
# 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






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# 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




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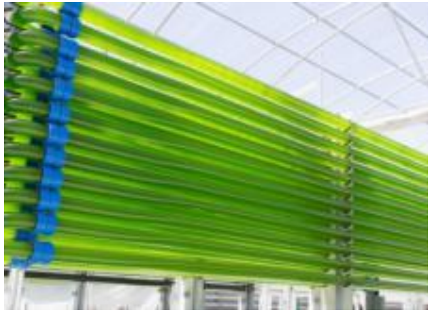
# Common Photoautotrophic Algae Cultivation Technologies

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

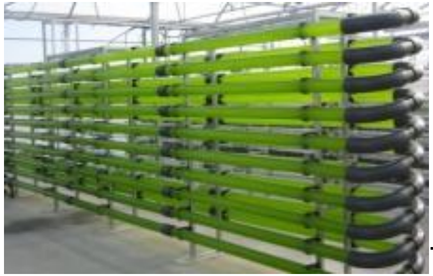
**Glass tubular systems**
Durable systems with high process control.



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

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

**Bags**



**Tubes**




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

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# 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.




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# Flat Panel Reactors

Image: Subitech website: subitec.com

Air-lift provides nutrients and keeps algae in motion

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


Image: Subitech website: subitec.com

**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




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# Polymer Bags

Floating PE polymer bags

Image: Algasol website: algasol.com

**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!

Plastic bags from Supreme Biotech




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# 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 risc 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)

BGG, China (glass tubes)

AlgaePARC, Wageningen, NL (polymer tubes)




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# Tubular materials in direct comparison
## Glass (Borosilicate) vs. PMMA and PVC

**Glass** ∅=65mm, d= 2.2 mm
SCHOTT Duran® standard PBR glass tubes

**PMMA** ∅=63mm, d= 4,69 mm
Sample received from outdoor-PBR operator

**UV-PVC** ∅=90mm, d=4.05 mm
Advertised by manufacturer for use in outdoor PBRs with solar illumination




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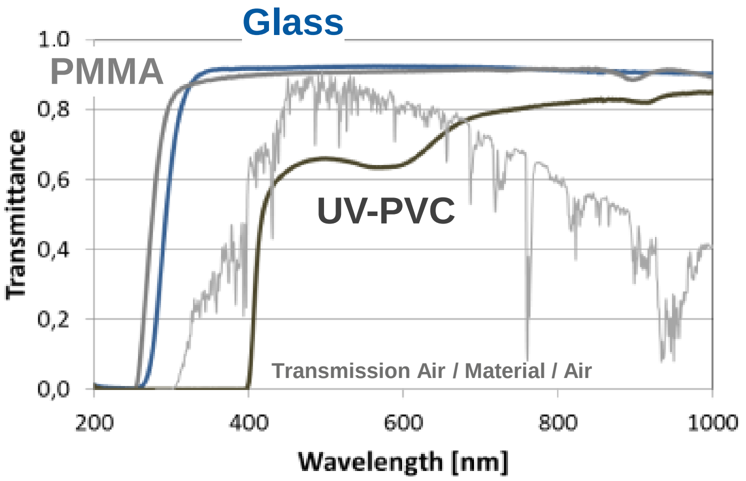
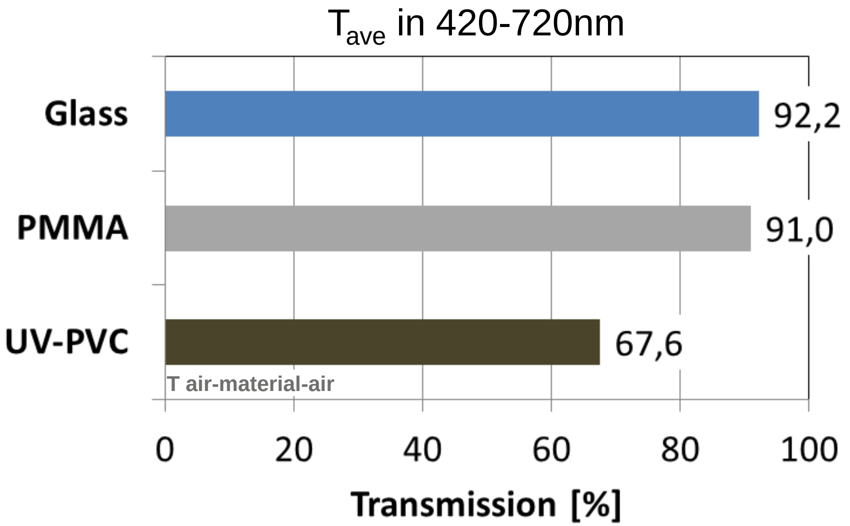
# Transmission of Glass and Polymer tubes




UV-PVC: T~0 in λ<400nm and low T in VIS

Glass, PMMA: High transmission > 90%

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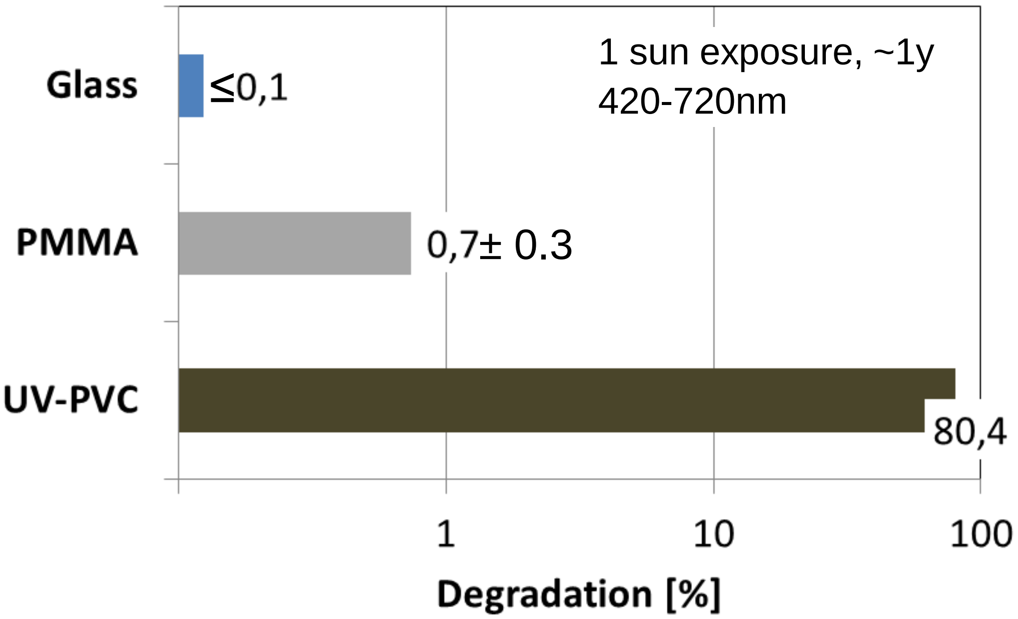
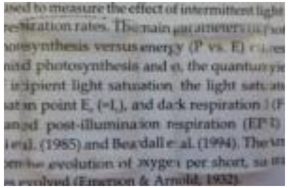
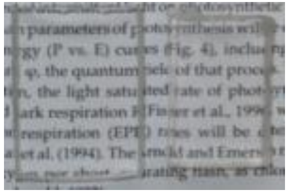
# Solar Degradation of Glass and Polymer tubes

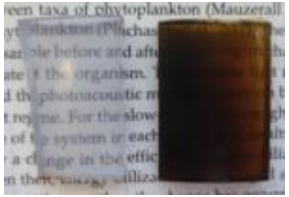


**Duran**
0 and 383 days 1x Sun



**PMMA**
0 and 385 days 1x Sun



**UV-PVC**
0 and 385 days 1x Sun

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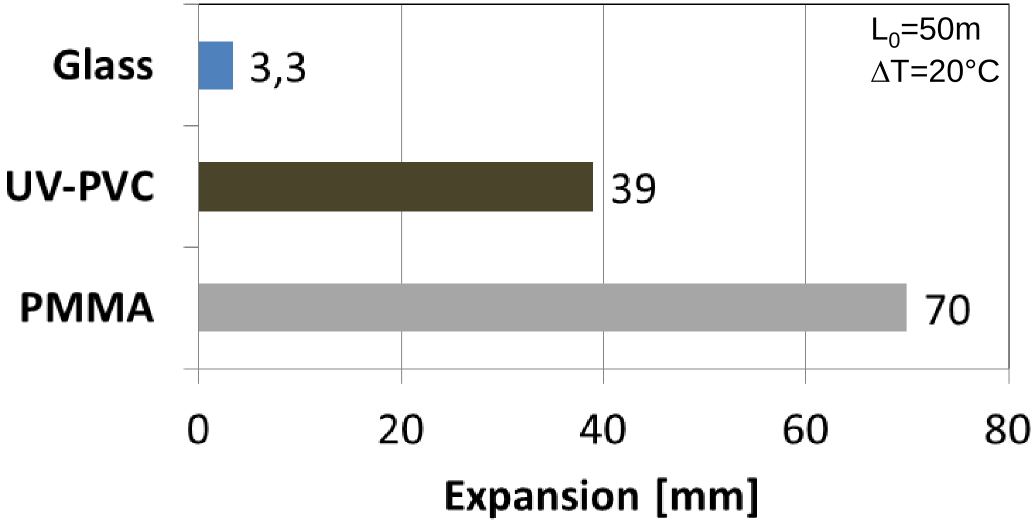
# Thermal Expansion

## Glass (Borosilicate) vs. PMMA, PVC




The thermal expansion of polymers is 10-20 fold higher than glass



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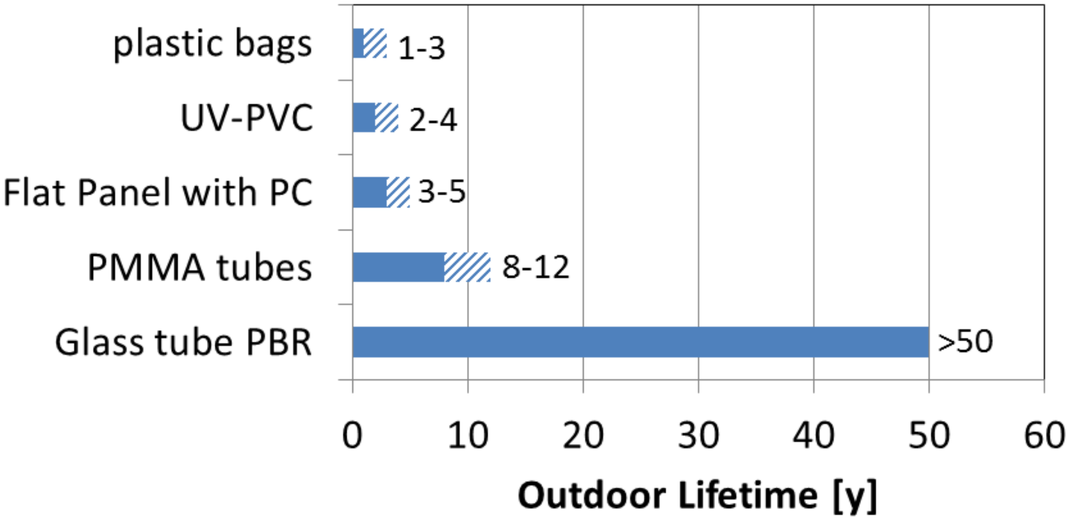
# Typical Outdoor Lifetimes of Algae Culture Containments




Information mostly obtained in private communications with PBR operators

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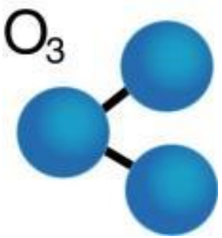
# Mechanical Cleaning of Glass Tubular PBRs

In situ with a pig,

…or with pellets

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



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# Limits of Photoautotrophic Algae Cultivation

**Photosynthesis: $6CO_2 + 6H_2O$ + light → $C_6H_{12}O_6 + 6O_2$**

| | |
|---|---|
| Solar energy in hot, sunny areas (here: USA) | 7.2 GJ/ ($m^2$*y) |
| Photon efficiency<br>*(reflexion and scattering losses ~ 10%, PAR ~ 45%, low PS quantum yield (~20%), energy loss from high energy photons, photoinhibition (~50%), respiration losses~10%)* | 1.7 - 3% |
| Available energy for biomass build-up | 0.1 - 0.2 GJ/($m^2$*y) |
| Caloric energy of biomass: | 20 GJ / ton |
| → theoretical biomass production (per active area) | **17-30 g/($m^2$*d)**<br>or **61-108 t / (ha*y)** |

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




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# 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 form phosphors and nitrates.


http://clearaswater.com




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# A4F Cascade Raceway (CRW)

Channel length: 75m, width = 10m ($1500m^2$)

Depth ~ 3cm

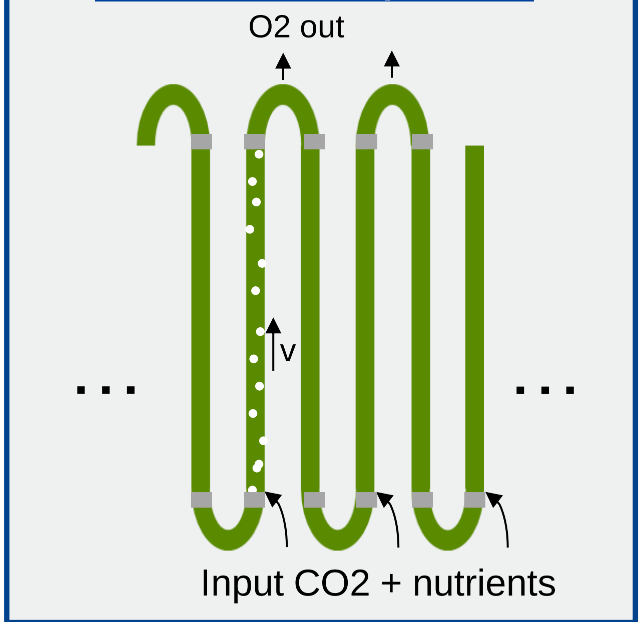
Channels are inclined, flow by gravitation
Cascade and pumps at end

+ 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

**Mechanism of Operation**




**Airlift drives algae upwards and sets entire culture in motion**

All advantages of a closed, glass-tubular system:
→ Durability, cleanability, low risc of contaminaton…

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 $O_2$-intoxication
→ Continuous harvest

In plan: Production with 600 $m^3$/ha PBR → 100 t/(ha·y)

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# Thank you for your attention

www.schott.com/pbr