Status and Trends of Photoautotrophic Algae Cultivation from the Viewpoint of a Glass Manufacturer

European Algae Biomass, April 20 & 21, 2016, Berlin
SCHOTT AG / N. Schultz
Content

1. Technologies of Photoautotrophic Algae Cultivation
2. Limits
3. Trends and new Technologies
A few Definitions

**Photoautotrophic** = phototrophic and autotrophic

**Phototrophic** = photon capture for energy acquisition.
Typically: photosynthesis for biomass build-up

**Autotrophic** = use of inorganic nutrients

**Heterotrophic** = use of organic nutrients for energy acquisition

**Mixotrophic** = use of both, inorganic and organic nutrients
Content

1. Technologies of Photoautotrophic Algae Cultivation

2. Limits

3. Trends and new Technologies
Common Photoautotrophic Algae Cultivation Technologies

**Open Raceway Ponds**  
Widespread systems. Low Capex

**Glass tubular systems**  
Durable systems with high process control.

**Polymer based systems**  
Polymer Types: PVC, PMMA, PE, PC*

**Flat panels**  
Most often polymer (sometimes glass).  
Good light utilization

*) polycarbonate plates, polyethylene bags, poly (methyl methacrylate) tubes,  
UV-stabilized polyvinylchloride tubes & plates
Open Raceway Ponds

**Pros:**
I. Apparently simple to construct and operate
II. Low installation cost per active volume
III. Scalability to huge systems

**Cons:**
I. Risk of bio-contamination & culture crashes
II. Salination / fresh water consumption due to water evaporation
III. Low volumetric productivity
IV. Limited to sunny and warm areas (but sandstorms, heavy rains (Monsun))

Advantageous for production:
Growth of algae that require selective environments.
Flat Panel Reactors

Air-lift provides nutrients and keeps algae in motion.

Modern systems (right) have structure for more uniform light distribution and cycling.

Pros:
I. Air-lift: No pumps – energy/cost saving!
II. Modularity
III. High volumetric productivity and biomass concentrations

Cons:
I. Sometimes biofilm formation with difficult cleanability
II. Polymer sheets – short outdoor lifetime (3-5y)
III. Hazard of overheating
Polymer Bags

Pros:
I. Low installation cost per active volume
II. Air-lift operation, no pumps
III. Simple technology (problems of biofilm formation resolved by material exchange)

Cons:
I. Strong biofilm formation
II. Short lifetimes (1-3 y), 1y in oceans – high material and labor cost for exchange!

Image: Algasol website: algasol.com

Plastic bags from Supreme Biotech
Tubular systems
Glass and polymer systems share a few common features

**Pros:**

I. Huge surface to volume ratio – good light dilution/utilization.

II. Closed systems (low risk of contamination, culture crashes)

**Cons:**

I. Oxygen accumulation in loop lengths > 200m (then degassing tank)

II. Overheating (but spray-water cooling)

![Algatechnologies, Israel (glass tubes)](image1)

![BGG, China (glass tubes)](image2)

![AlgaePARC, Wageningen, NL (polymer tubes)](image3)
Tubular materials in direct comparison
Glass (Borosilicate) vs. PMMA and PVC

**Glass**  \(\varnothing=65\text{mm}, \ d=2.2\text{ mm}\)
- SCHOTT Duran® standard PBR glass tubes

**PMMA**  \(\varnothing=63\text{mm}, \ d=4.69\text{ mm}\)
- Sample received from outdoor-PBR operator

**UV-PVC**  \(\varnothing=90\text{mm}, \ d=4.05\text{ mm}\)
- Advertised by manufacturer for use in outdoor PBRs with solar illumination
Transmission of Glass and Polymer tubes

UV-PVC: $T \sim 0$ in $\lambda < 400$nm and low $T$ in VIS
Glass, PMMA: High transmission $> 90\%$
Solar Degradation of Glass and Polymer tubes

- **Glass**: ≤0.1 after 383 days of 1 sun exposure, ~1 year.
- **PMMA**: 0.7±0.3 after 385 days of 1 sun exposure.
- **UV-PVC**: 80.4% degradation after 385 days of 1 sun exposure.

The following materials were tested:
- Duran: 0 and 383 days 1x Sun
- PMMA: 0 and 385 days 1x Sun
- UV-PVC: 0 and 385 days 1x Sun

UV exposure range: 420-720nm.
Thermal Expansion
Glass (Borosilicate) vs. PMMA, PVC

The thermal expansion of polymers is 10-20 fold higher than glass.
Typical Outdoor Lifetimes of Algae Culture Containments

- Plastic bags: 1-3 years
- UV-PVC: 2-4 years
- Flat Panel with PC: 3-5 years
- PMMA tubes: 8-12 years
- Glass tube PBR: >50 years

Information mostly obtained in private communications with PBR operators.
Mechanical Cleaning of Glass Tubular PBRs

In situ with a pig,

...or with chemistry (HCl, H2O2, citric acid, NaOH, Ozone...)

...or with pellets
Content

1. Technologies of Photoautotrophic Algae Cultivation

2. Limits

3. Trends and new Technologies
Limits of Photoautotrophic Algae Cultivation

Photosynthesis: \(6\text{CO}_2 + 6\text{H}_2\text{O} + \text{light} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2\)

Solar energy in hot, sunny areas (here: USA) 7.2 GJ/ (m\(^2\)*y)

Photon efficiency 1.7 - 3%
(reflection and scattering losses ~ 10%, PAR ~ 45%, low PS quantum yield (~20%), energy loss from high energy photons, photoinhibition (~50%), respiration losses~10%)

Available energy for biomass build-up 0.1 - 0.2 GJ/(m\(^2\)*y)
Caloric energy of biomass: 20 GJ / ton

\(\rightarrow\) theoretical biomass production (per active area) 17-30 g/(m\(^2\)*d)
or 61-108 t / (ha*y)

Reduction through diff. location, clouds, downtime, non-ideal temperature...
Content

1. Technologies of Photoautotrophic Algae Cultivation
2. Limits
3. Trends and new Technologies
Trends and new Technologies

1. Market on the rise: Waste water cleaning (Clearas)

2. Cascade Raceway Pond (A4F)

3. Vertical glass tube PBR (Ecoduna)
Growing Market: Waste Water Cleaning

Example: Clearaswater’s Advanced Water Recovery Process

Algae bloom after discharge of waste water with phosphorous from commercial agricultural runoff, sewage, and industry → Algae release toxins: risc for aquatic life and human health (when swimming or drinking the water)

With algae, by the same principle, waste water can be cleaned from phosphors and nitrates.

European Algae Biomass, 20.-21.04.16, N. Schultz, F. Wintersteller
© SCHOTT AG
A4F Cascade Raceway (CRW)

Channel length: 75m, width = 10m (1500m²)

Depth ~ 3cm

Channels are inclined, flow by gravitation
Cascade and pumps at end

+ high vol. productivity
+ upto 4g/l (stable culture) → power saving
+ fast emptying at bad weather
Ecoduna (AT) – vertical tubes with air-lift
The vertical PBR of Ecoduna, AT

All advantages of a closed, glass-tubular system:
→ Durability, cleanability, low risk of contamination...

Large surface to volume ratio – good light dilution, i.e., less photoinhibiton effects → high areal growth efficiencies.

Airlift drives culture
→ No pumps necessary
→ Uniform distribution of nutrients
→ no O₂-intoxication
→ Continuous harvest

In plan: Production with 600 m³/ha PBR → 100 t/(ha·y)
Thank you for your attention

www.schott.com/pbr