Strategie Innovative per la Produzione di Energia da Biomasse di Terza Generazione

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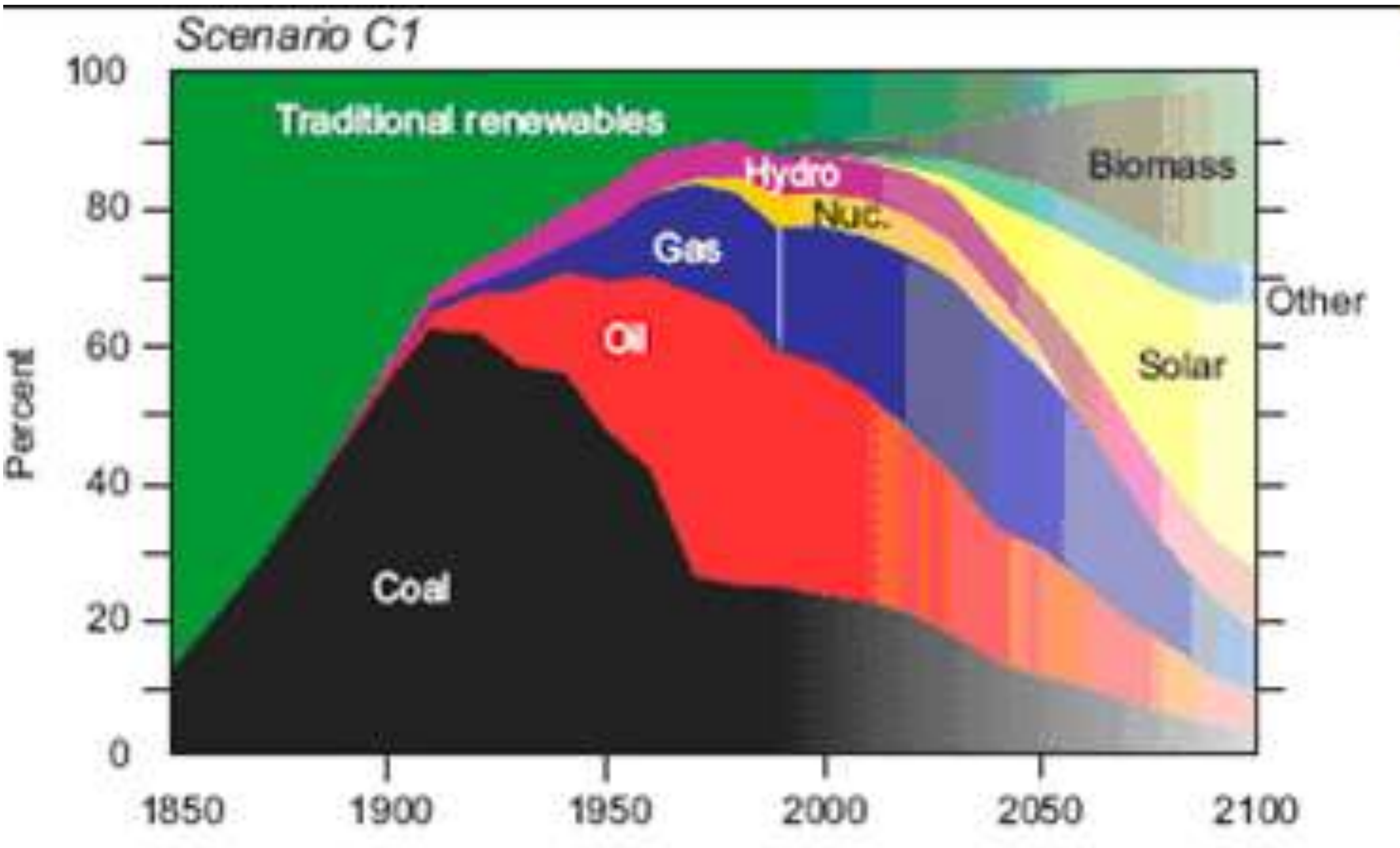
Alba, 21 Giugno 2011

Energy Consumption 1850-2100



Nakicenovic, N. et al. (eds) 1998. Global Energy Perspectives. Cambridge,

Definition

First-generation or **conventional biofuels** are made from feedstocks (sugar, starch, and vegetable oil) that have traditionally been used as food.

Second generation biofuels (e.g. cellulosic ethanol are derived from non-edible feedstocks (lignocellulosic crops)

Third-generation biofuels are made from nonfood feedstocks (**microalgae**), but the resulting fuel is indistinguishable from its petroleum counterparts.

ECONOMIC IMPORTANCE of MICROALGAE

- *Dunaliella* – good source of beta-carotene --- used for food coloring;
- *Chlorella* – “health food”—protein supplement and is commercially grown in Asia. Recently has been sold at 43’000 $ per ton;
- Different species are used in aquaculture to feed fish;
- Nutraceuticals;

Algae and Biodiesel

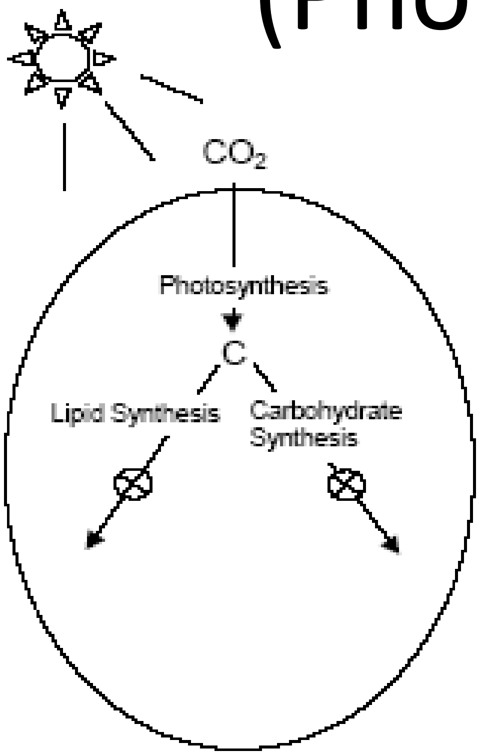
- Algae Biodiesel is a good replacement for standard crop Biodiesels like soy and canola
- Up to 70% of algae biomass is usable oils
- Algae does not compete for land and space with other agricultural crops
- Algae can survive in water of high salt content and use water that was previously deemed unusable
- Wastewater (sewage) can be used.
- Expensive agricultural fertilizers avoided.
- No addition of CO_2 needed but could use flue gases from fossil fuel power stations.

Oil yields of crops vs microalgae

Crop	Oil yield (L/ha)
Maize	172
Soybean	446
Oil seed rape	1190
Jatropha	1892
Oil palm	5950
Microalgae grown in raceway ponds.	17000

Source: Chisti, Y 2007 and J. Benemann, J 2008

Storing the Sun's Energy in Algae (Photosynthesis)

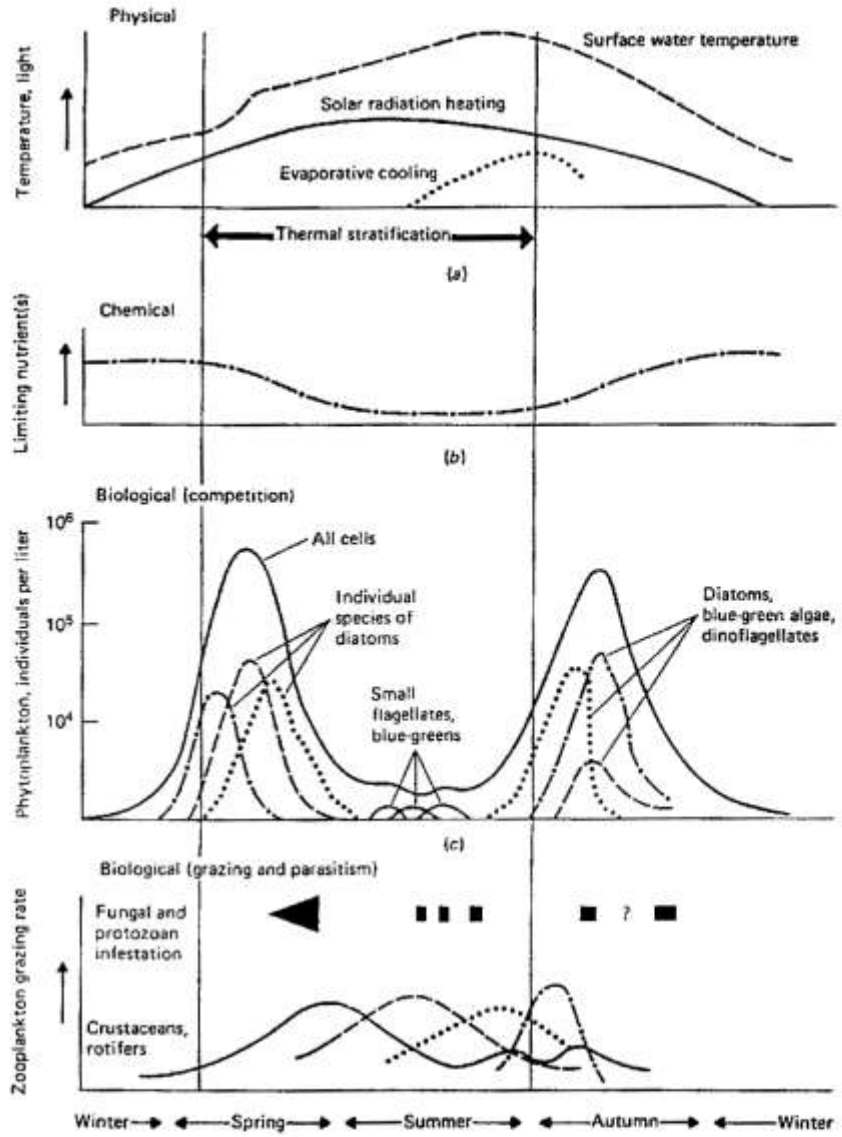


- What is needed
  - Sunlight
  - CO_2
  - Nutrients
- Storage of Energy
  - Lipids and oils
  - Carbohydrates

The fastest growing sunlight-driven cell factories

http://www.veggievan.org/downloads/articles/Biodiesel%20from%20Algae.pdf

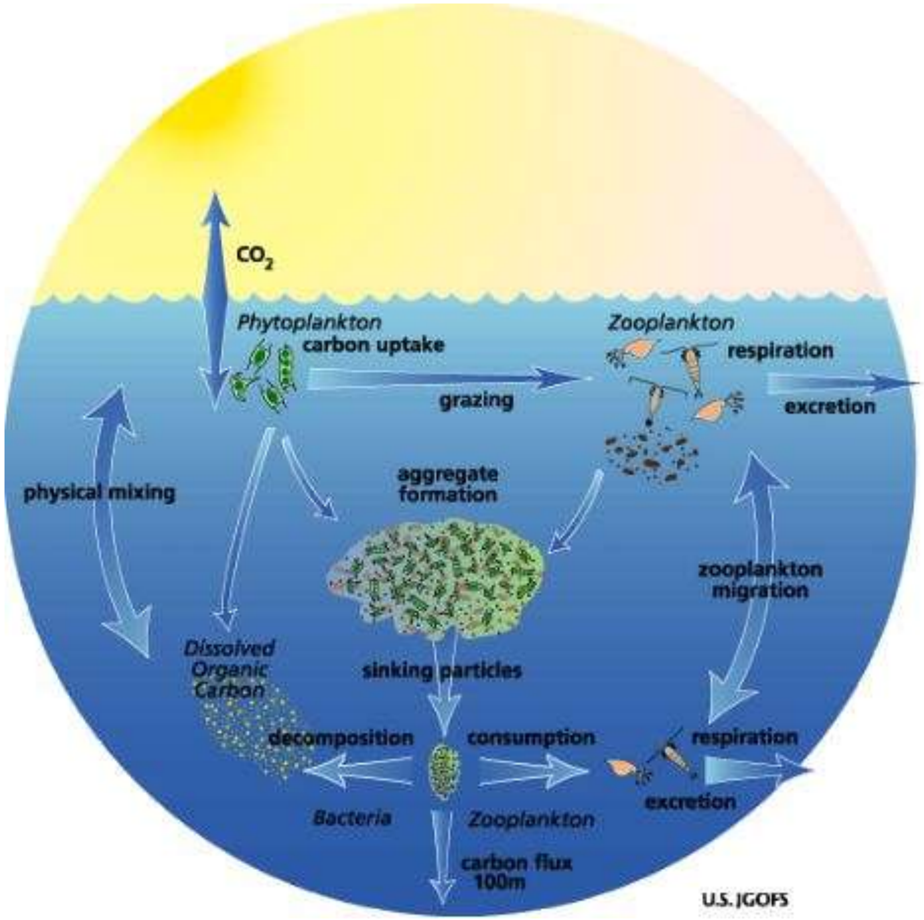
Ocean (Micro)Algal Blooms



Seasonal cycle of phytoplankton

CARBON FIXATION IN OCEAN

$1x10^{10}$ t year^{-1}

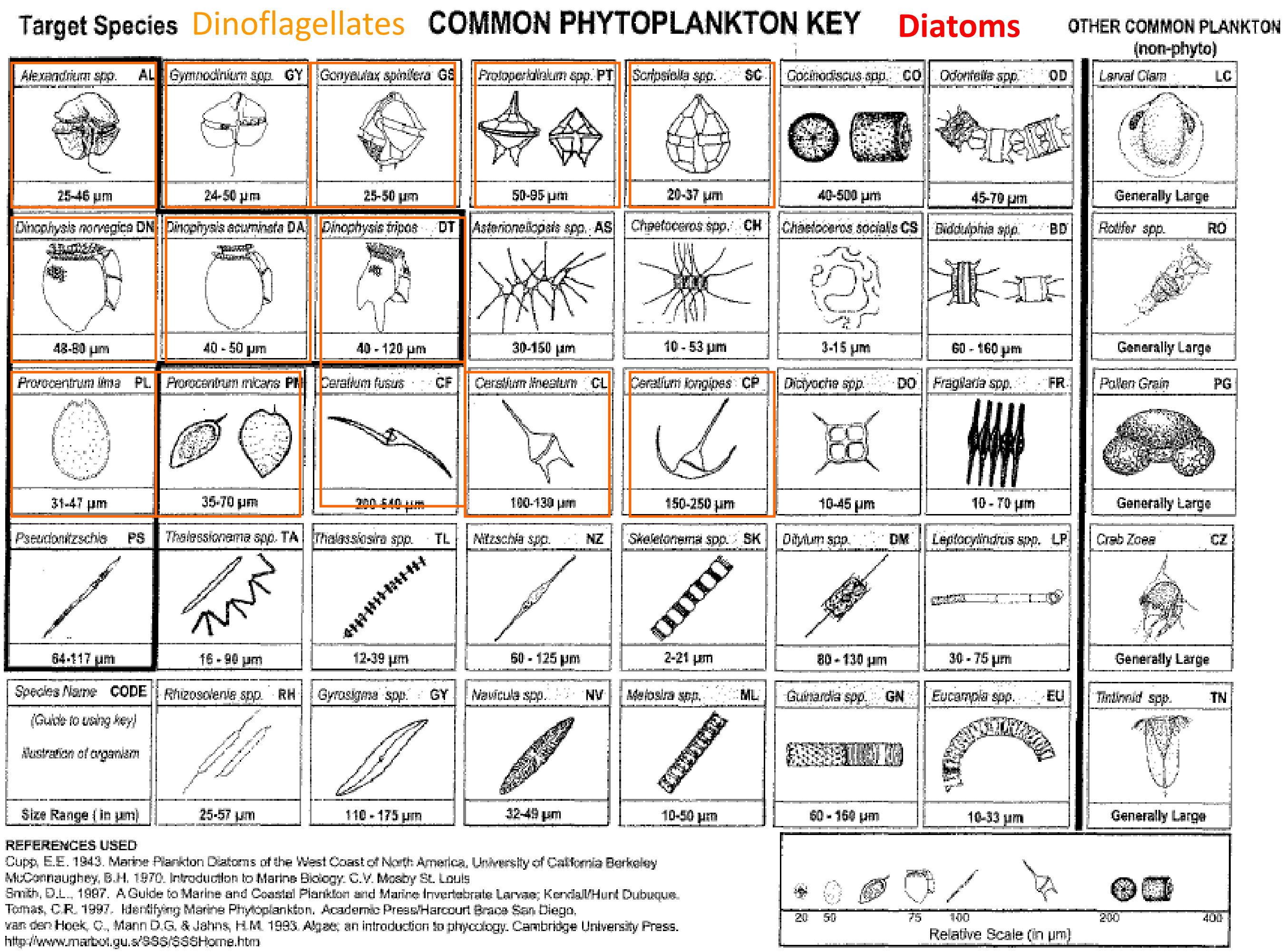


Marine Microalgae origins 45% global carbon fixed on Earth

The very primary mechanism of carbon sequestration on Earth

Zubkov and Scalan, J. Int. Soc. Microb. Ecol., 2010

Floating microalgae: Phytoplankton



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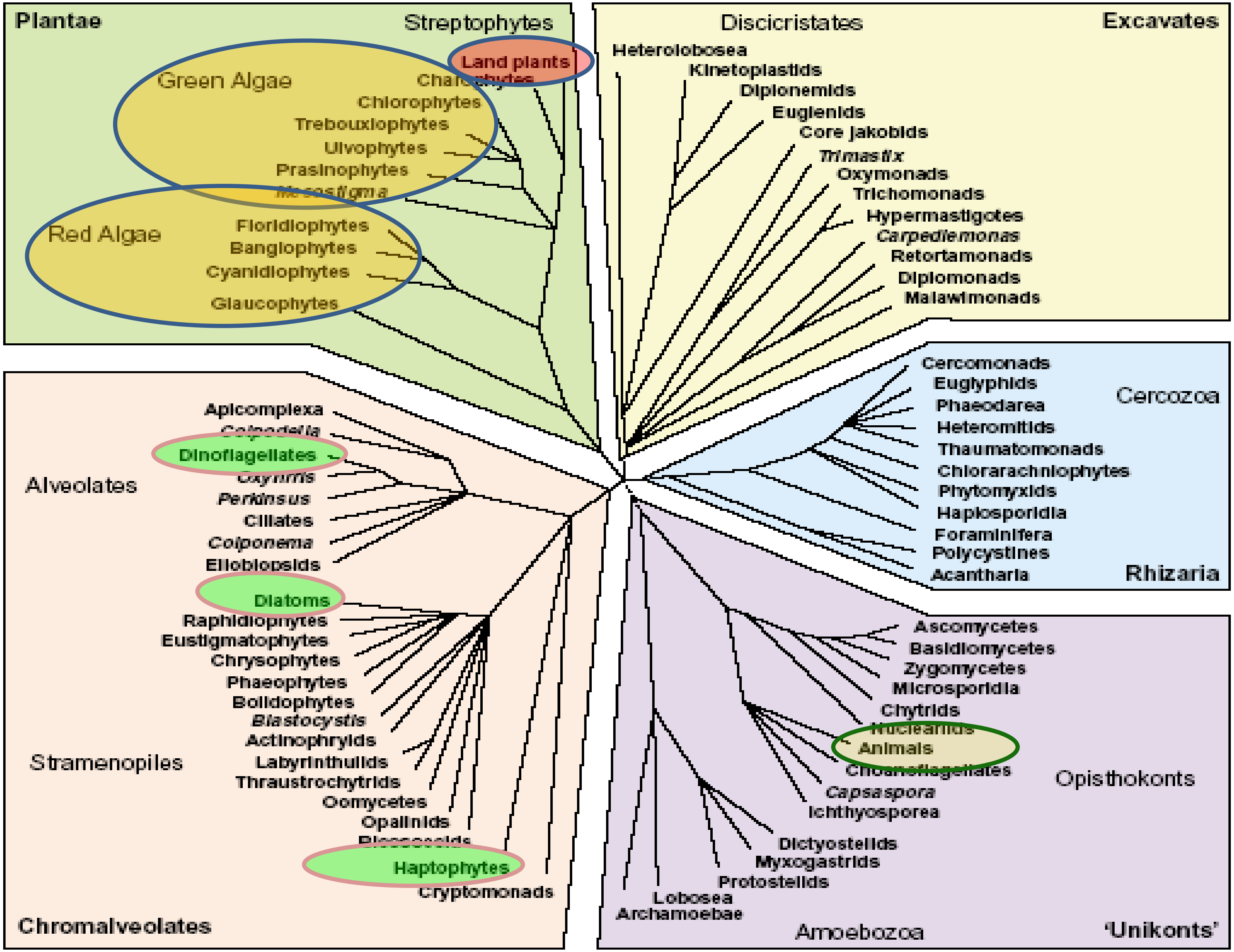
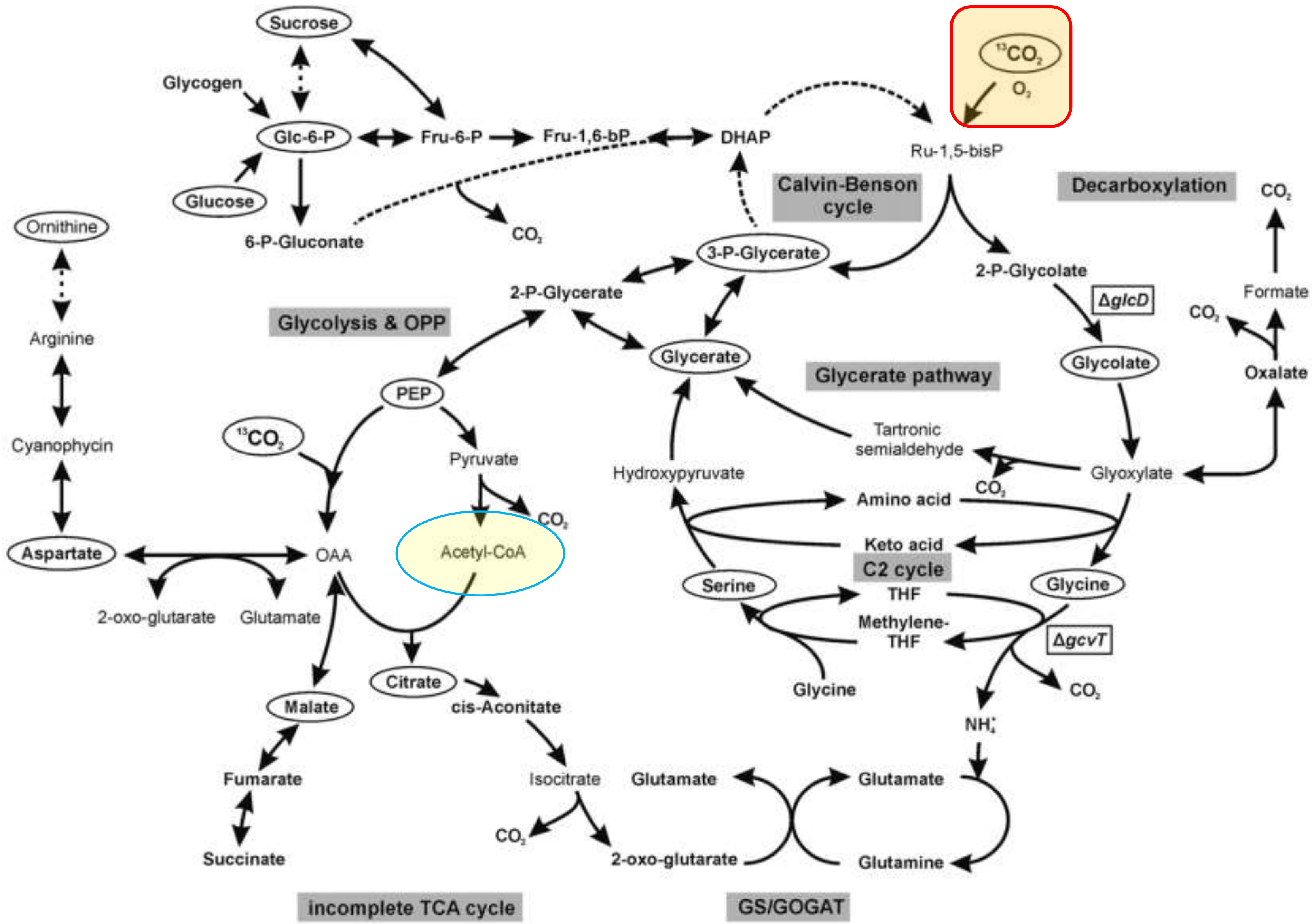
van den Hoek, C., Mann D.G. & Jahns, H.M. 1993. Algae: an introduction to phycology. Cambridge University Press.
http://www.marbot.gu.s/SSS/SSSHome.htm

Unicells, Filamentous, Colonies – chains, or spheres

The tree of eukaryotes



Trends Ecol. Evol., 20 (12) 2005

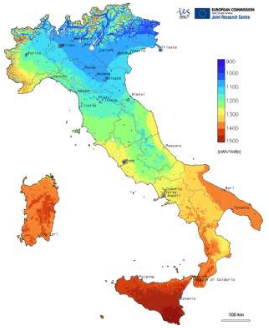


Scheme of central carbon and nitrogen metabolism in *Synechocystis* sp. strain PCC 6803.

Huege et al., Plos One, 2011

Energy Output per Unit Area

1 kWh = 3,6 megajoules



Solar Panel*	**130-210 kWh m^{-2} $year^{-1}$**
Solar Plant	**47-76 GJ ha^{-1} $year^{-1}$**

*0.3-0.8 kWh/m^2

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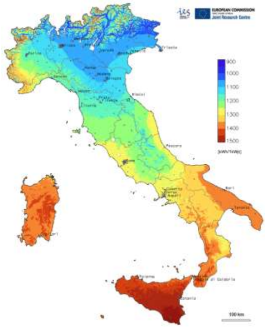

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Vegetable oil crops	40–110 GJ ha^{-1} $year^{-1}$
Microalgae	790–920 GJ ha^{-1} $year^{-1}$

*0.3-0.8 kWh/m^2

Reilly and Paltsev, 2007

Economy matters…..

If you took the average Canadian and put them on a treadmill, and asked them to start walking to generate electricity, they could probably manage to generate 100 watts of electricity. If you paid them to do that for 40 hours a week, with two weeks of vacation and statutory holidays, it would take almost nine years to generate the same amount of energy as in a barrel of oil, and you'd have to pay them $140,000 even at minimum wage.

For gas, we pay about $0.03 for a million joules of energy. It costs pretty much the same to buy that amount of energy in electrical form.

However, in food form, it costs roughly 11 times as much ($0.35) to buy that energy in potatoes, and 130 times as much in chicken ($4).

Brian McCain What's in Watt. The Gaia Project. December 18, 2009

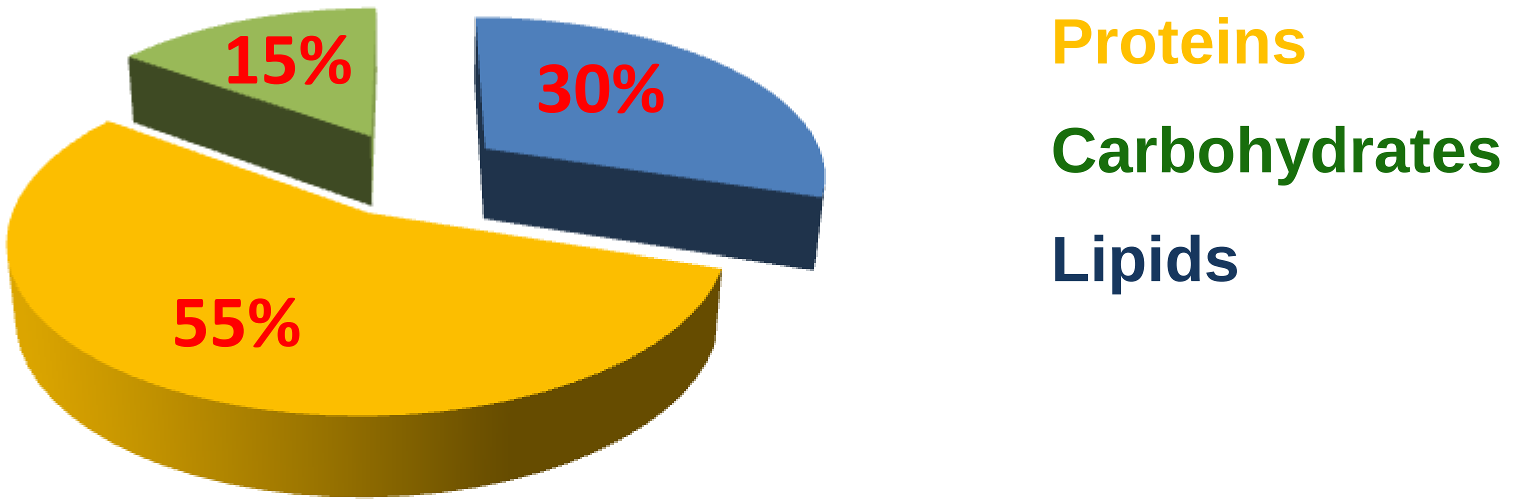
2007 Feasibility Study Biofuels from Algae
(Netherland)

Closed Photobioreactors

1ha	7.9	€/Kg Biomass
100 ha	4.0	€/Kg Biomass
Potential	0.4	€/Kg Biomass
	15	€/GJ

Rene H. Wijffels , Wageningen University, Bioprocess engineering
ESF Conference - Marine Biotechnology: future challenges, 2010

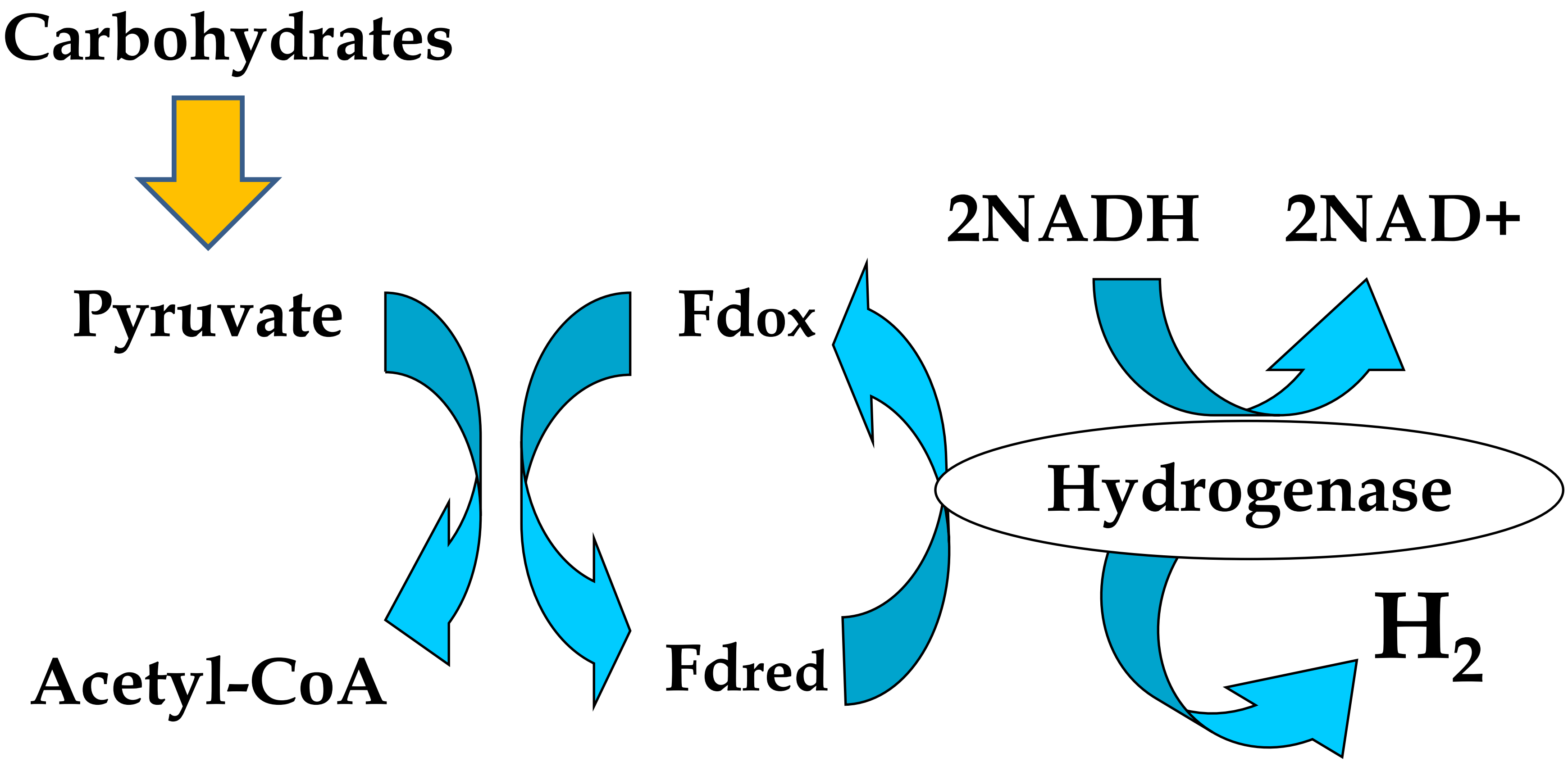
IDEAL COMPOSITION OF DRY BIOMASS



Bio-Hydrogen

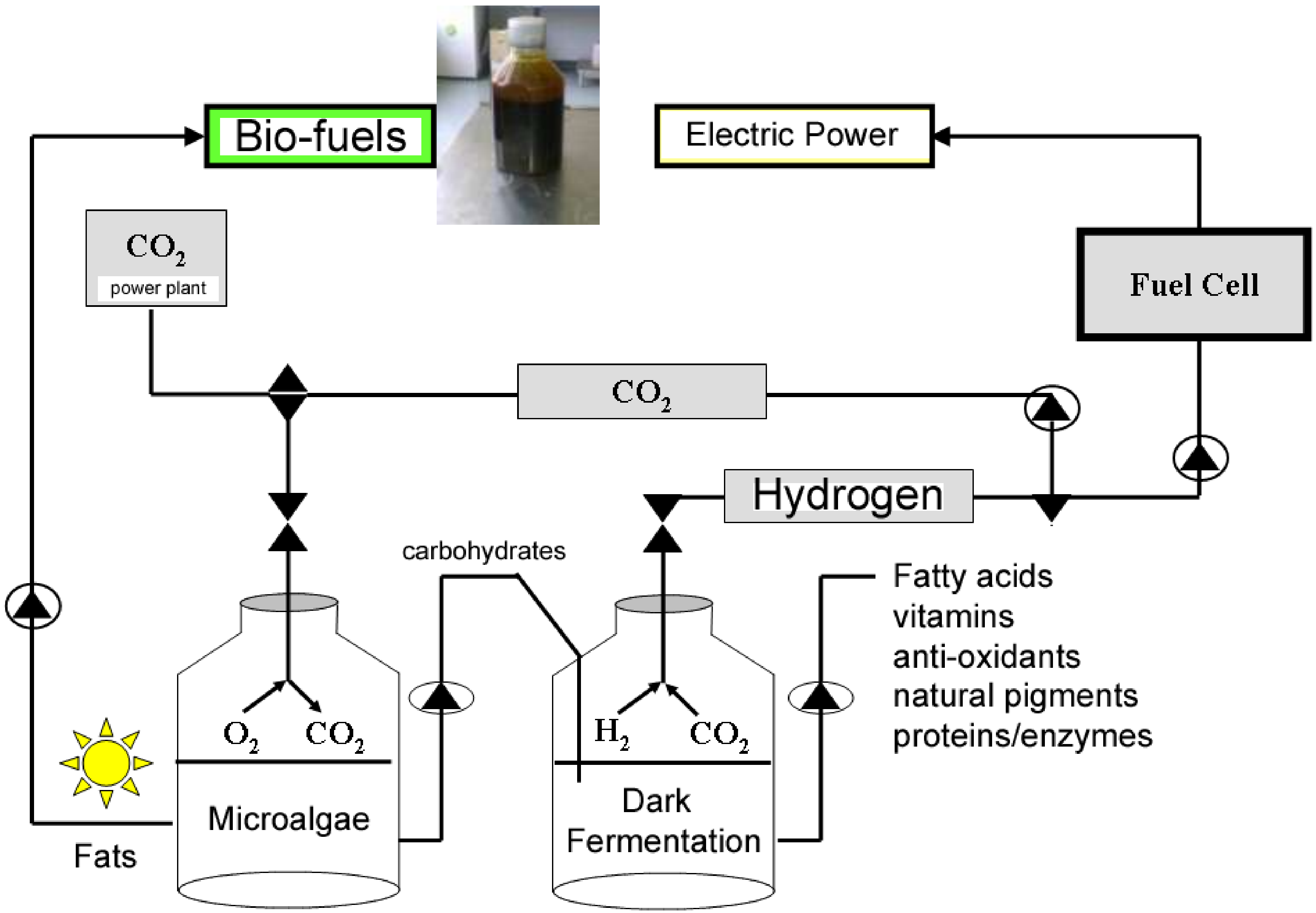
The hydrogen contains almost three times as much energy as natural gas. When consumed its only emission is pure water.

Bio-Hydrogen Production (Dark Fermentation)



Putative Yield 4 mol H_2 / mol glucose equivalent

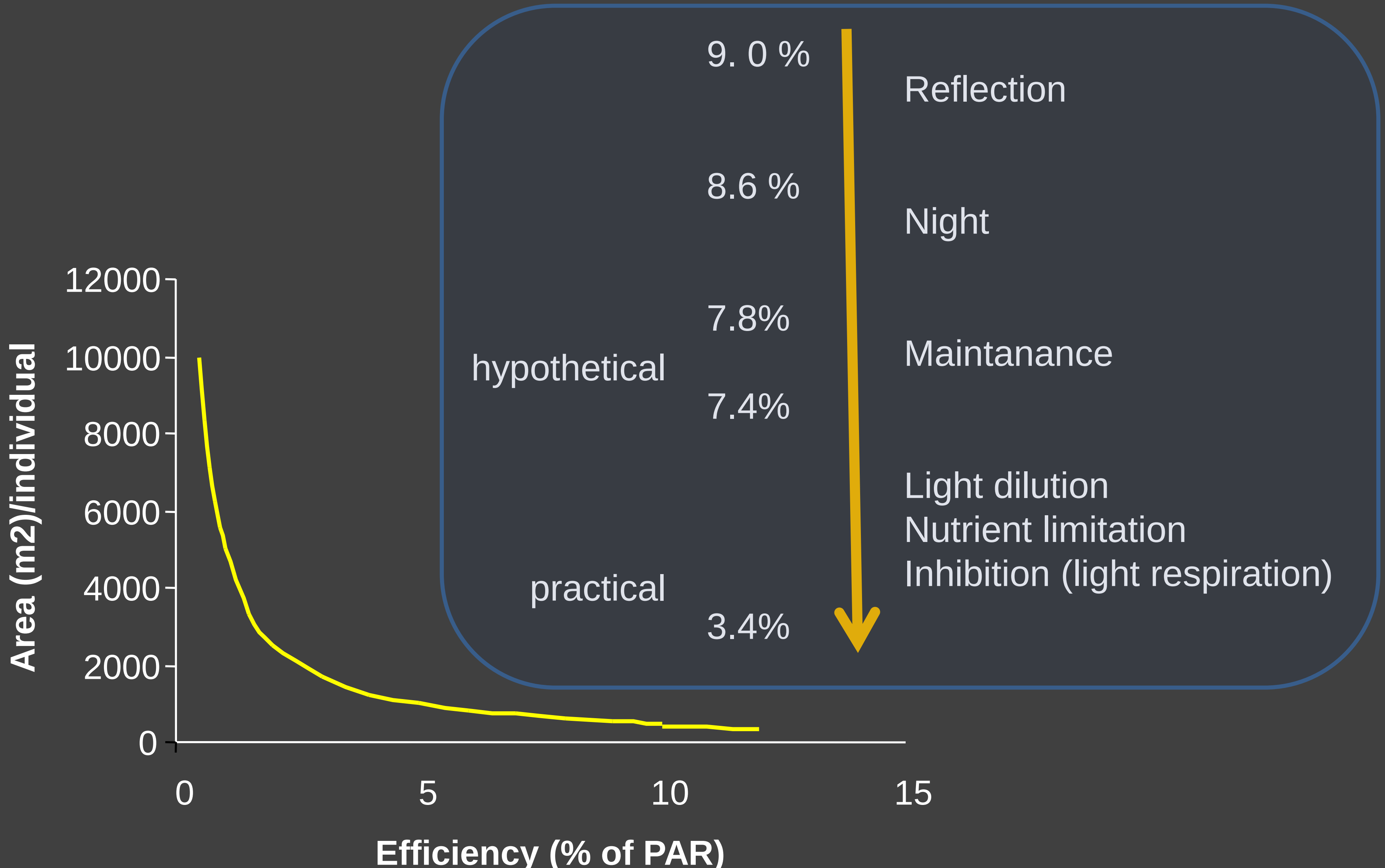
Production of Energy from Integrated Exploitation of Microalgal Biomass



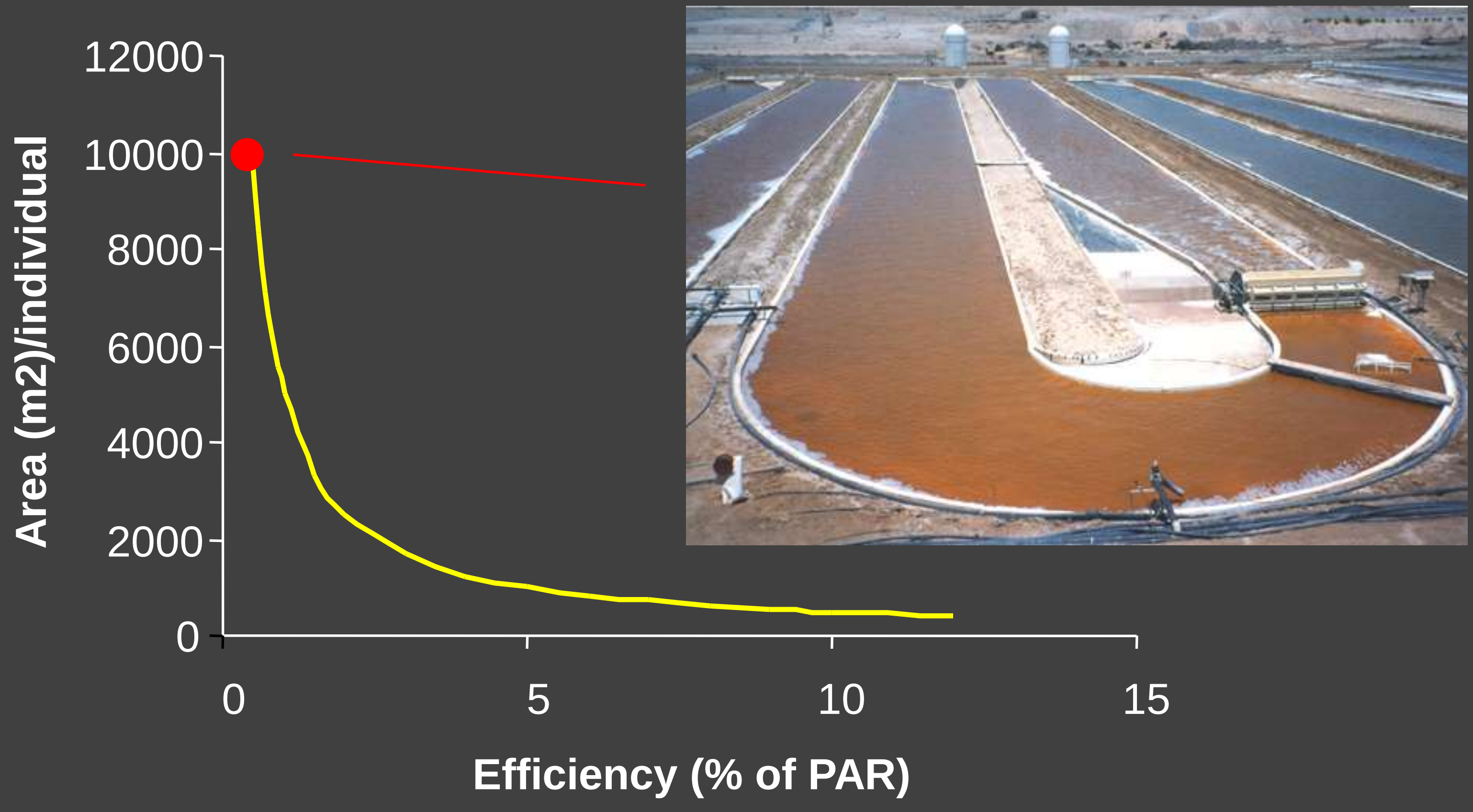
What affects microalgae production?

- Genus and species
- Culture techniques
  - Open ponds
  - Closed photobioreactors
- Culture conditions
  - Depletion of Nitrogen and Silicate
  - Phosphorous content
- Climate
  - Cold weather reduces algae oil production
  - Overcast days reduce sunlight and lower oil production

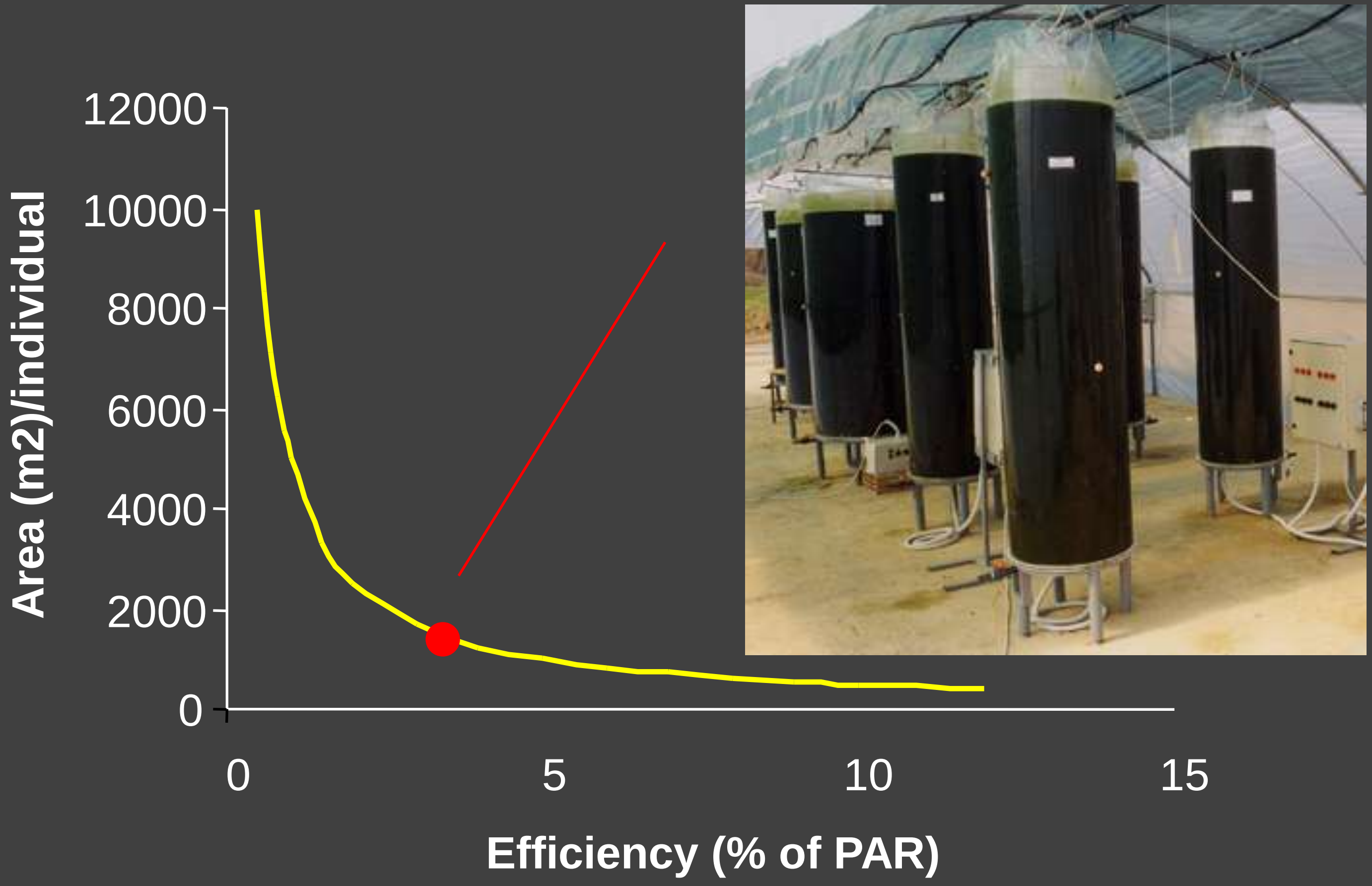
Photosynthetic yield



Photosynthetic yield

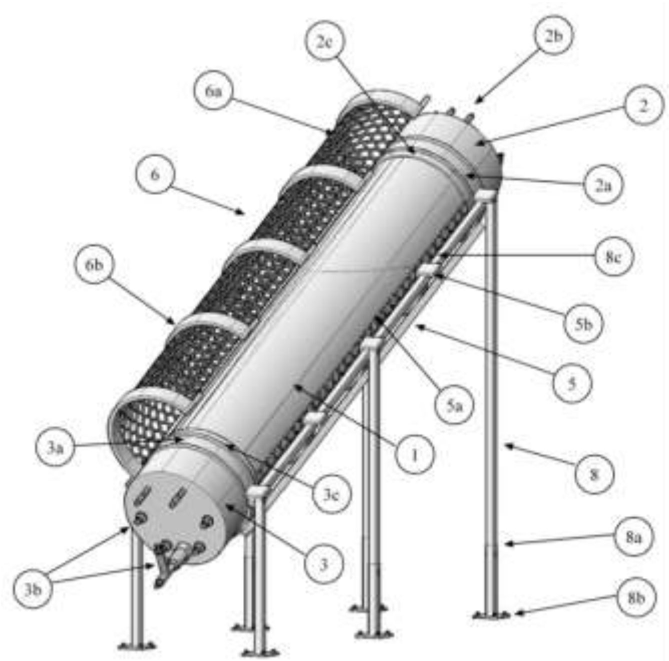


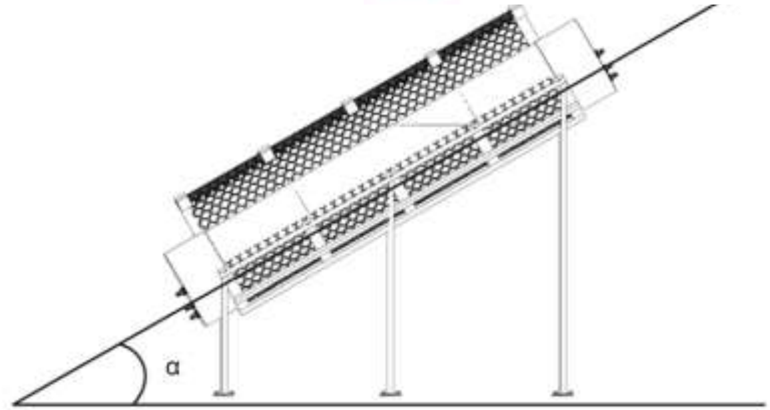
Photosynthetic yield

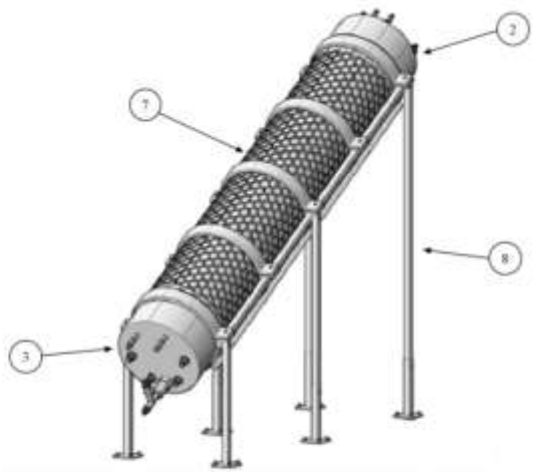


Photobioreactor of Fexible Material and Structure thereof
WO/2011/007250 (PCT/2010/001751)

ITALIA DEGLI INNOVATORI
Agenzia per la diffusione delle tecnologie per l'innovazione
Presidenza del Consiglio dei Ministri







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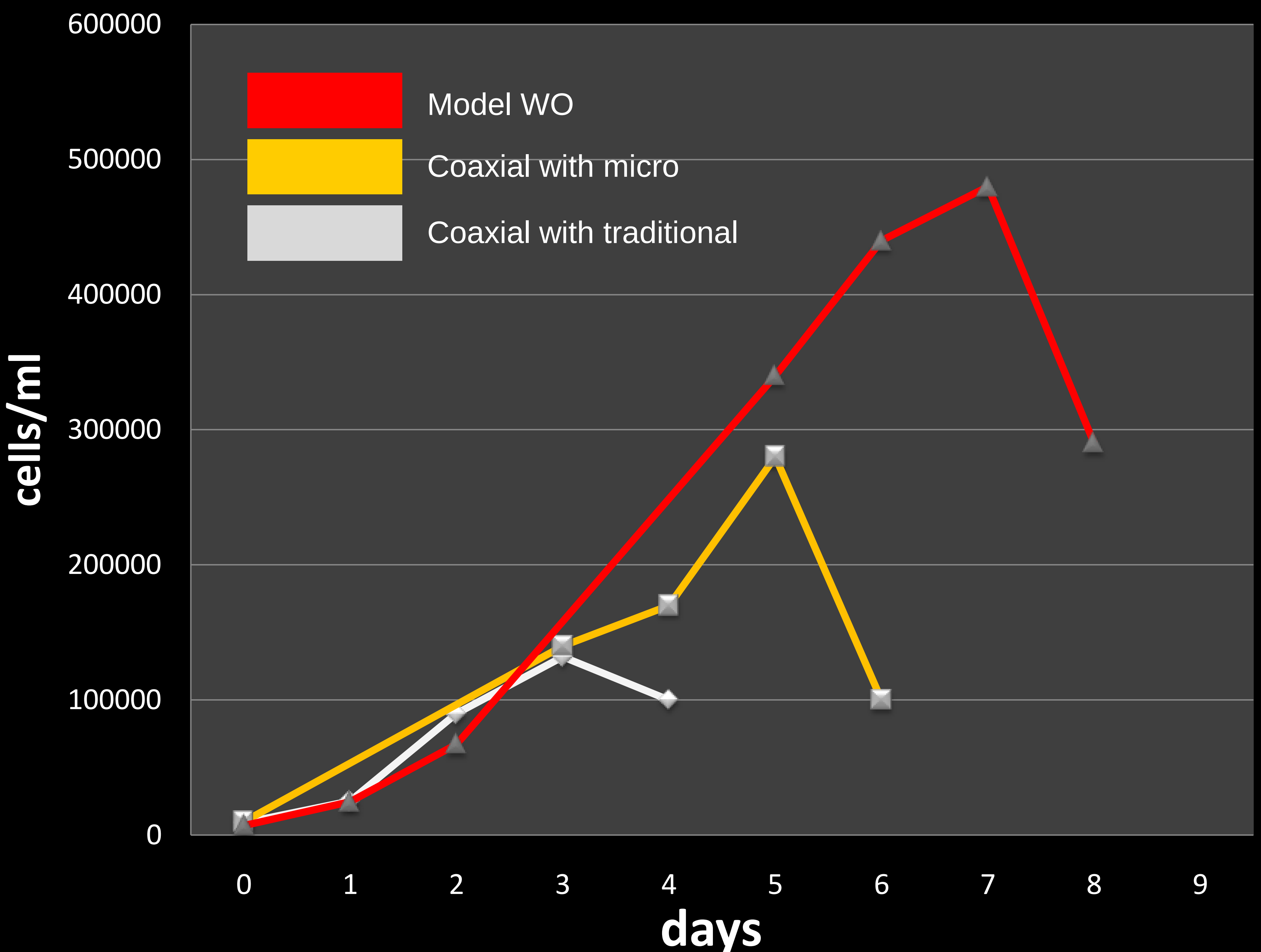
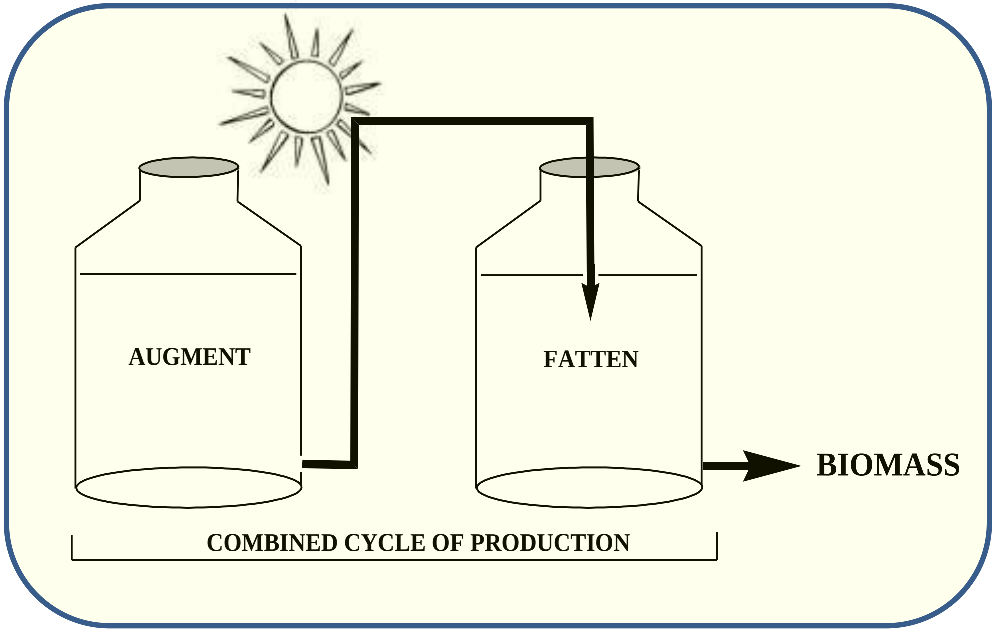
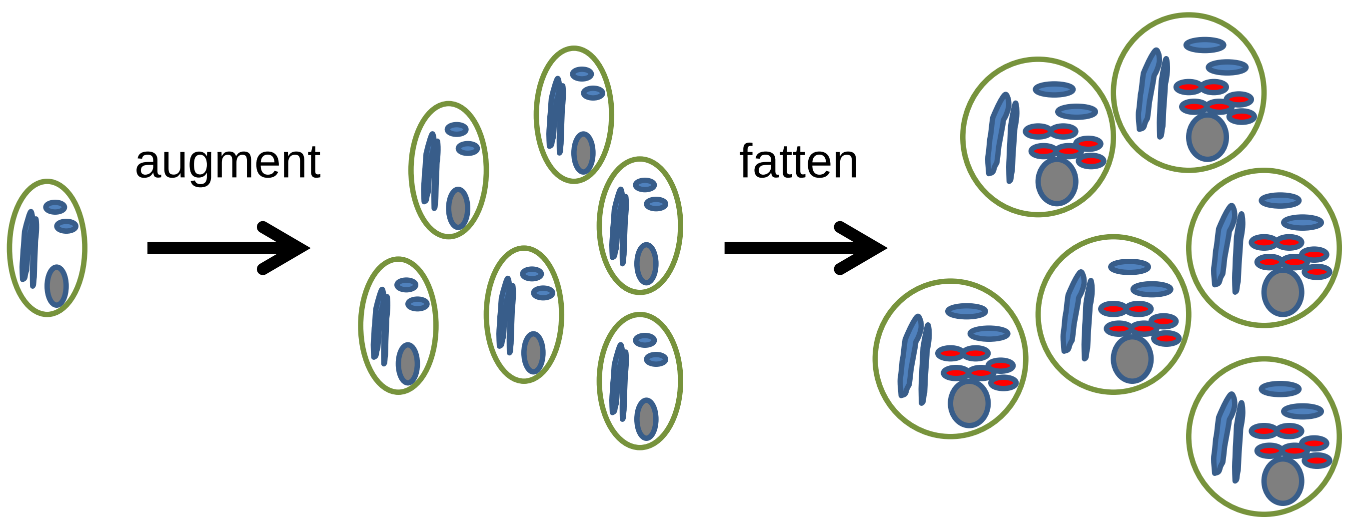


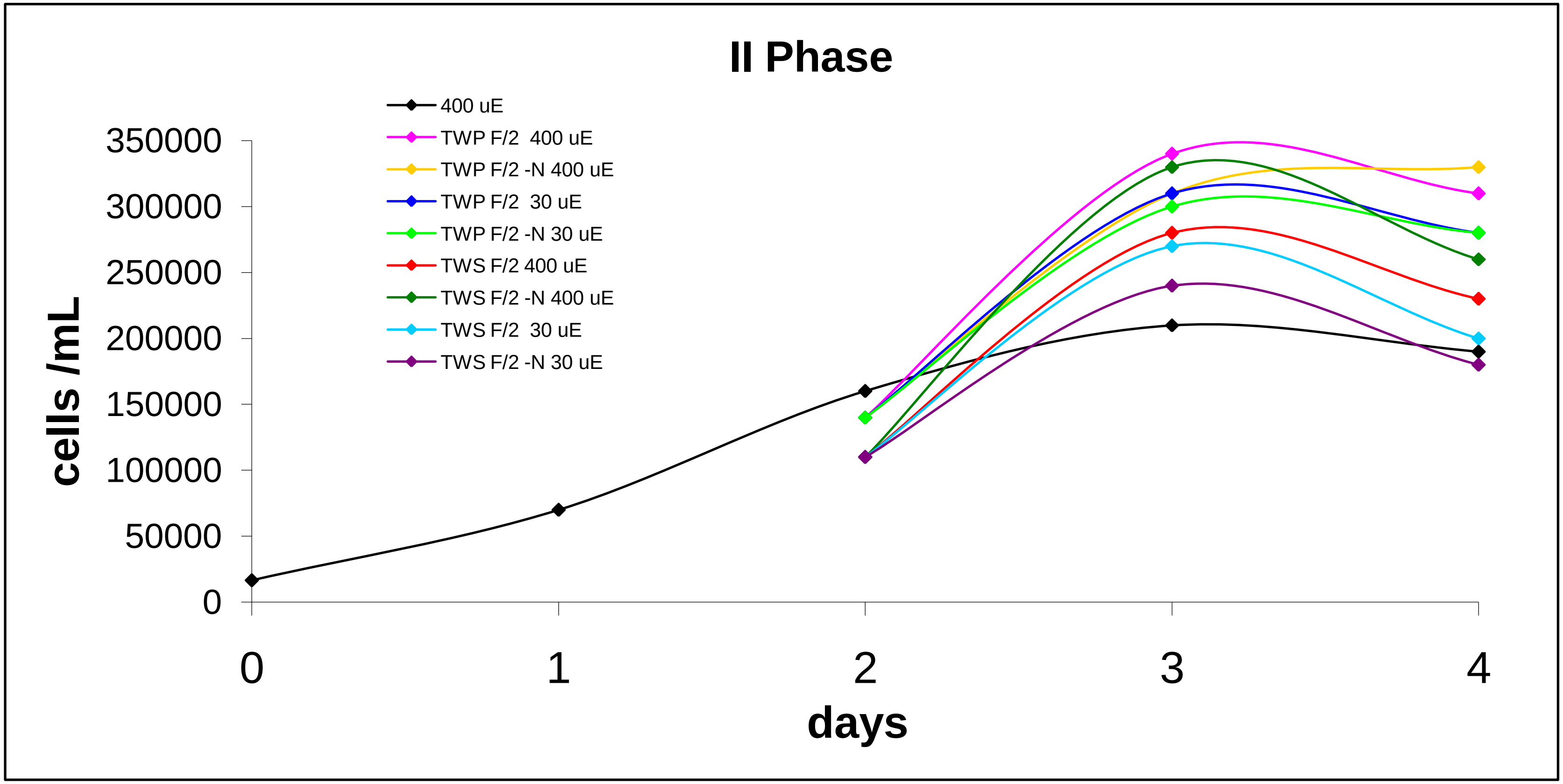
Model WO
Coaxial with micro
Coaxial with traditional
cells/ml
600000
500000
400000
300000
200000
100000
0
0
1
2
3
4
5
6
7
8
9
days

Growth Cycles

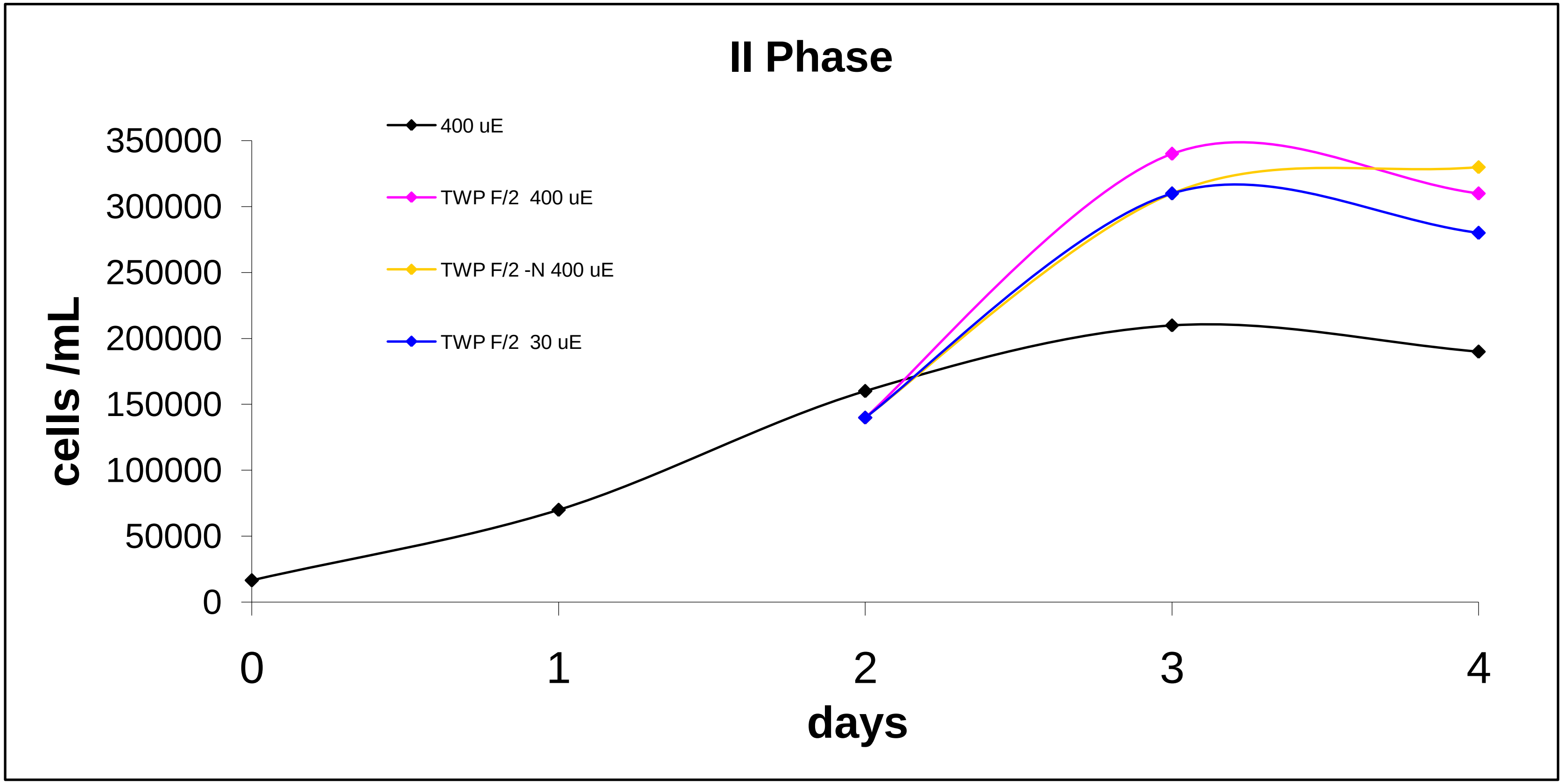




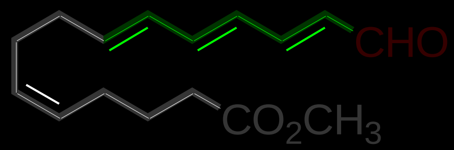
Growth Cycles

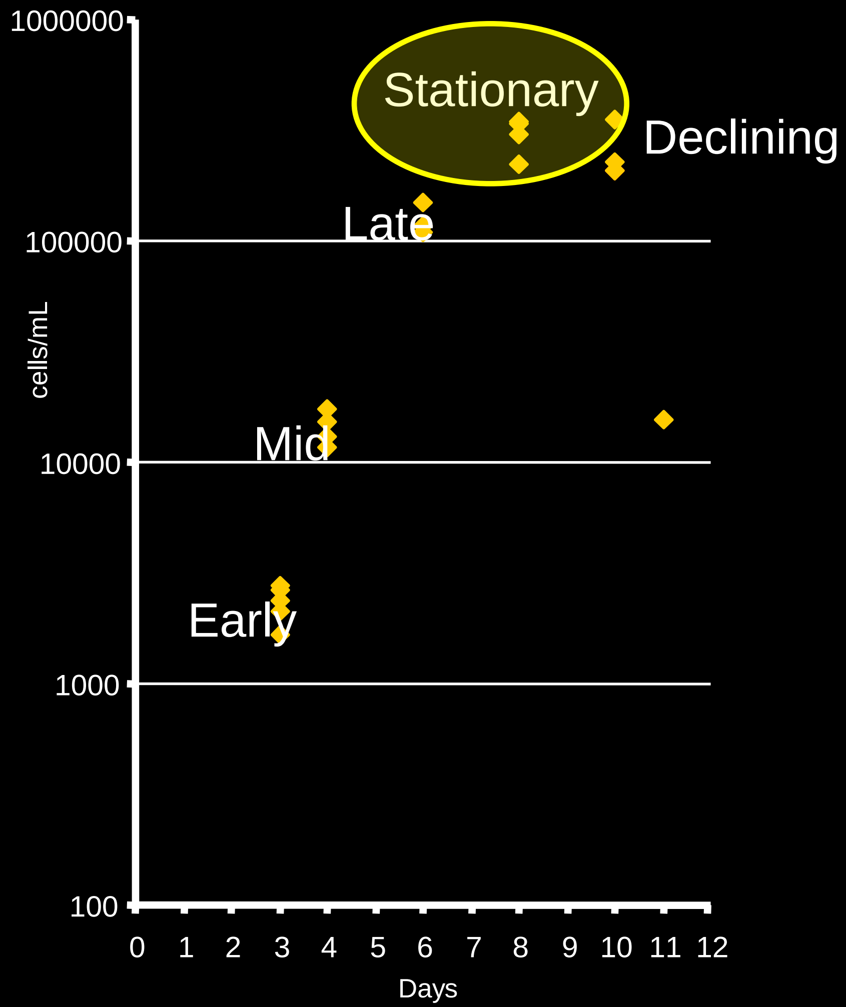


Growth Cycles



Controlling Cell-Cell Communication





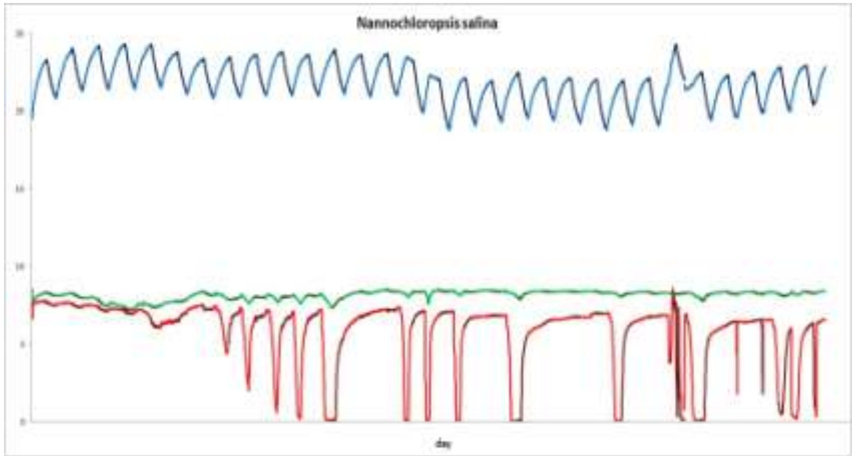
•Synthesis and regulation of phyco-oxylipins seem to correspond to a signaling mechanism that governs adaptation of diatoms along the growth till bloom termination (quorum-sensing mechanism).

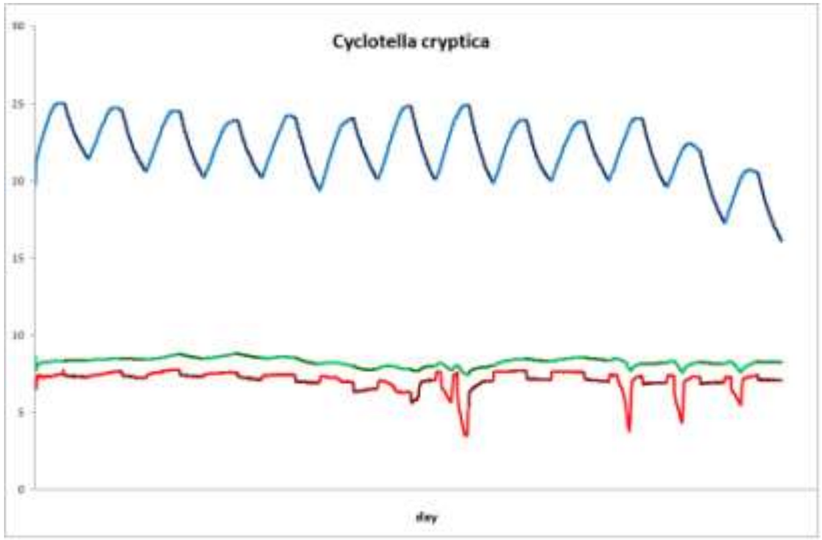
•Synthesis of 15-oxoacid constrained within a time window of a few hours just before the collapse of the culture, implies the involvement of a physiological control not directly dependent on distress or death of diatom cells.

New Phytol.ogist 2009 , *183*, 1064-1071

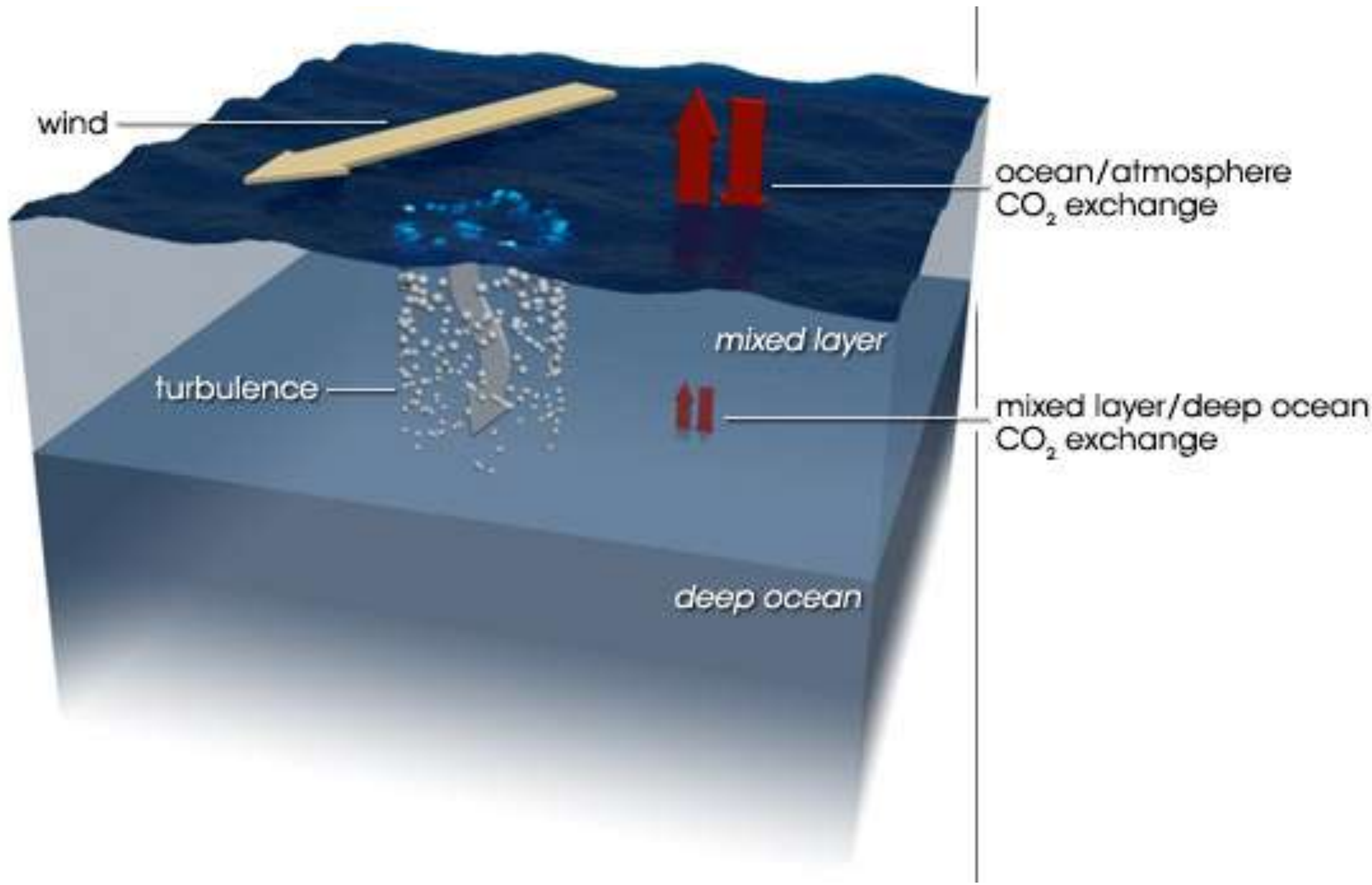
Culture Parameters
(photorespiration)

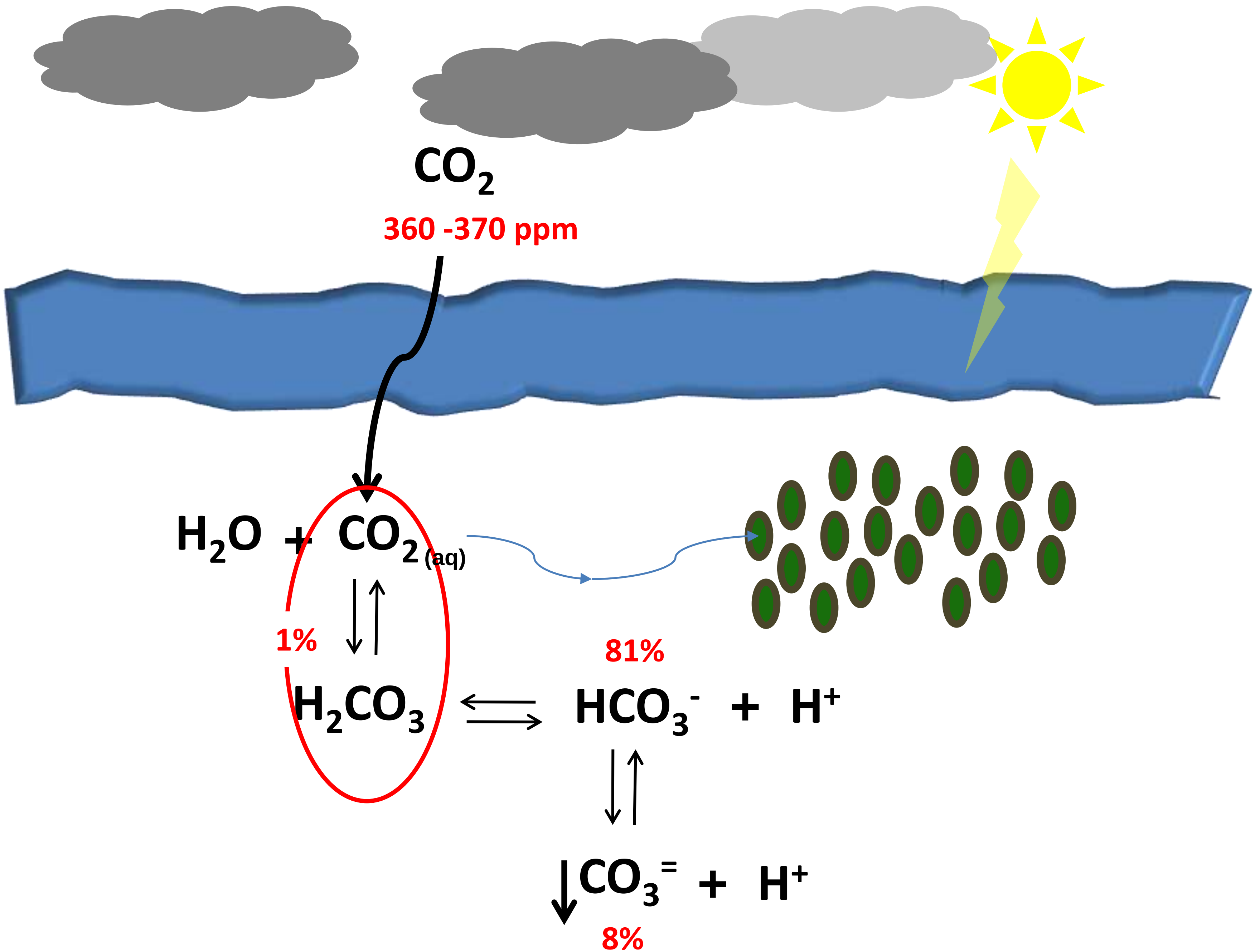
C
pH
oxygen





What happens in the ocean?

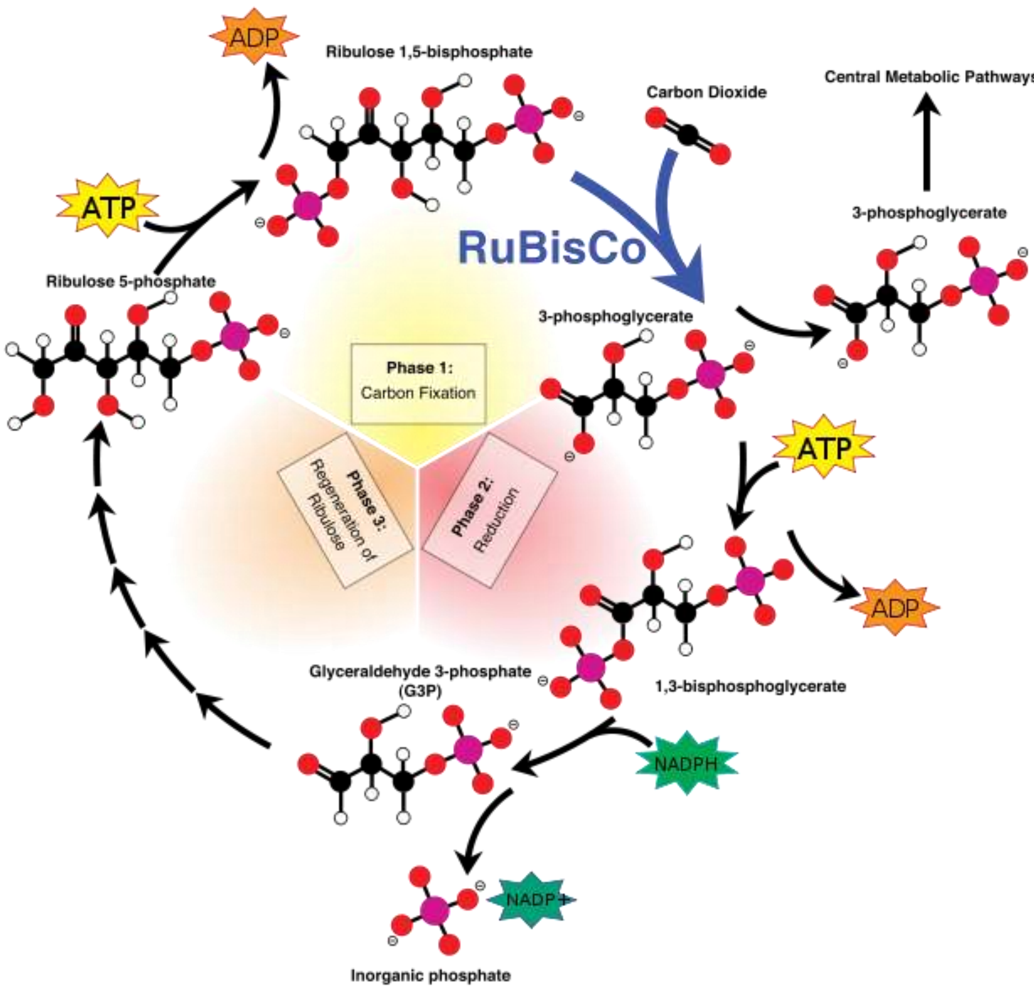




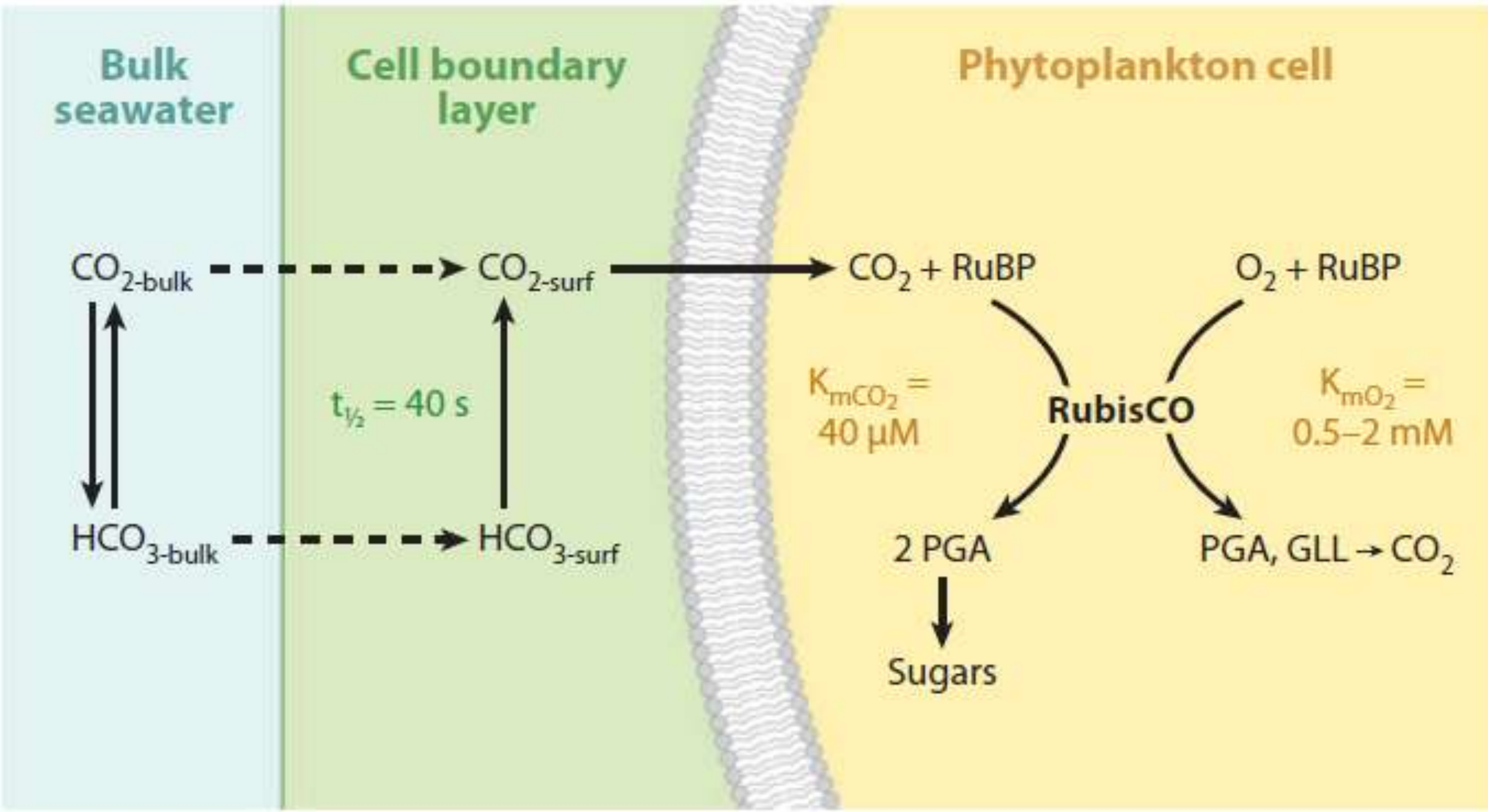
CO_2
360 -370 ppm
H_2O + $CO_{2(aq)}$
1%
H_2CO_3
81%
HCO_3^- + H^+
$CO_3^=$ + H^+
8%

Chloroplast – Dark Reaction

CALVIN –BENSON CYCLE



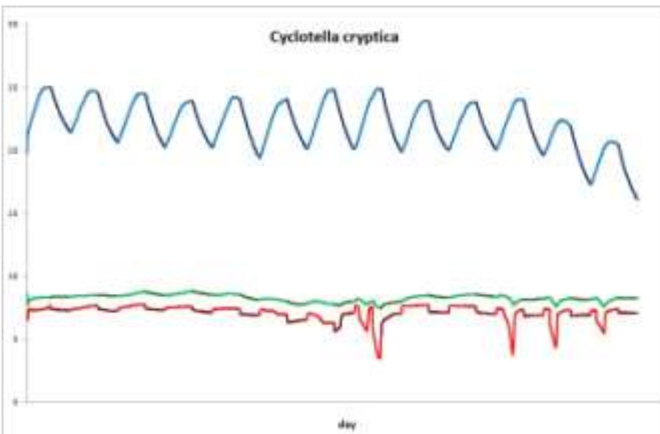
$3\ CO_2 + 6$ NADPH $+ 5\ H_2O + 9$ ATP $\rightarrow$ glyceraldehyde-3-phosphate (G3P) $+ 2\ H^+ + 6\ NADP^+ + 9$ ADP $+ 8\ P_i$

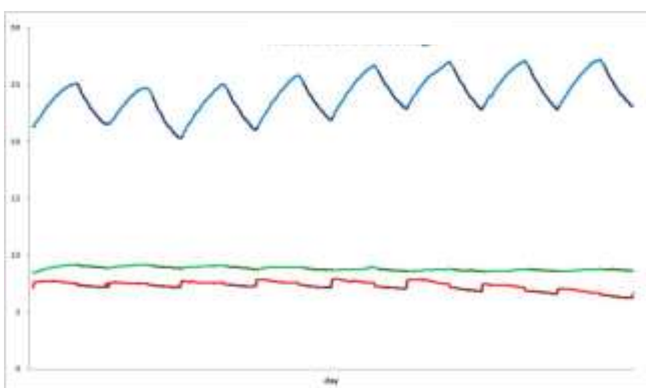


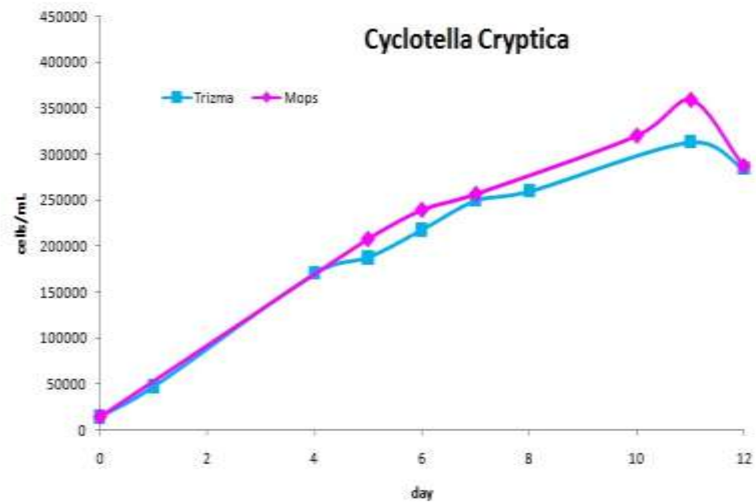
Reinfelder, Ann. Rev. Mar. Sci. 2011

Culture Parameters
(Cyclotella cryptica)

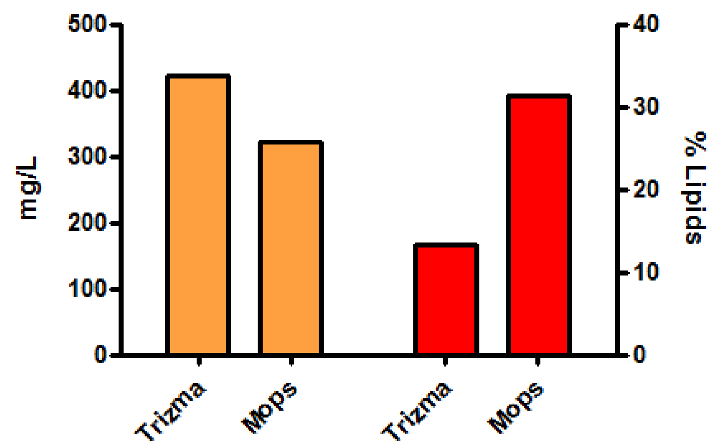
C pH oxygen

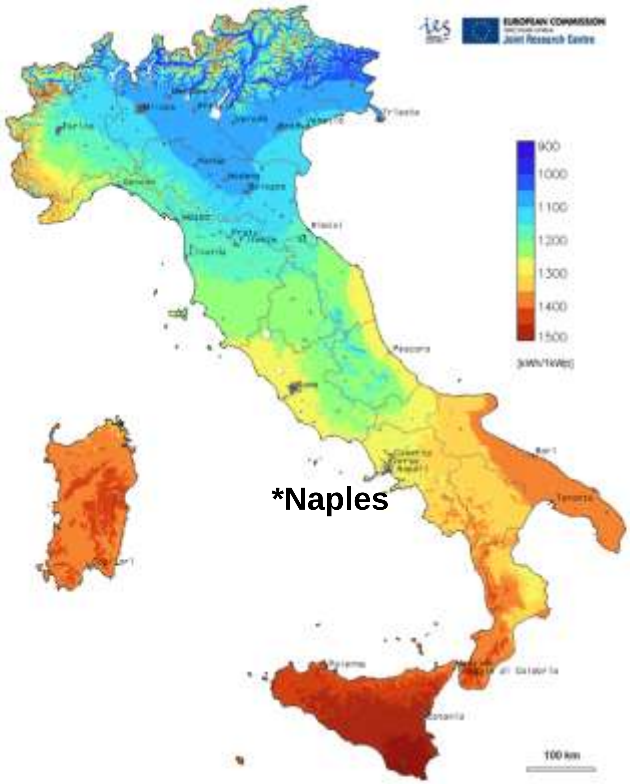






Biomass Lipids





	Fats	Biomass
Annual Average Yield*	7,5 mg/L/d	58 mg/L/d
Culture Conditions	x 1,6	x 0,8
9% CO_2	x 1,2	x 1,87
Two-step Cultures	x 2,5	x 2,1
Photobioreactor Design	1495 m^3/ha	1495 m^3/ha
Total	**33.9 Ton/ha**	**142.1 Ton/ha**

Bio-Hydrogen from Microalgae

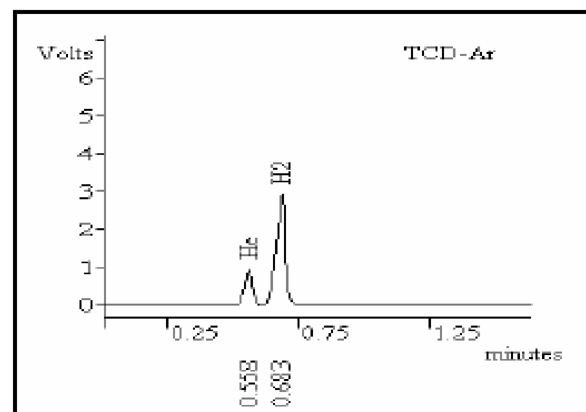
80 L of cultures

100 g of biomass

Oil and Residual Biopolimers

2 g glucose eq.

0.5 L of Hydrogen



manuscript in preparartion

Energy Output per Unit Area

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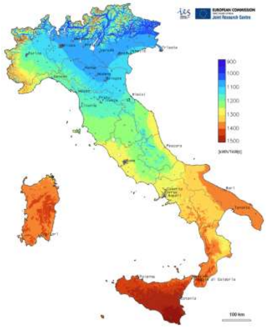

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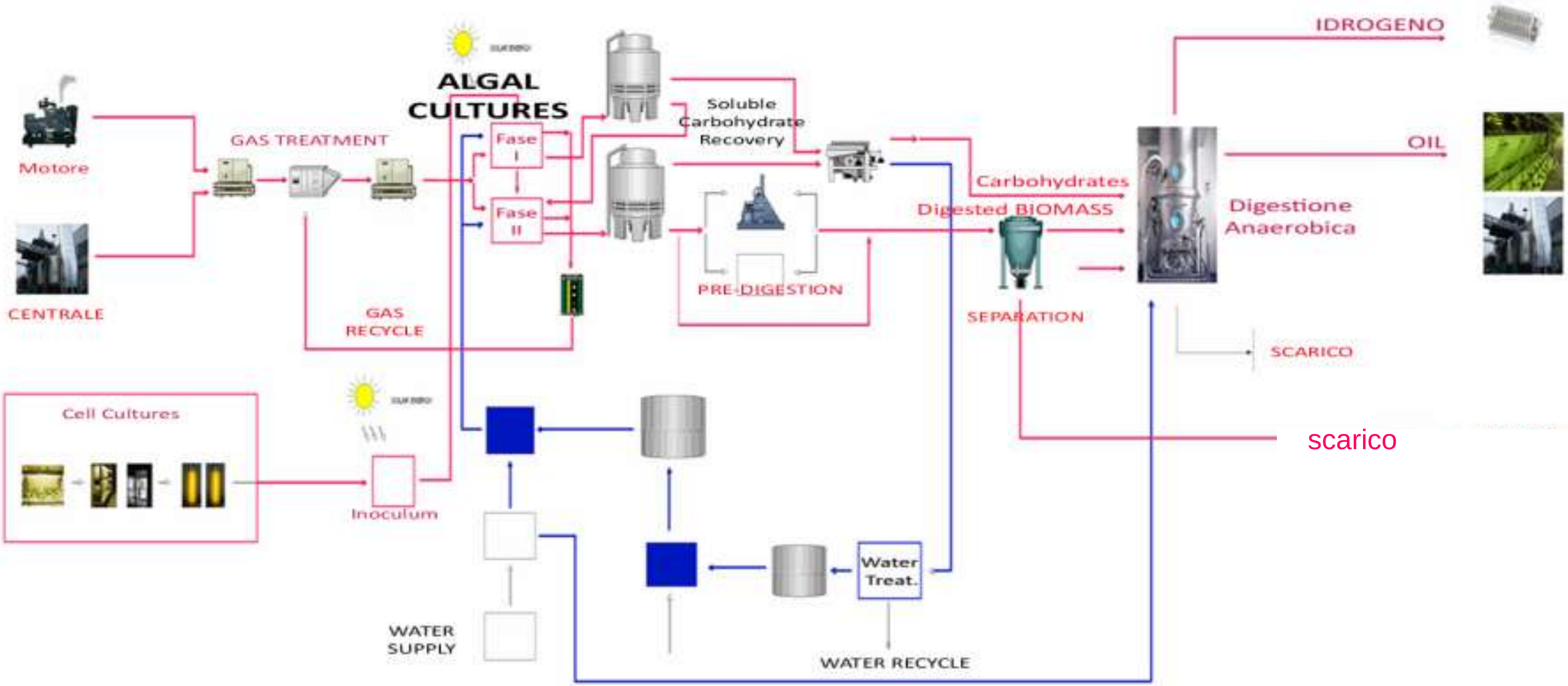
Microalgae (2)	1200 GJ ha^{-1} $year^{-1}$

*0.3-0.8 kWh/m^2

Reilly and Paltsev, 2007

Sfruttamento Integrato di Biomasse Algali in Filiera Energetica di Qualità



Prototype the process:

algal Plant: 2-3 milion liters per hectare

50 - 70 ton oli grezzi per ettaro/anno

18 -20 milioni di litri H_2 (gas)

CONCLUSIONS

The exploitation of biomass energy can play a strategic role, contributing to a sustainable and balanced development of the planet. A widespread use of biomass can:

lead to strong impact on economy, environment and employment;

contribute to reduce emissions of carbon dioxide and other pollutants , and then to improve life quality;

create professionals and companies specialized in the field;

give impetus to research and technological development for the sustainable exploitation of renewable energy resources;

increase the autonomy of national energy.

CONCLUSIONS

There are still a number of issues that deserve scientific attention:

- **Extraction or gasification (pyrolysis) of biomass and esterification of fatty acids;**
- **Controlling chemical composition lipid extract (increased triglyceride vs. phospholipids and glycolipids**
- **Exploitation of products remaining after extraction (nano-silica particles of diatoms)**
- **Carbon dioxide mitigation and reduction of climate-altering gases.**

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CNR - Dipartimento di Progettazione Molecolare
Progetto PIRODE
Progetto EFOR