Porous Substrate Photobioreactors: : A novel algal cultivation technology for health care products and nutritional food production

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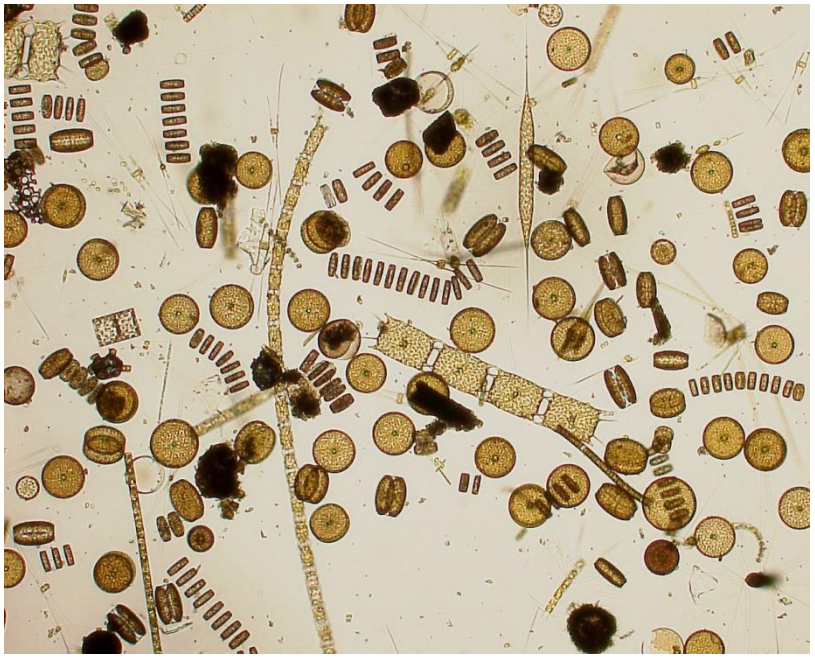
There are Two Ways to Make a Living as a Microalga: To Float or to Stick



Plankton

Benthos

To Float (Plankton)

Phytoplankton

To Stick (Benthos)

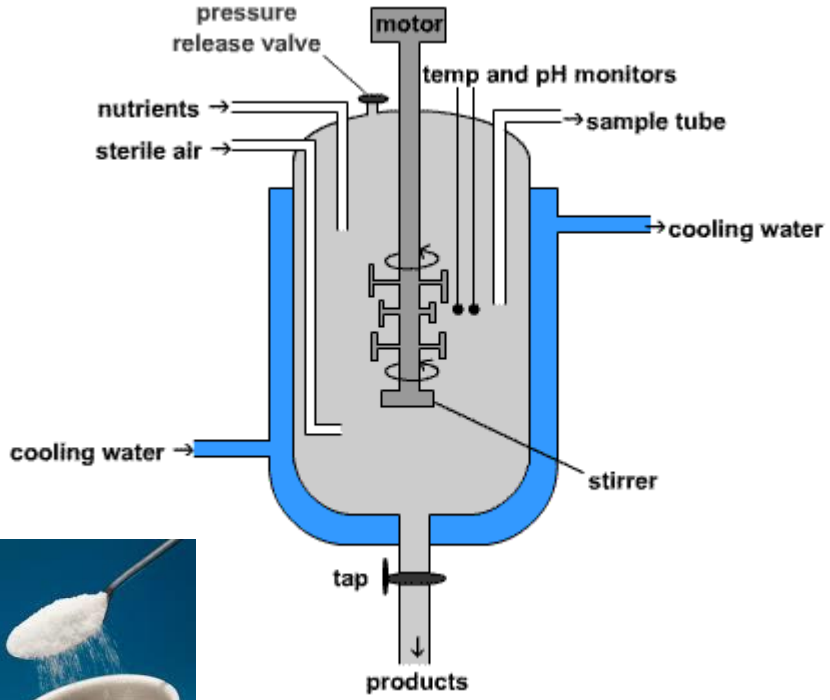
Microphytobenthos
(Periphyton *s.l.*)

Where are the most productive algal habitats and why?

The Wadden Sea at low tide

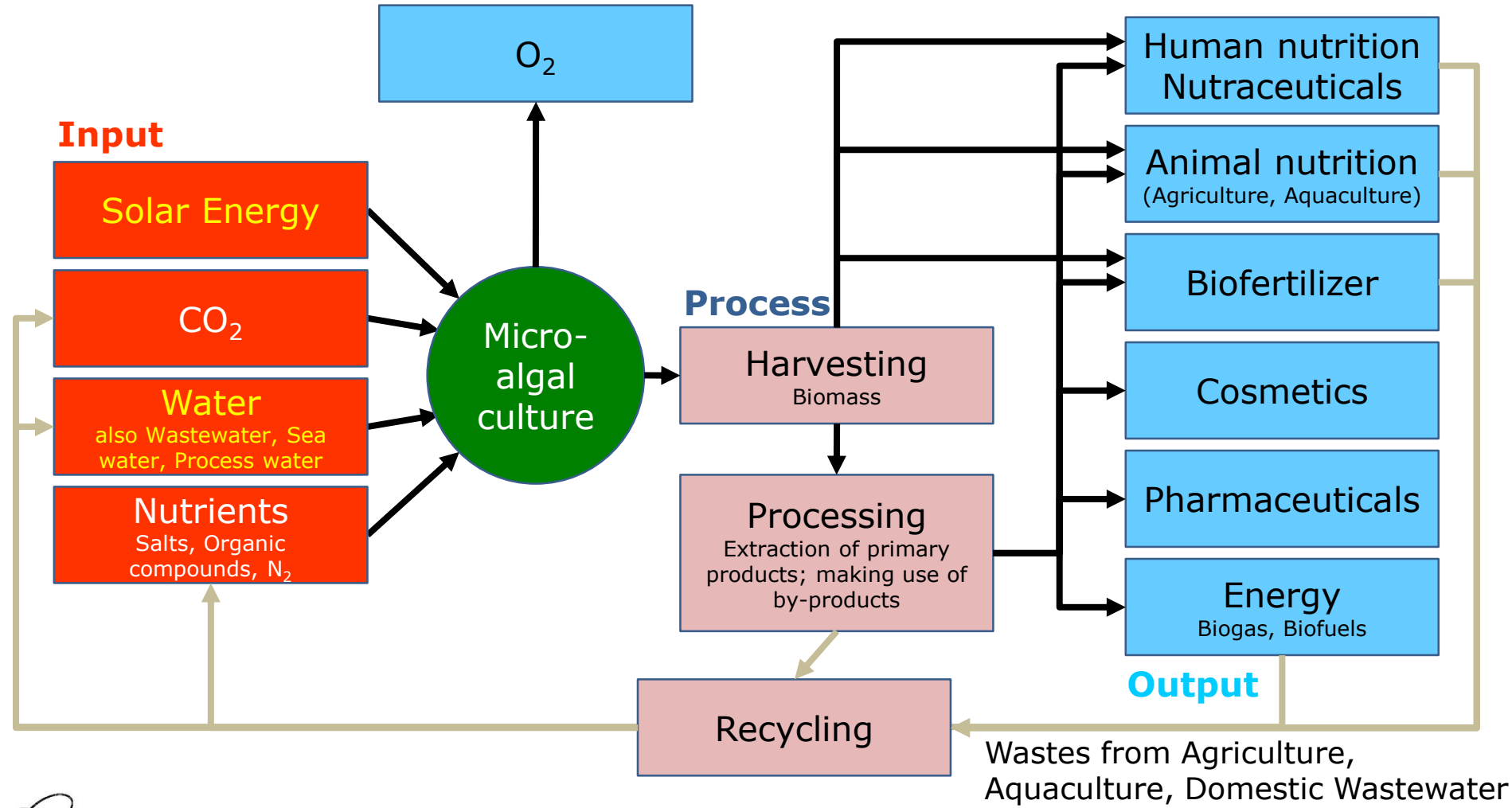
Algae at waterfalls

Microbial Biotechnology uses Fermenters, but not for microalgae

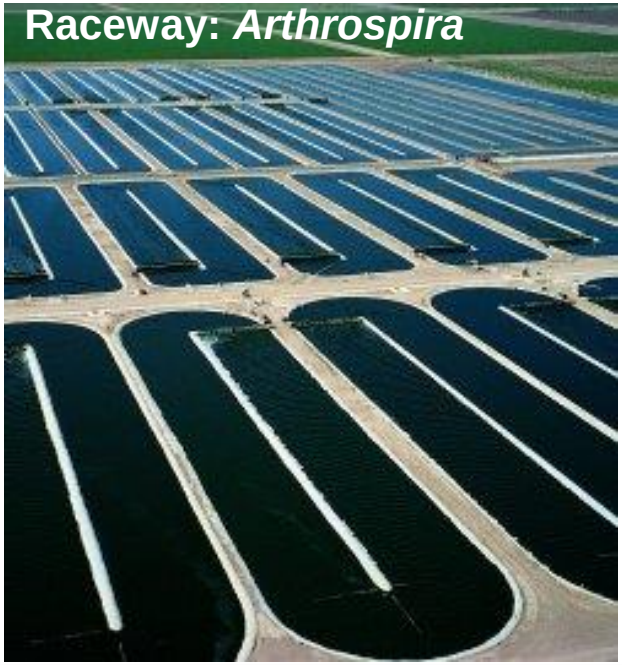


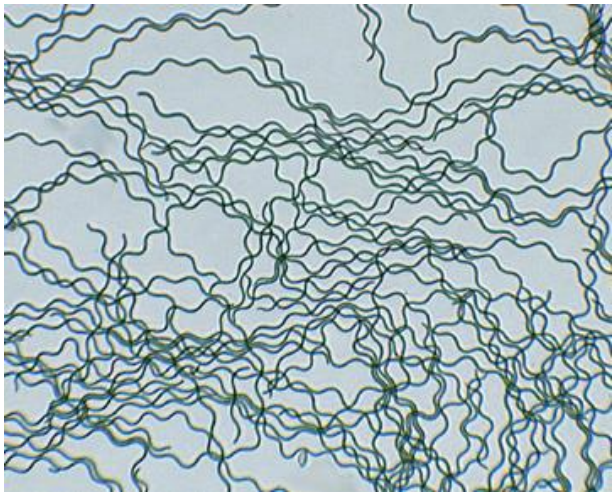
Sugar molecules can be dissolved in 3D, but photons?

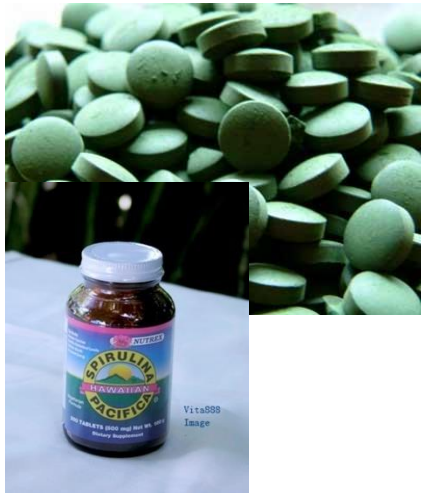
Flows and Processes in Microalgal Biotechnology



Technical Cultivation of Microalgae: Open Systems







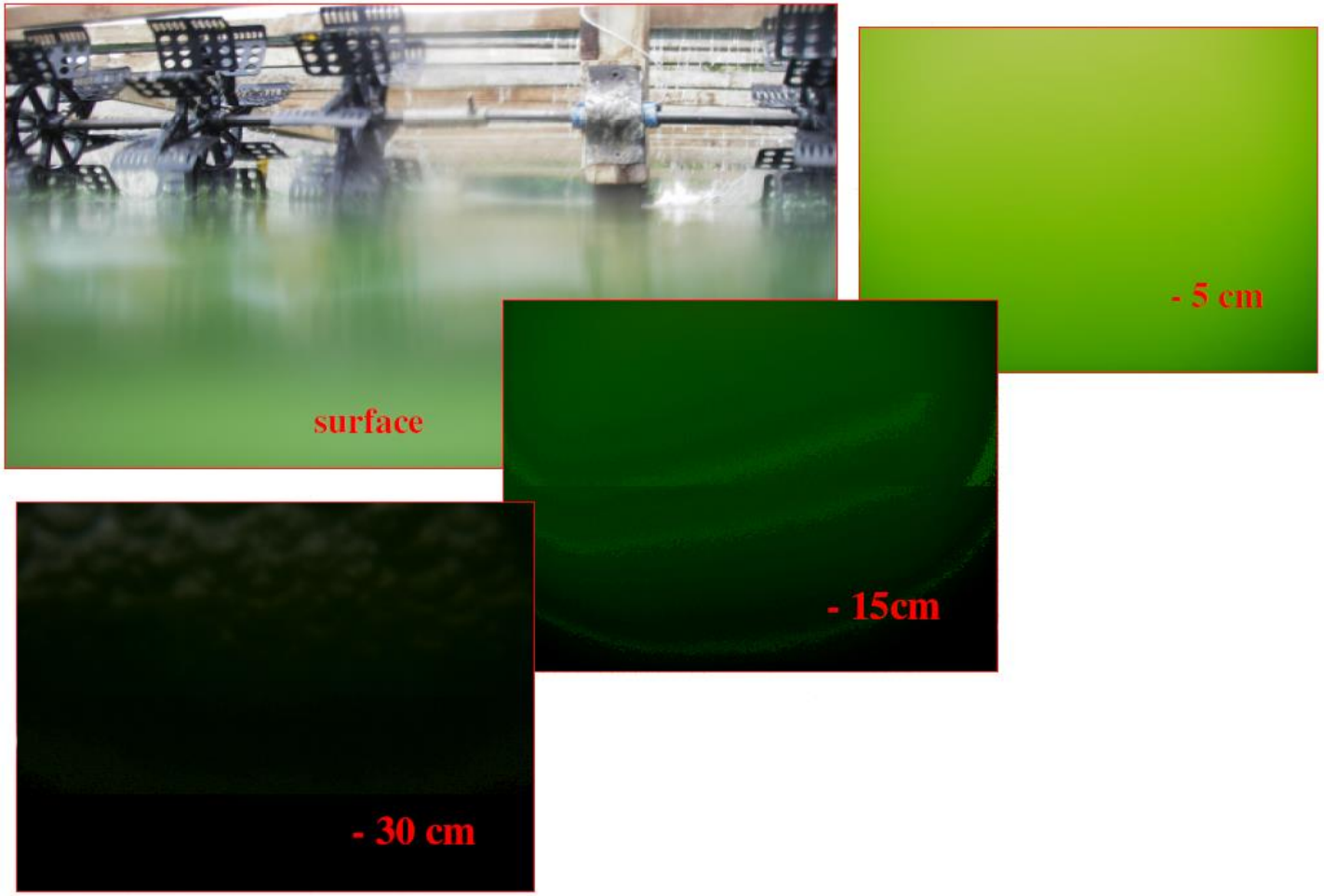
Arthrospira* (Spirulina) *platensis

Growth of Microalgae in Open Systems Requires Very Specific Conditions

Species Condition	*Dunaliella salina*	*Arthrospira platensis*
Natural Habitat	Hypersaline Brines	Alkaline Soda Lakes
Salinity (% w/v NaCl)	22-35	0-1 (brackish)
Temperature (°C; optimum)	30-40	30-38
pH (optimum)	~9	9-11

These conditions minimize contamination, but do not prevent exposure to predators, pathogens and parasites

Light Distribution in a Raceway Pond

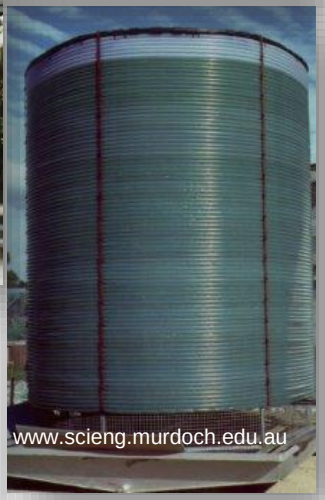


***Spirulina culture*, Twing Taung, Myanmar. March 2006**.

Pulz (2007). Biosystemtechnik zur Konversion von Photonenenergie in Wasserstoff, IGV GmbH, Nuthetal. https://www.vdivde-it.de/mst/mikrosystemtechnik/medien/03_pulz.pdf

Technical Cultivation of Microalgae: Closed Systems

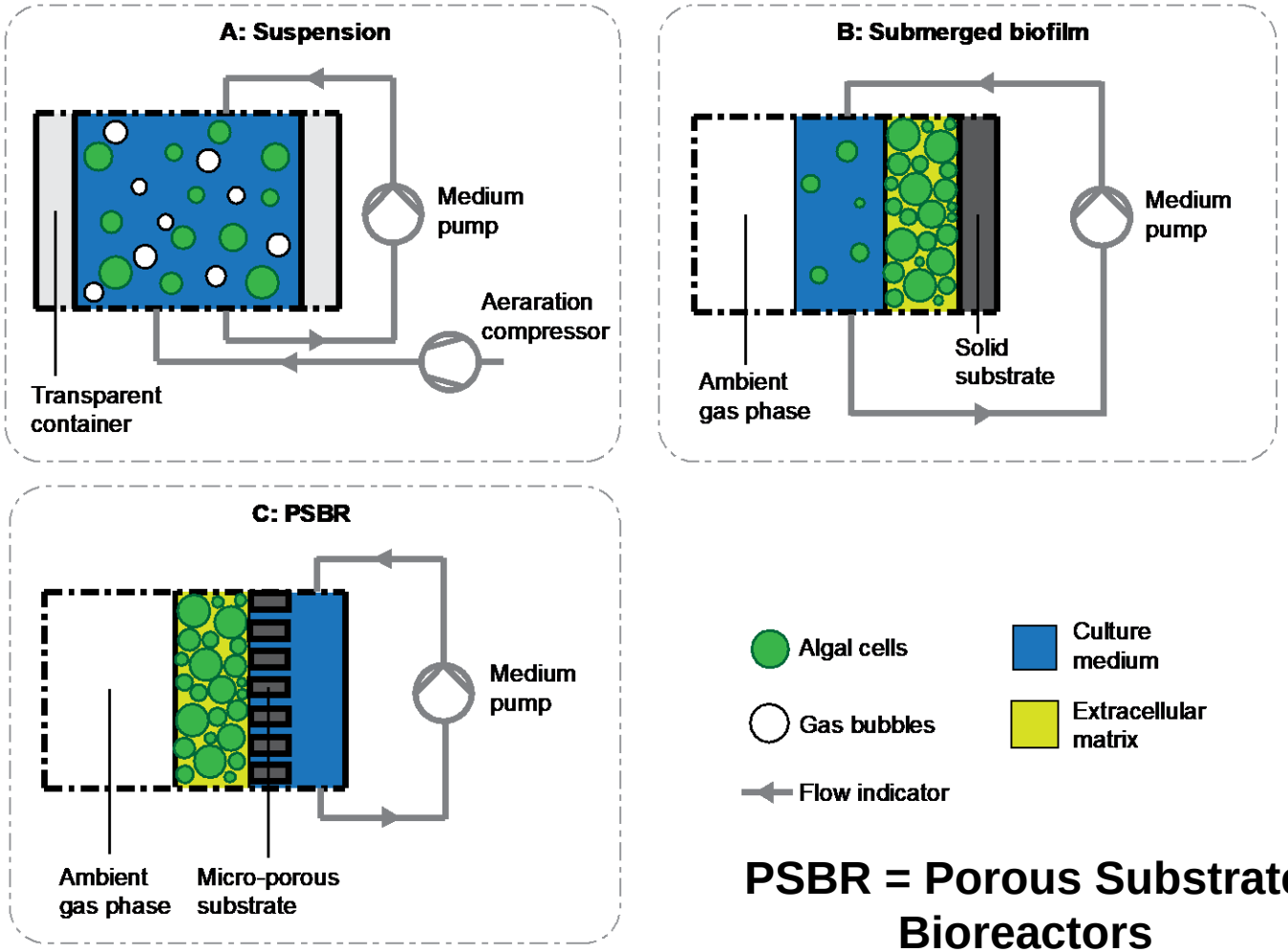
- More efficient light utilization by increasing the surface/volume ratio



An Emerging Paradigm Shift in Microalgal Biotechnology: From Suspension Cultures to Porous Substrate Bioreactors

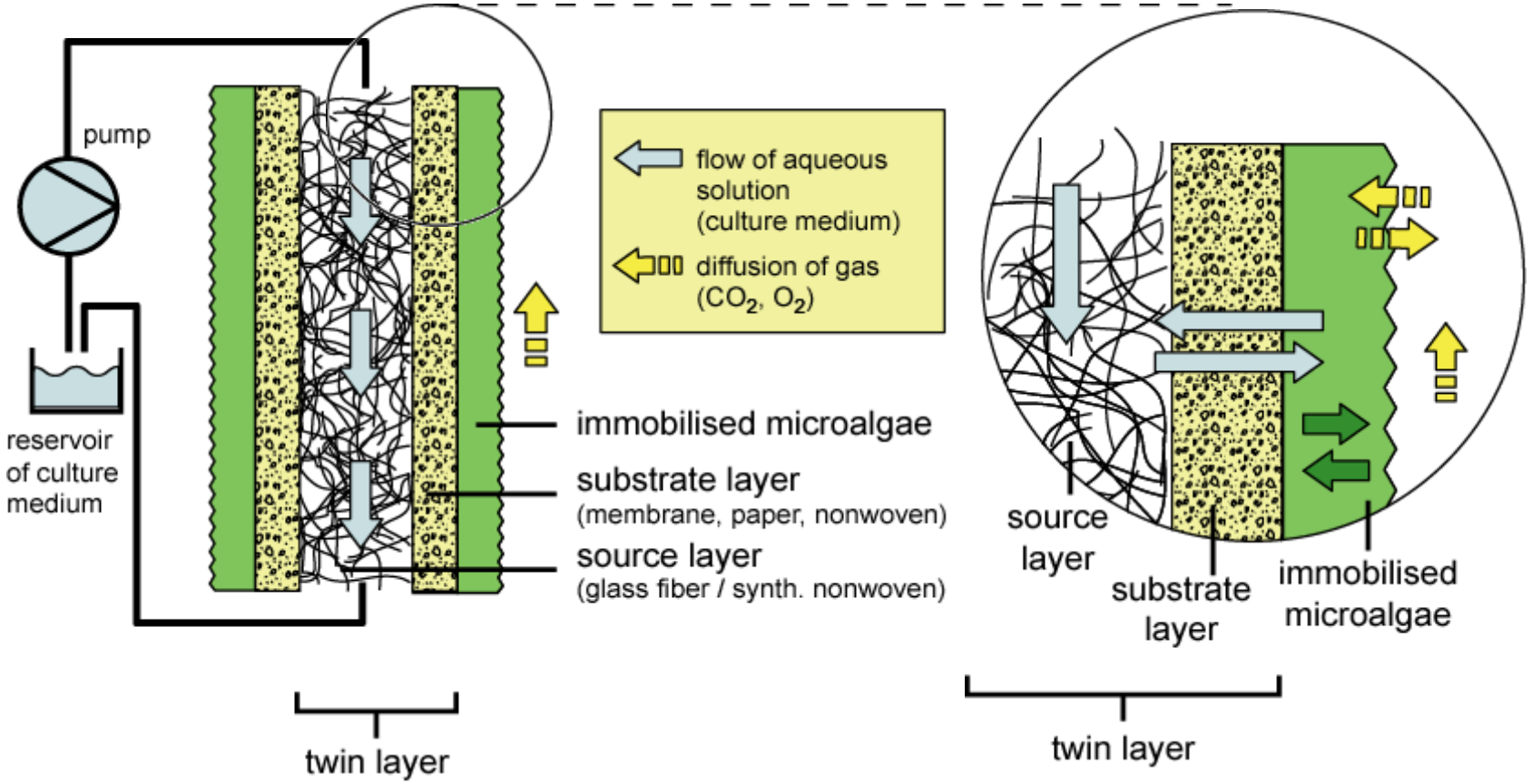
Problems in suspension culture	Possible solutions by immobilization
Mass transfer (Energy for Mixing, Aeration)	Significantly reduced energy input for mass transfer
Harvesting	Cultivation at much lower water content
Hydrodynamic forces	No hydrodynamic shear
Contaminations	No spreading in culture medium
Construction Costs High	Construction Costs relatively low

Porous Substrate Bioreactors – Comparison with Suspensions and Submerged Biofilms



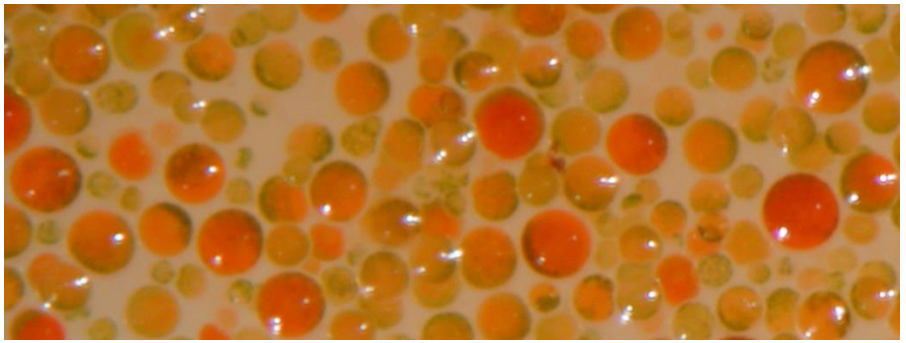
PSBR = Porous Substrate Bioreactors

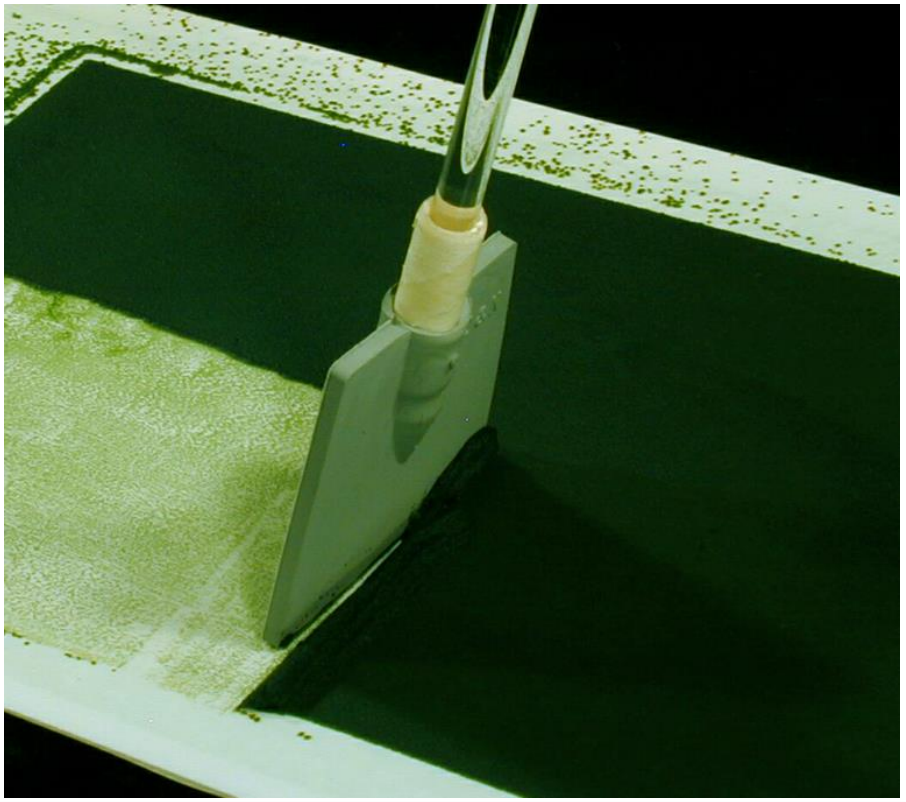
Twin Layer Technology – The Algal Leaf



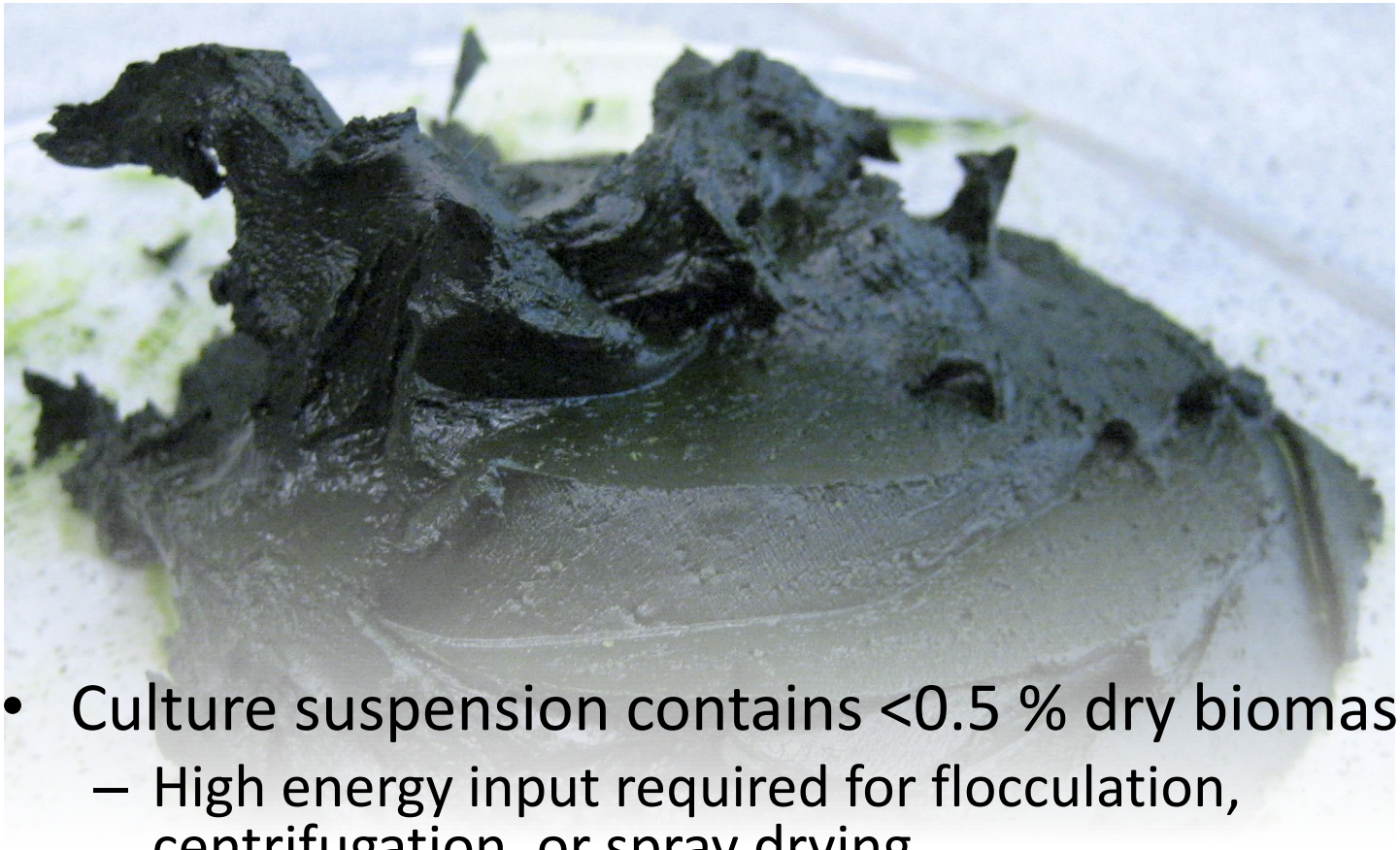
Principle of the Twin Layer: Effective separation of algae from culture medium

Twin Layer Technology – The Algal Leaf





Harvesting Microalgae

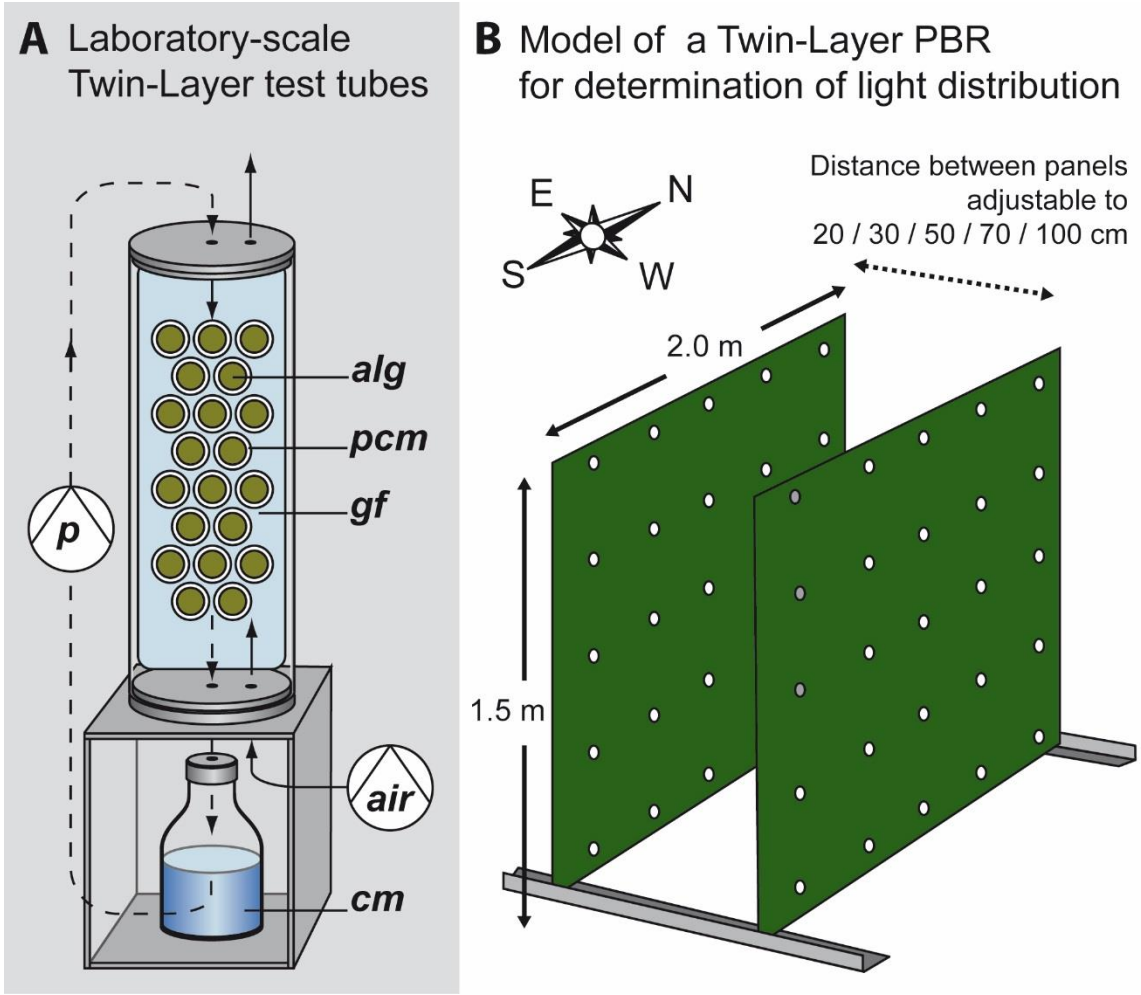


- Culture suspension contains <0.5 % dry biomass
  - High energy input required for flocculation, centrifugation, or spray drying
- Immobilized Twin-Layer cultures usually contain 20-30 % dry biomass

Water Contents and Requirements

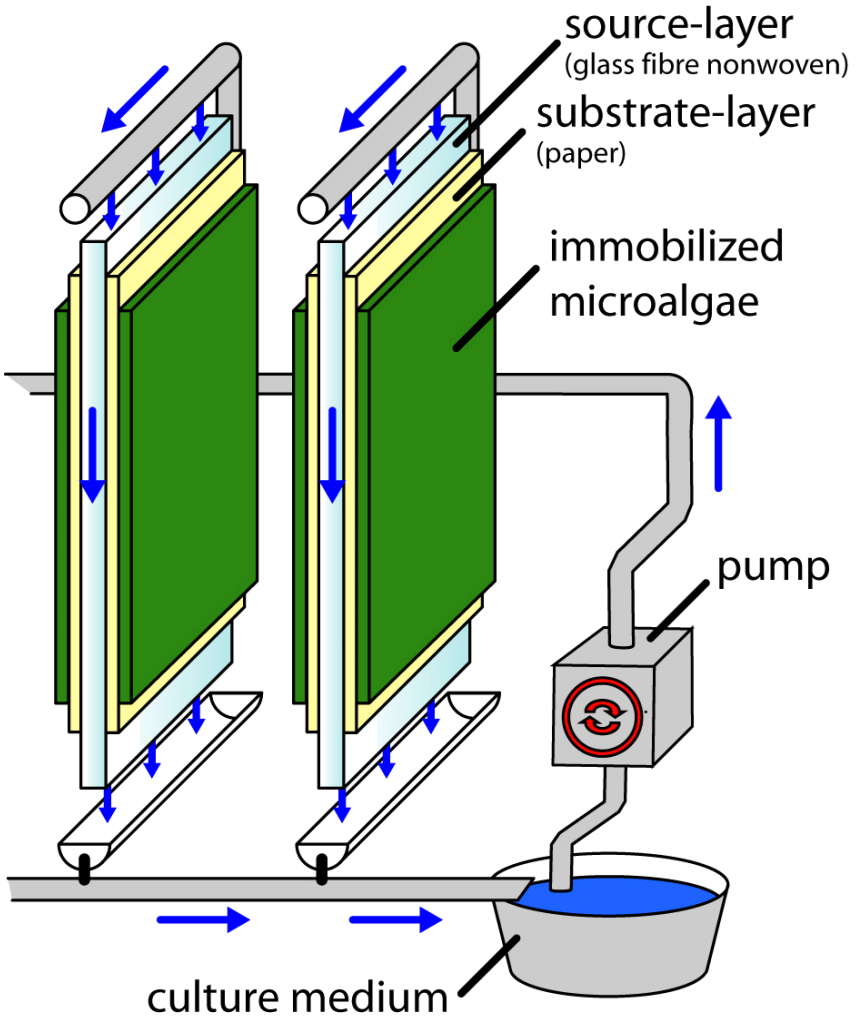
PBR type	Maximal biomass density of culture g L^{-1}	Total system volume required to produce 1 kg dry matter L kg^{-1}
Suspension PBRs		
Raceway pond	0.35 – 0.5	2,000 – 2,850
Closed PBRs	2.0 – 6.0	170 – 500
Biofilm PBRs		
Conventional biofilm	63 – 170	87 – 609
PSBR	150 – 300	36 - 250

Twin-Layer Setups: From Laboratory to Pilot



A Prototype Twin-Layer PBR

***Cosmarium pachydermum*:**
Application in Cosmetics (Make-Up)



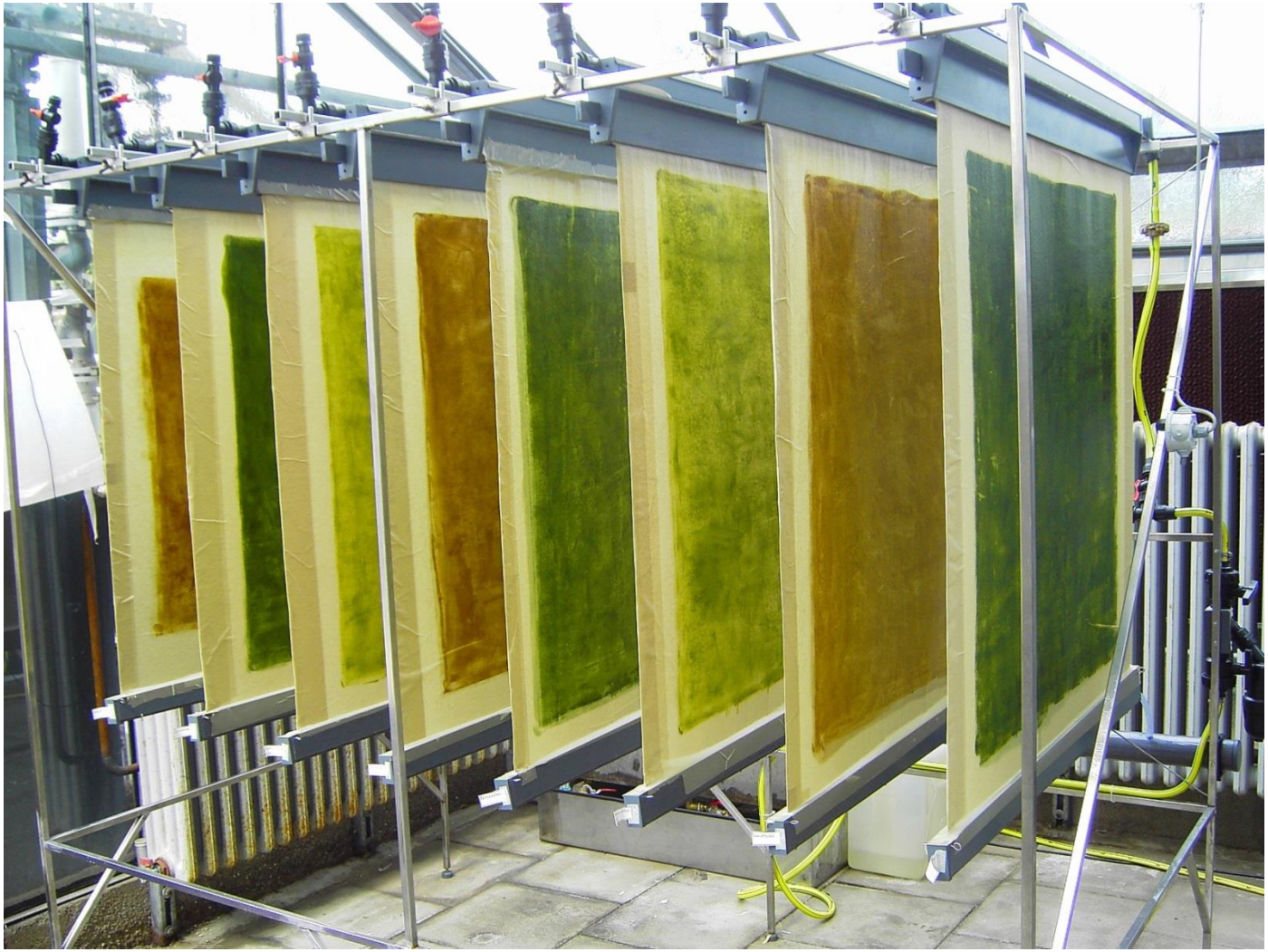
Naumann, T., Çebi, Z., Podola, B., Melkonian, M. (2013): Growing microalgae as aquaculture feeds on twin-layers: a novel solid-state photobioreactor. Journal of Applied Phycology **25**: 1413-1420

A Prototype Twin-Layer PBR (2004)

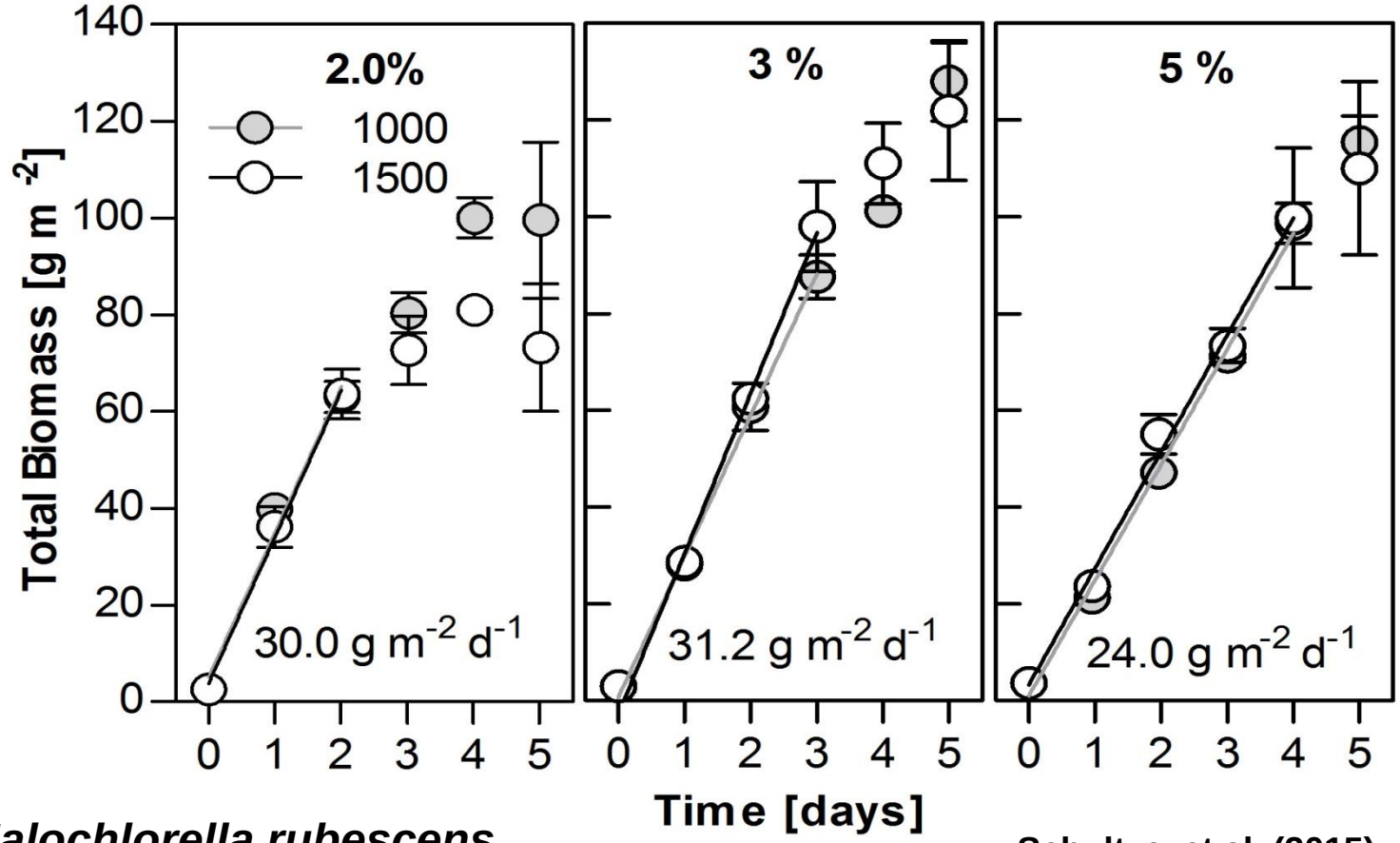
Microalgae as aquaculture feeds:

- ***Nannochloropsis oculata***
- ***Tetraselmis striata***
- ***Isochrysis Iso T***

The algae have been grown on plain printing paper as substrate layer



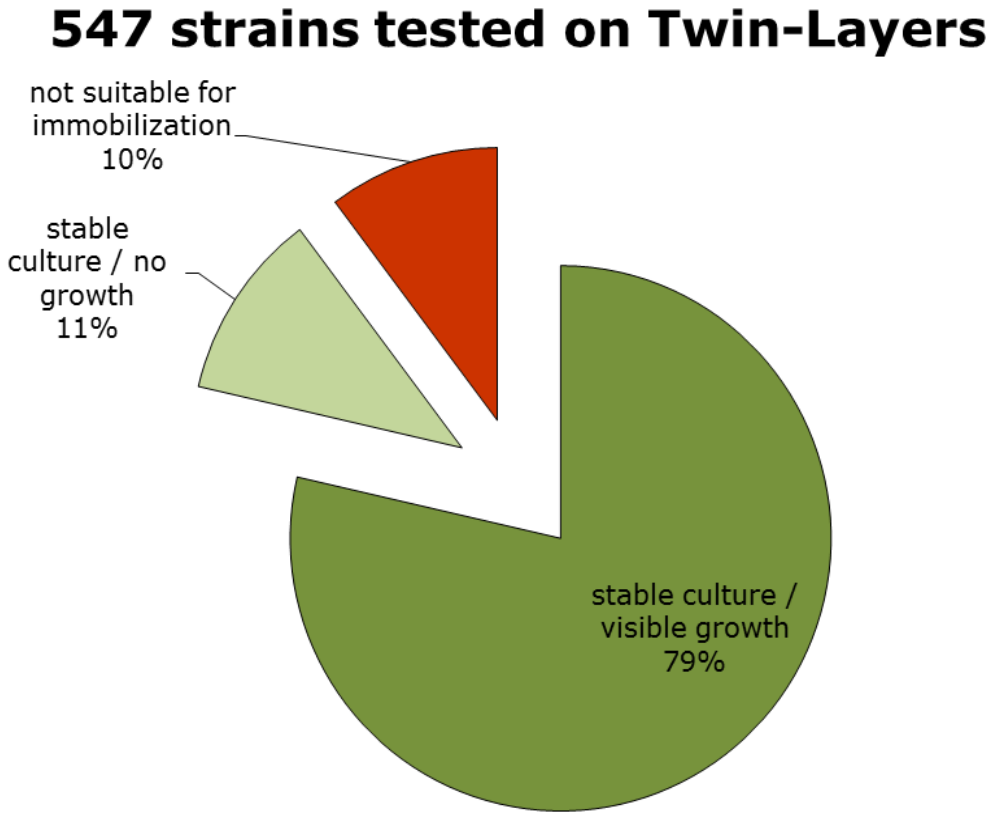
Optimizing Microalgal Growth on Twin-Layers



Halochlorella rubescens

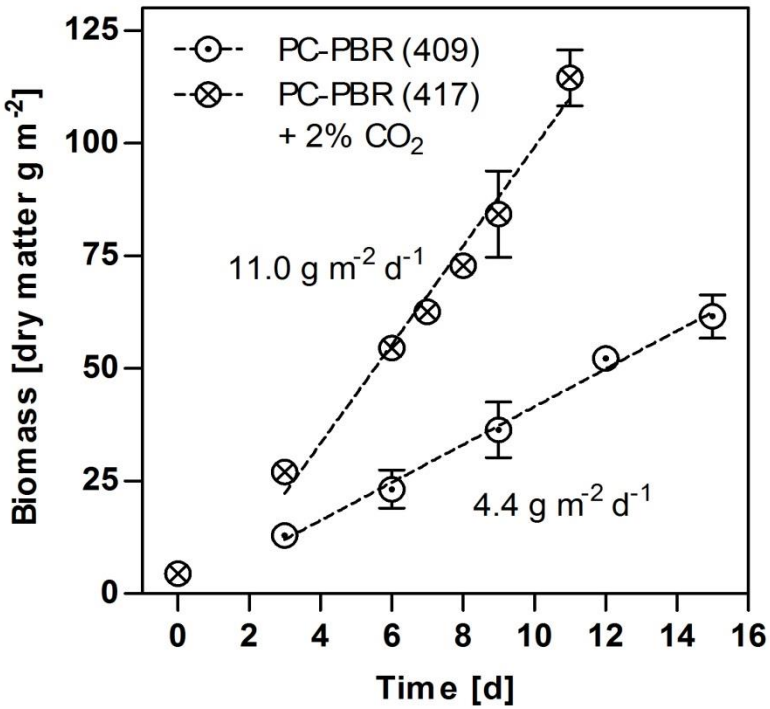
Schultze, et al. (2015): Algal Research 8C: 37–44

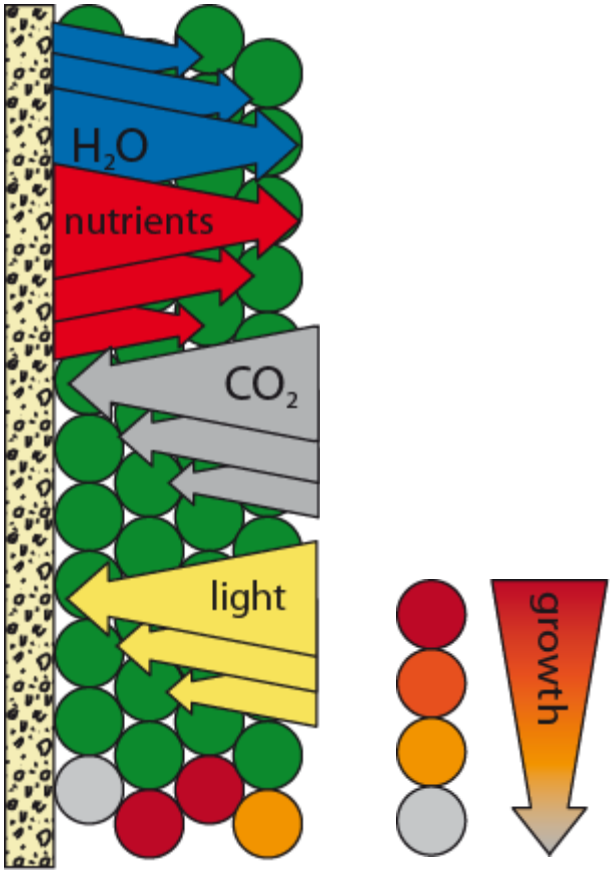
How many microalgal species can be grown on Twin-Layers?



Growing Dinoflagellates on Twin-Layers: Kinetics and Gradients

Effrenium voratum





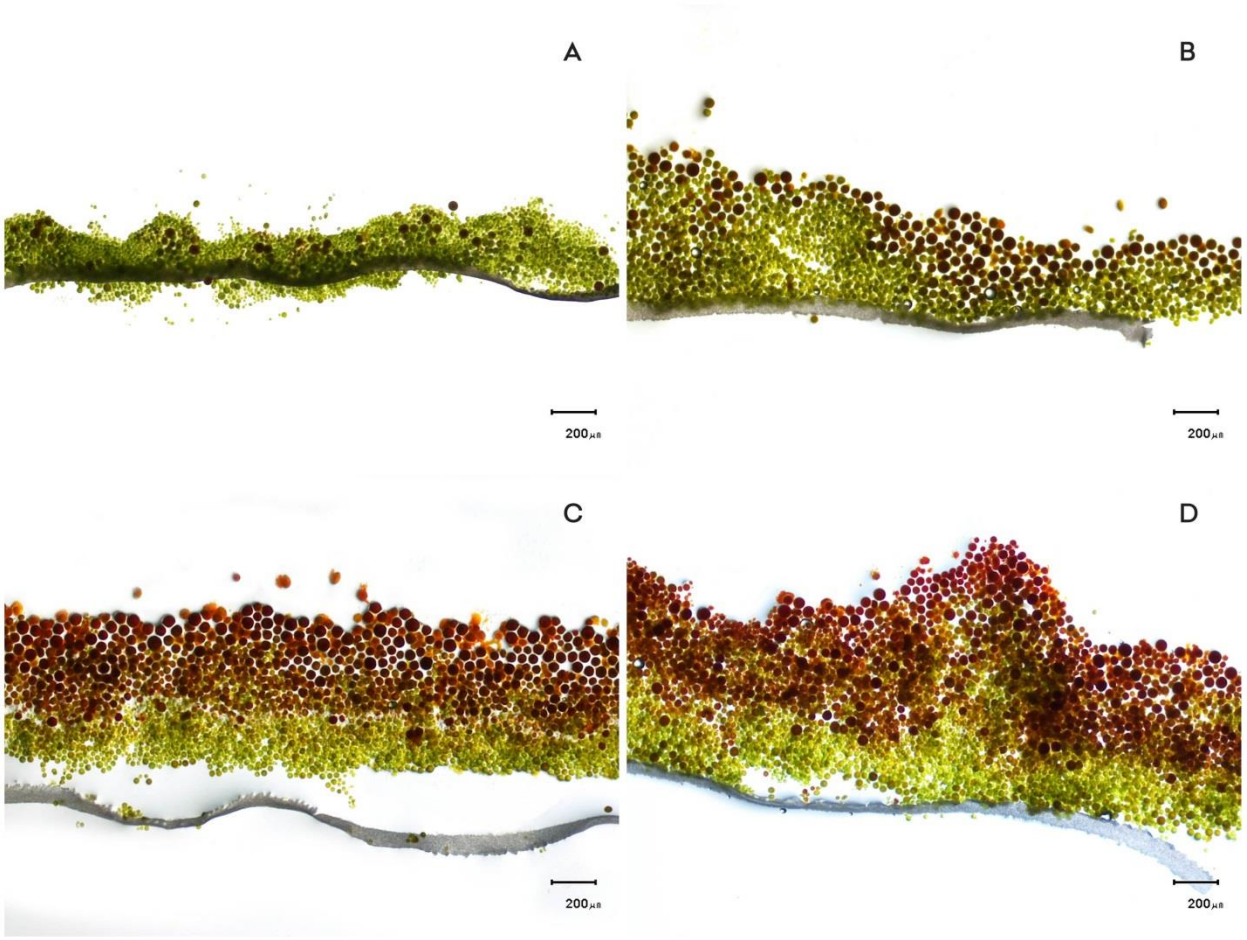
Benstein, R.M., Cebi, Z., Podola, B., Melkonian, M. (2014): Marine Biotechnology: doi: 10.1007/s10126-014-9581-0

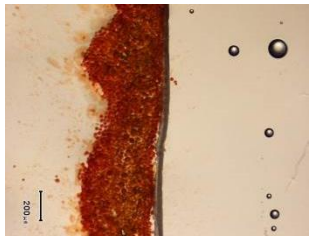
Effrenium voratum, a Valuable Source of Peridinin, the Most Potent Antioxidant Carotenoid Known

A horizontal Twin-Layer Bioreactor

Development of a Twin-Layer biofilm in *Haematococcus pluvialis*

Micrographs of biofilm sections after 16 days cultivation at: **A** 20 µmol photons m-2 s-1, **B** 89 µmol photons m-2 s-1, **C** 329 µmol photons m-2 s-1 and **D** 1,015 µmol photons m-2 s-1. Experiments were conducted with ambient air supplemented with 5% CO2 and BG11 culture medium.

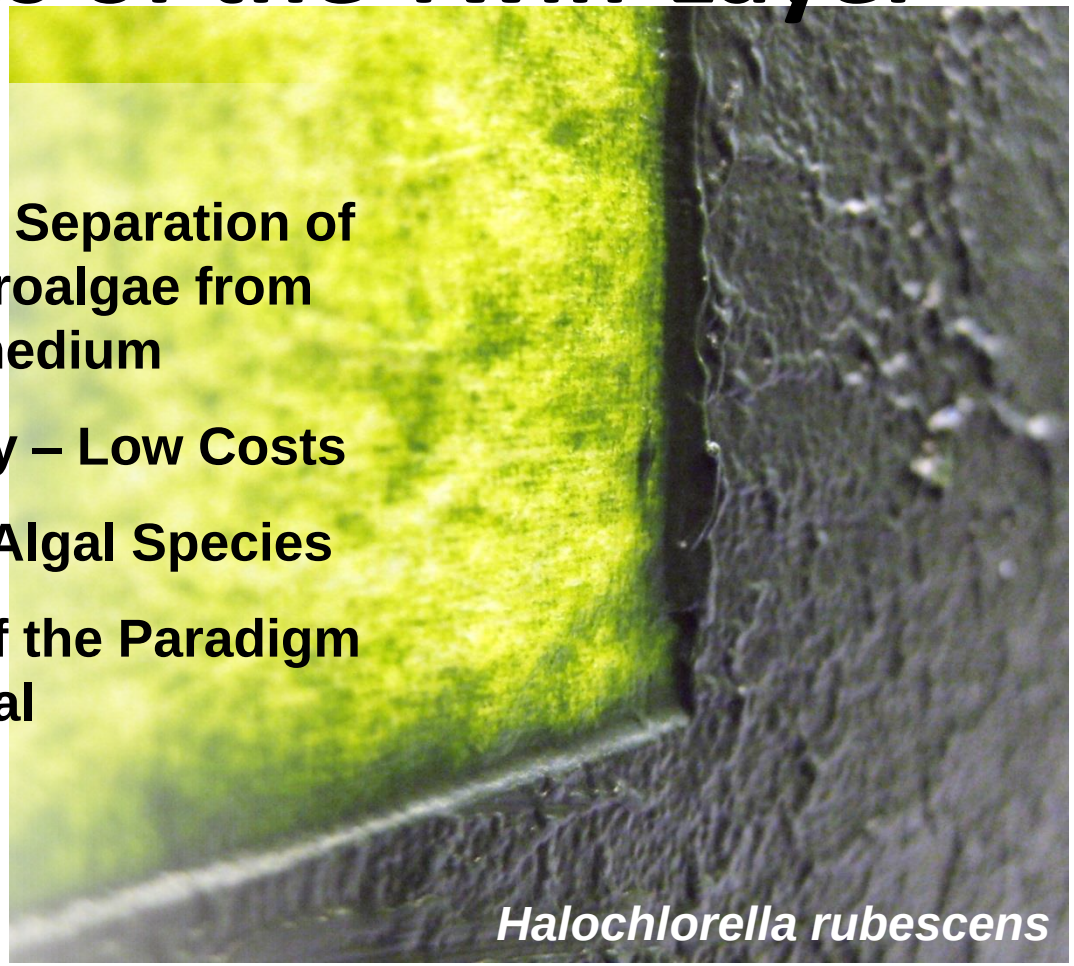




Summary

Characteristics of the Twin-Layer

- **Defining feature: Separation of immobilized microalgae from bulk of culture medium**
- **High Productivity – Low Costs**
- **Broad Range of Algal Species**
- **At the Frontier of the Paradigm Shift in Microalgal Biotechnology**




Bastian Piltz Nutrient recycling
Alice Ekelhof Polysaccha -rides
Dorothee Langenbach Twin-Layer cultivation of dinoflagellates
Tong Li Microscale profiling & modelling of biofilms
Björn Podola Develop-ment of Twin-Layer Technology
Frederik Koepsell Microscale profiling in *Haemato-coccus* biofilms
Zehra Cebi *Haemato-coccus*
Alice C. Kiperstok *Haemato-coccus*
Petra Sebestyen
Amerssa Tsirigori
Many Thanks to All of You!