zanichelli (2004)**

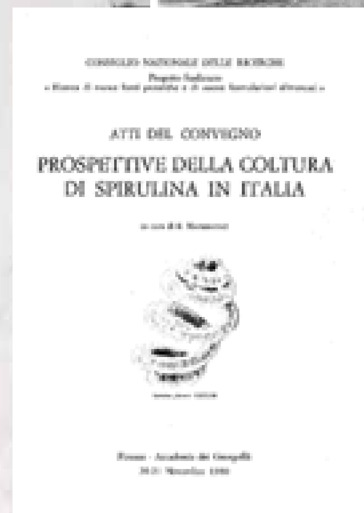



LA RICERCA SPERIMENTALE DEL CNR A LAMEZIA

**Metano, fertilizzanti e mangimi coltivando le alghe marine**

*Il CNR, d'intesa con la Regione e l'Università della Calabria ha in corso a Lamezia Terme una ricerca sperimentale che ha già registrato significativi risultati*





«Maricoltura su terra»: nuove prospettive per l'utilizzazione dell'energia solare

*Di fronte ai problemi ecologici, alimentari ed energetici del nostro tempo, le interazioni tra fotosintesi microbica, salvaguardia dell'ambiente e produzione di alimenti assumono una fondamentale importanza teorica e pratica per i possibili contributi agli equilibri del sistema biosferico, divenuti fragili e delicati.*

2.10.1977 Gino Florenzano

**Emissioni di $CO_2$ da centrali elettriche a carbone**
[ Milioni di tonnellate – impianti funzionanti a pieno regime ]

| | | |
|---|---|---|
| Brindisi Sud | Enel | 15,9 |
| Fusina | Enel | 5,8 |
| Sulcis | Enel | 4,1 |
| Vado Ligure | Tirreno Power | 4,0 |
| Brindisi Nord | Edipower | 3,8 |
| Fiumesanto | Endesa | 3,8 |
| **La Spezia** | **Enel** | **3,6** |
| Monfalcone | Endesa | 2,0 |
| Genova | Enel | 1,8 |
| Marghera | Enel | 0,9 |
| Bastardo | Enel | 0,9 |
| Totale | | 46,6 |

Fissare il 10%
↓
360.000 ton/anno

Ragionevole produzione di 80 t di biomassa algale secca per ha per anno

(x 1.83) → 150 ton di CO2 fissata per ettaro per anno

2400 ha (6x4 km)

190.000 t di biomassa di cui 48.000 t olio + 144.000 t di residuo proteico