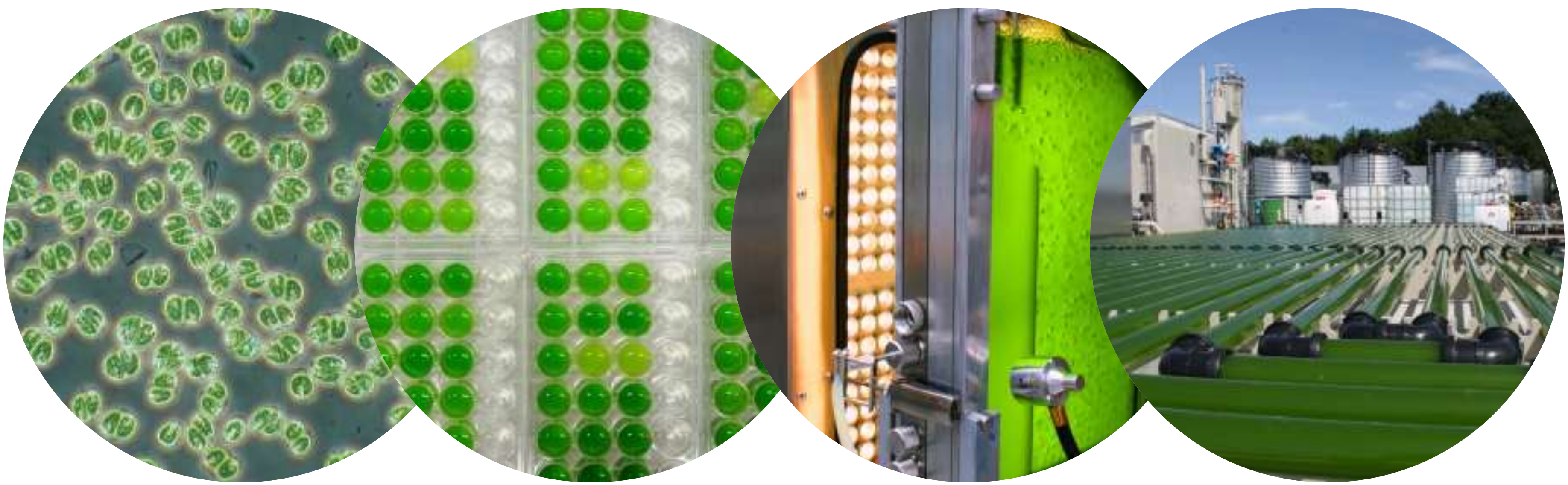
# Microalgae as source of bulk chemicals

## AlgaePARC

## Algae Production And Research Center

**Rouke Bosma**
Maria Cuaresma
Marcel Janssen



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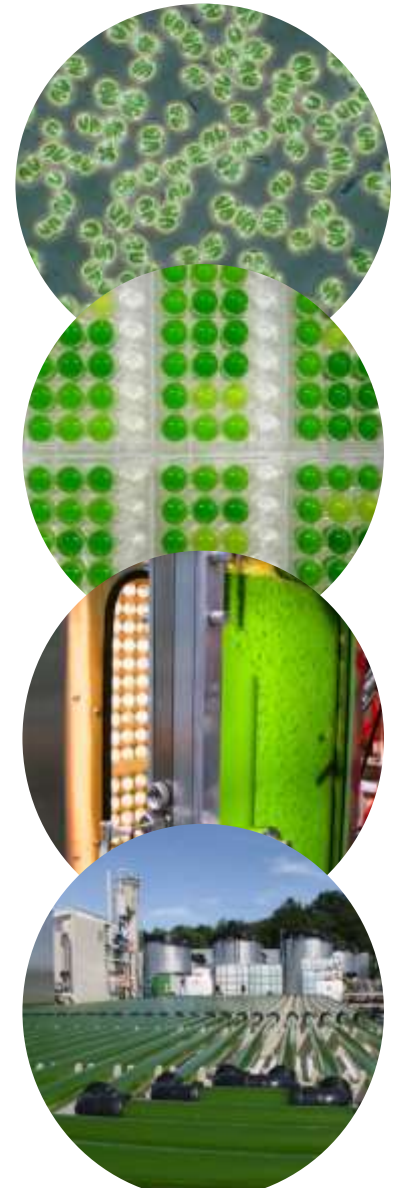
# Overview presentation

- Biobased economy
- Microalgae as possible solution
- AlgaePARC
- Commercial flat panel (Infors)
  - Why developed
  - Experiments
  - Improvements



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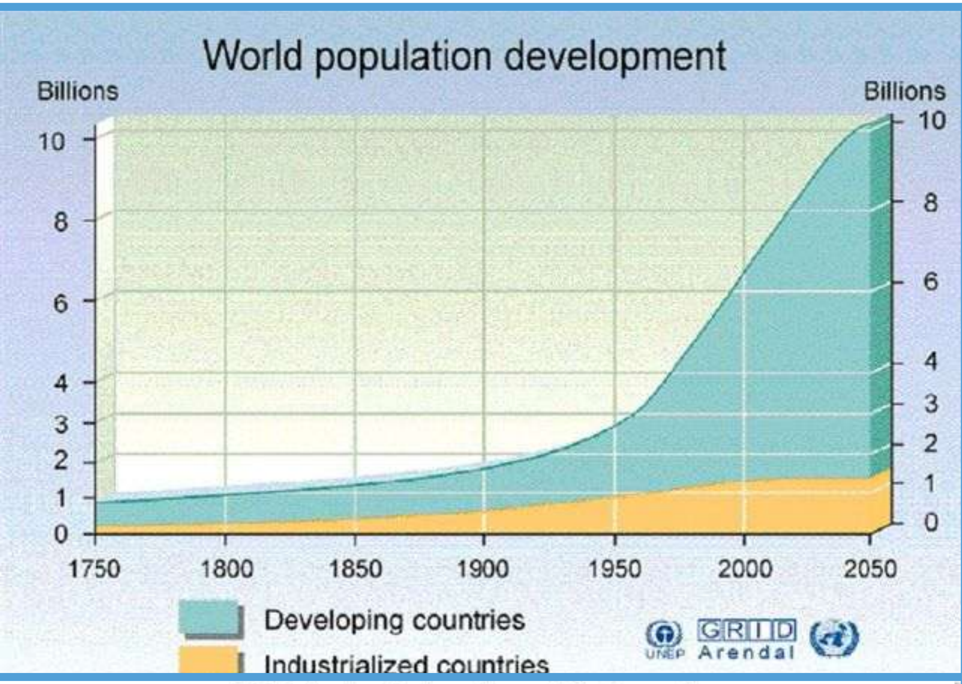
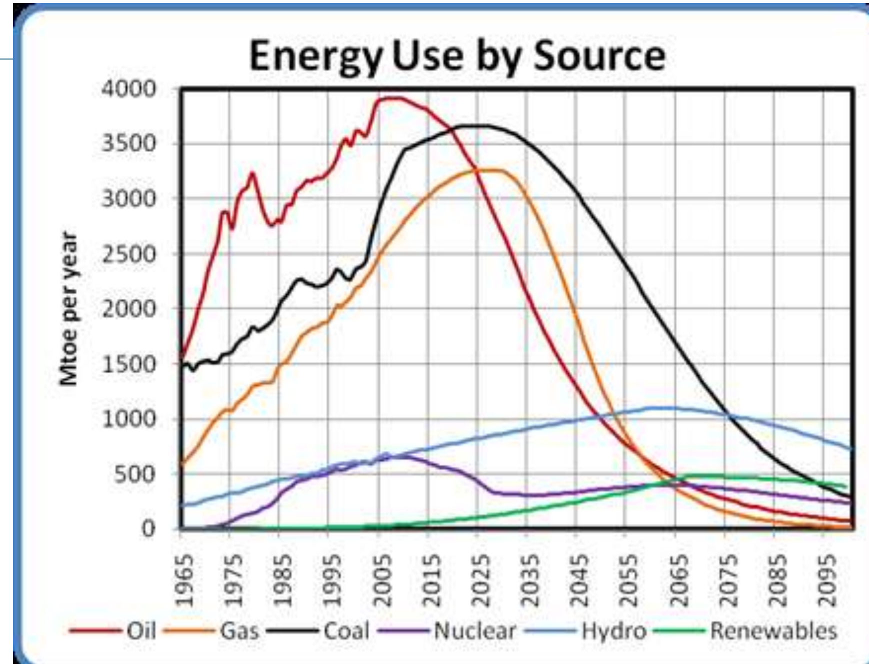
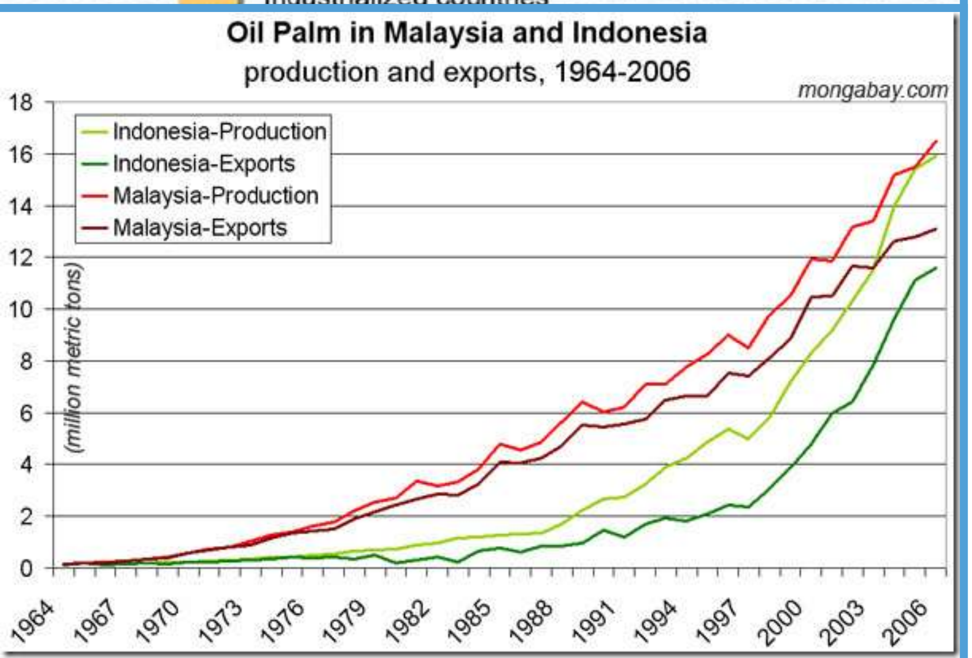
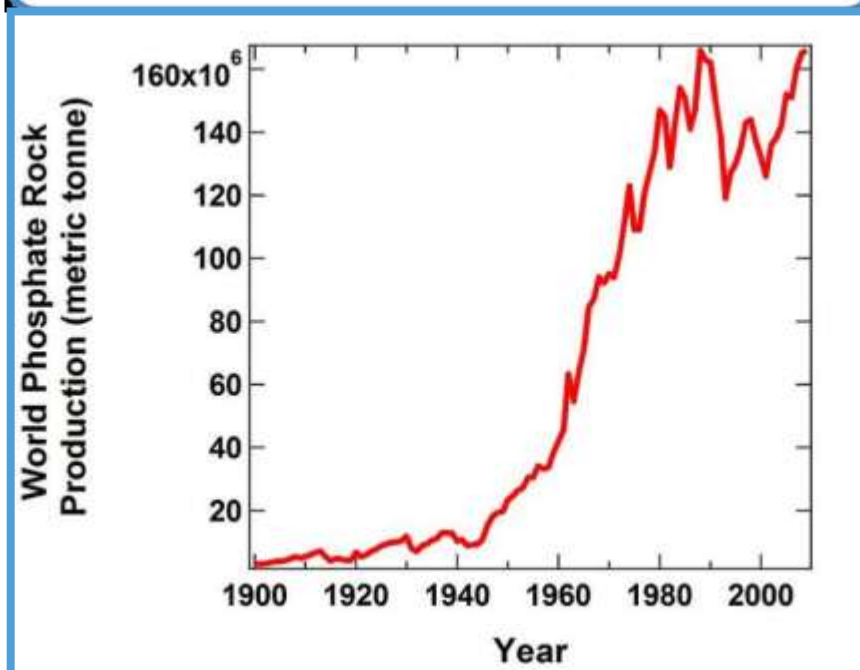
# The world is growing...

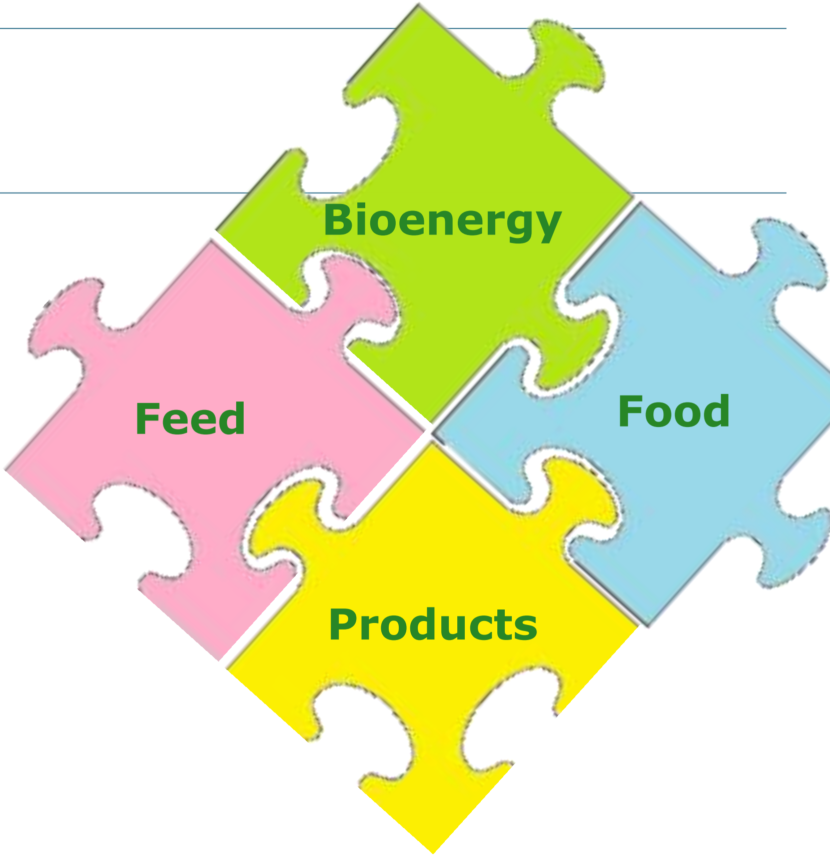


# The biobased economy




Production from biomass of:

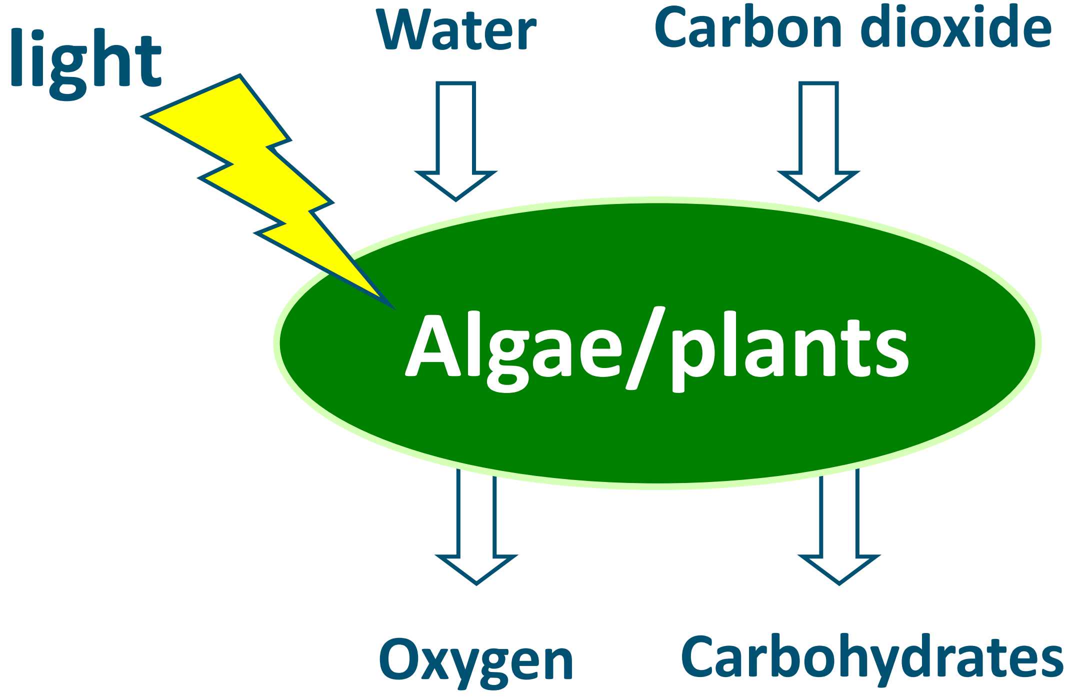
- fuels/energy
- human and animal feed
- bulk- en fine chemicals

By (re)usage of:

- raw materials
- rest streams (free nutrients)
- biological production processes

# Important fact

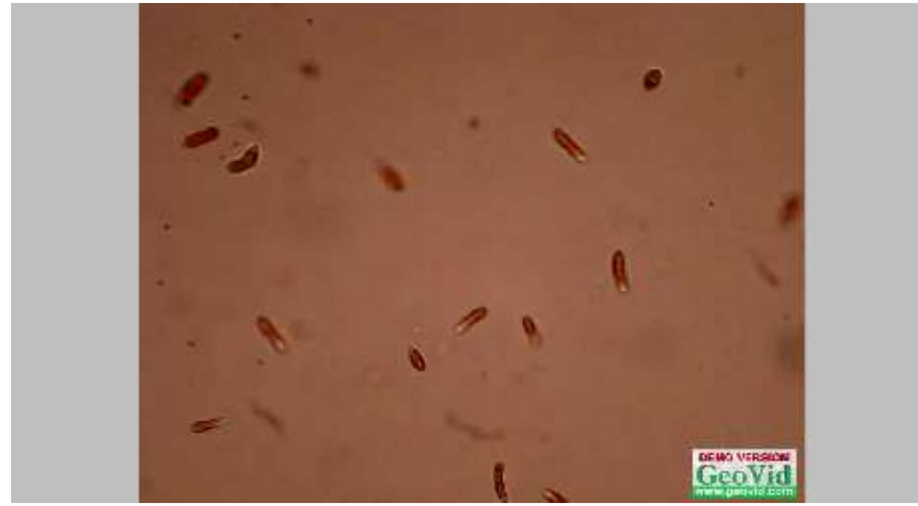
- Solar energy provides more energy to the earth in 1 hour than all energy consumed by humans in 1 year
- How to store solar energy ?
  - Photosynthesis!




# Algae

macroalgae
*Macrocystis*

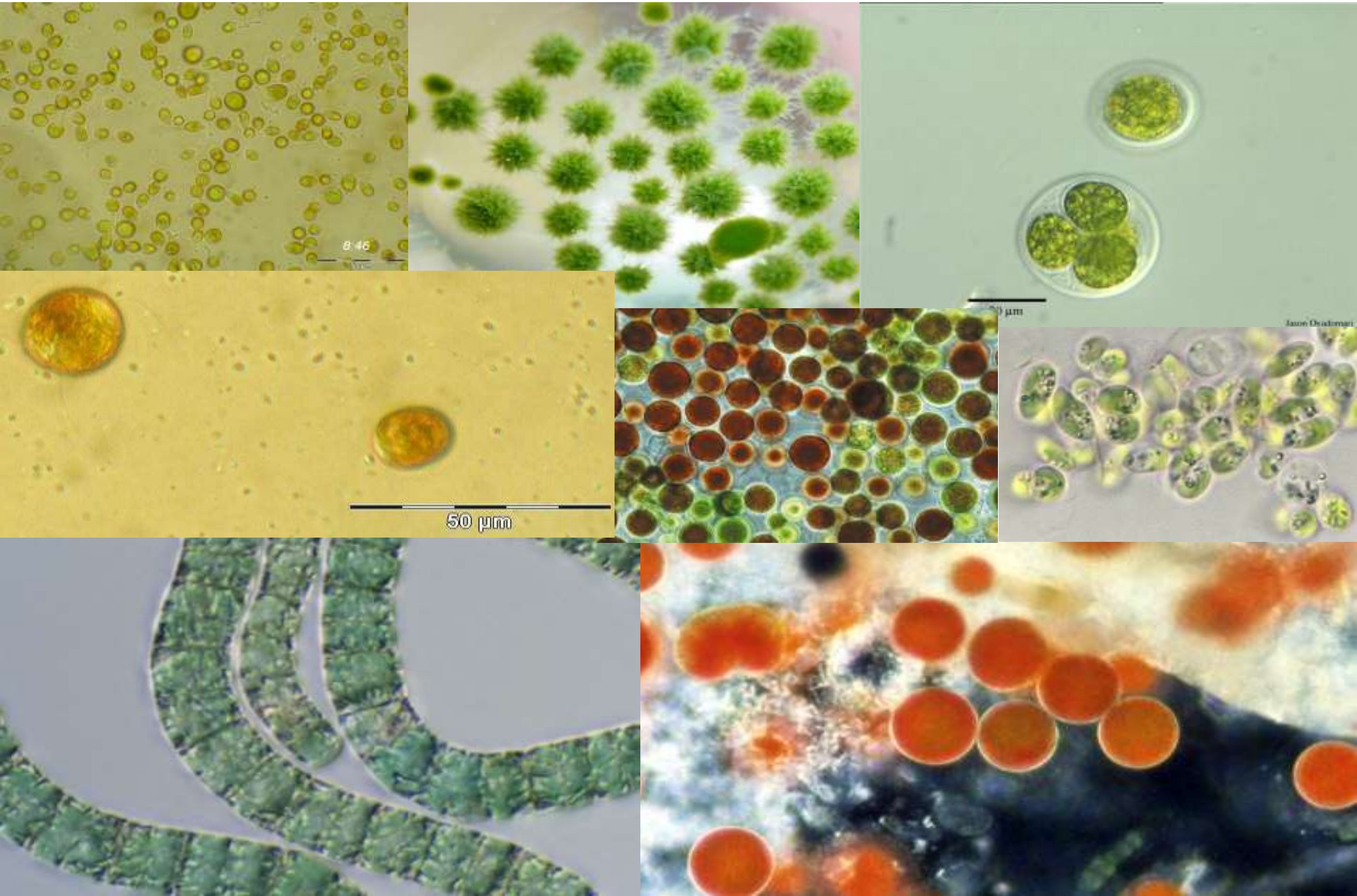
*Foto: Biology, Campbell*




microalgae 400 x magn.
*(Dunaliella salina)*

- Simple plants, contain Chlorophyll
- Size between 1 µm to 100 m
- Photosynthetic organisms

# Microalgae species (± 200.000)

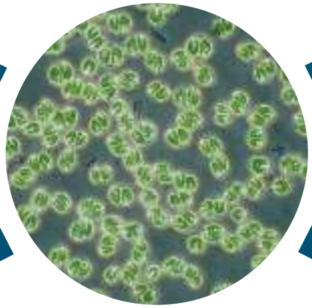


# Potential application of algae


Market : 1-2 b$
Price : 500 - 5000 $ $kg^{-1}$

**Carotenoids**


**Proteins**



**Biomass**

Market : ± 1.5 b$
Price : 10 - 50 $ $kg^{-1}$

**Phyco-biliproteins**

Market : 50 m$
Price : 3 to 25 $ $mg^{-1}$

**Sugars**
**Carbohydrates**

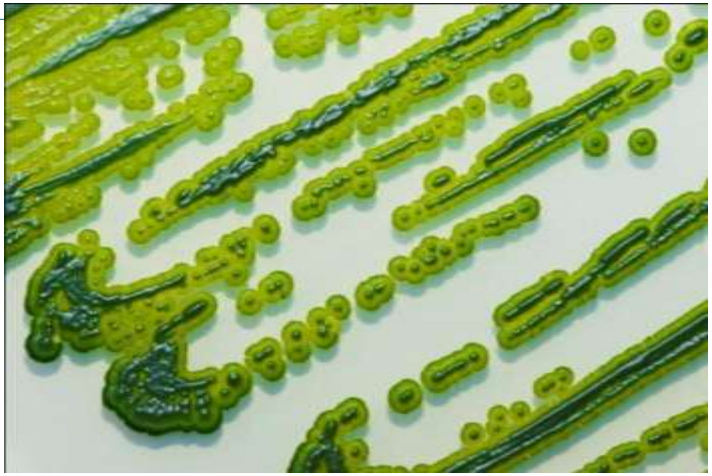
**Lipids**
**Omega-3**
**Omega-6**

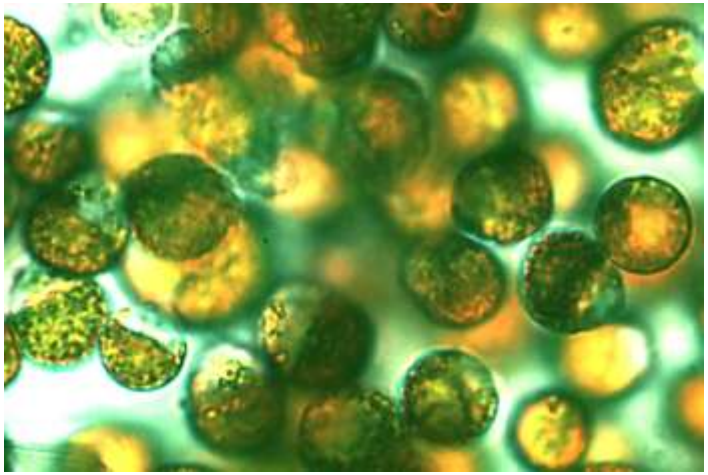

Market : 1.5 b$
Price : 400 - 2000 $ $kg^{-1}$

*Maharajh et al. workshop South Africa, 2012*

# Algae as a promising innovation

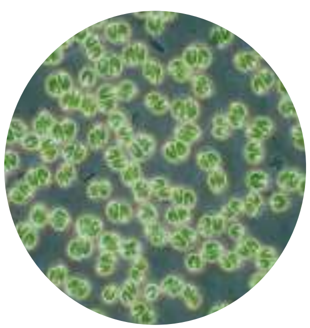
- High productivity
  - Oil content: 20-60%
  - 20,000-50,000 liter/ha/year oil
  - Palm oil: 6,000 liter/ha/year
- No ‘competing claims’
  - Grow on seawater
  - Use of residual nutrients ($CO_2$, N, P)
  - Co-products have value (e.g. lipids, proteins)





# From a craft to an industrial process…

- Current worldwide microalgal manufacturing infrastructure ~5000 tons of dry algal biomass
- High value products such as carotenoids and ω-3 fatty acids used for food and feed ingredients.
- Total market volume is €1.25 billion
  (average market price of €250/kg dry biomass)
- World production of palm oil is nearly 40 million tons, with a market value of ~0.50 €/kg



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Wijffels R.H., Barbosa M.J. (2010) An outlook on microalgal biofuels. ***Science*** 329: 796-799

# How can we decrease production costs?

- At 1 ha scale today: 10 €/kg
- At 100 ha scale today: 4 €/kg
- What could be possible: 0.50 €/kg

**Still too expensive for biodiesel alone**

- Increasing photosynthetic efficiency
- Integrate processes (free nutrients)
- Decreasing mixing
- Developing cheaper and less energy consuming harvesting technologies
- Choosing locations with higher irradiations




Norsker et al. (2011) Microalgal production- a close look at economics, *Biotechnology Advances* **29**: 24-27

Bosma, R. et al. (2010). Towards increased microalgal productivity in photobioreactors, International Sugar Journal 112: 74-85.

# AlgaePARC

## Algae Production And Research Center

Bridge the gap between fundamental research and scalable applications in industry

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# Example, photosynthetic efficiency

| | |
|---|---|
| Theoretical maximum photosynthetic efficiency | 9% |
| 10% of light lost by transmission | x 0.90 |
| 5% of biomass lost during the night | x 0.95 |
| 10% of energy used for maintenance | x 0.90 |
| Maximum photosynthetic efficiency in photobioreactors: | 7% |

- At lab scale a photosynthetic efficiency of 6% is obtained

- What about
  - Pilot scale 10 – 100 $m^2$
  - Extended time > 1 yr

- How to design/operate even larger (1-100 ha plants)?

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*Bosma, R. et al. (2010). International Sugar Journal 112: 74-85*
*Cuaresma M. et al. (2011). Bioresource Technology 102: 5129-5137*

# MANY SCATTERED ACTIVITIES

- Different locations
- Different designs
- Different measurements
- How to compare systems?
- How to learn from this process ?

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# AlgaePARC objectives

- International center of applied research
- Bridge between basic research and applications
- Development of competitive technology-economics, sustainability
- Acquire information for full scale plants
- Algal biomass for food, feed, chemicals and fuels

# Funding AlgaePARC 8M€

## Facility financed by

- Ministry EL&I
- Province Gelderland
- Wageningen UR

## Research program financed by

# Official opening of AlgaePARC 17 June 2011


16 juni 2011, pag. 2

Wageningen onderzoekt goedkope productie

## Olie krijgt concurrentie algen

**BENNEKOM - De productiekosten van algen als vervanger van fossiele olie moeten in tien jaar omlaag van de huidige €4 per kilo naar €0,40.**

Met dit doel voor ogen gaat het onderzoeksproject AlgaePARC in Bennekom morgen van start. Onderzoekers van Universiteit Wageningen willen toewerken naar duurzame algenproductie op industriële schaal. In het park zijn [...]er soorten reactoren geplaatst [...]arin de algen een snelle groei [...]rmaken.

[...]n hoek van het terrein is nog [...] Rouke Bosma, de man die [...]ark draaiende moet houden, [...]t dat hier uiteindelijk de ideale reactor moet komen. De vier typen die er nu liggen, hebben alle hun voor- en nadelen. De een gebruikt te veel materialen, de andere te veel energie en de afnade open reactor is gevoelig voor verontreiniging.

De komende jaren worden de door Paques in Balk vervaardigde reactoren uitgebreid getest om een combinatie van de vier bestaande technieken te ontwikkelen, die de beste resultaten geeft. Want algen zijn veelbelovend als vervangers van fossiele olie. Bovendien is de kweek niet concurrerend met de voedselproductie voor mensen.

Om voldoende olie uit algen te halen die de hele Europese transportsector van brandstof kan voorzien, zou uiteindelijk een gebied ter grootte van Portugal nodig zijn. Dit hoeft evenwel niet op vruchtbare grond. Woestijn, vervuilde grond, daken en drijvende constructies op zee voldoen als bodem. Het vele benodigde water komt gewoon uit zee.

Bovendien levert de productie van zoveel brandstof ook nog eens 0,3 miljard ton eiwit op en dat is veertig keer zoveel eiwit als Europa jaarlijks invoert aan soja-eiwit.

Daarnaast is voor de productie van algen het broeikasgas $CO_2$ nodig. Jaarlijks 1,1 miljard ton en dat is eenderde van de totale productie van $CO_2$ in Europa. Daarmee zou Europa ook veel minder bijdragen aan klimaatverandering.

Met het AlgaePARC wil Wageningen Universiteit/Researchcenter (WUR) een belangrijke speler worden in het onderzoek naar algenproductie. [...]

**Ontwikkeling ideale reactor**

**Op zee, dak of in woestijn**

**Oplossing voor broeikasgas**



# Production systems at AlgaePARC

Raceway pond

Horizontal tubular reactor

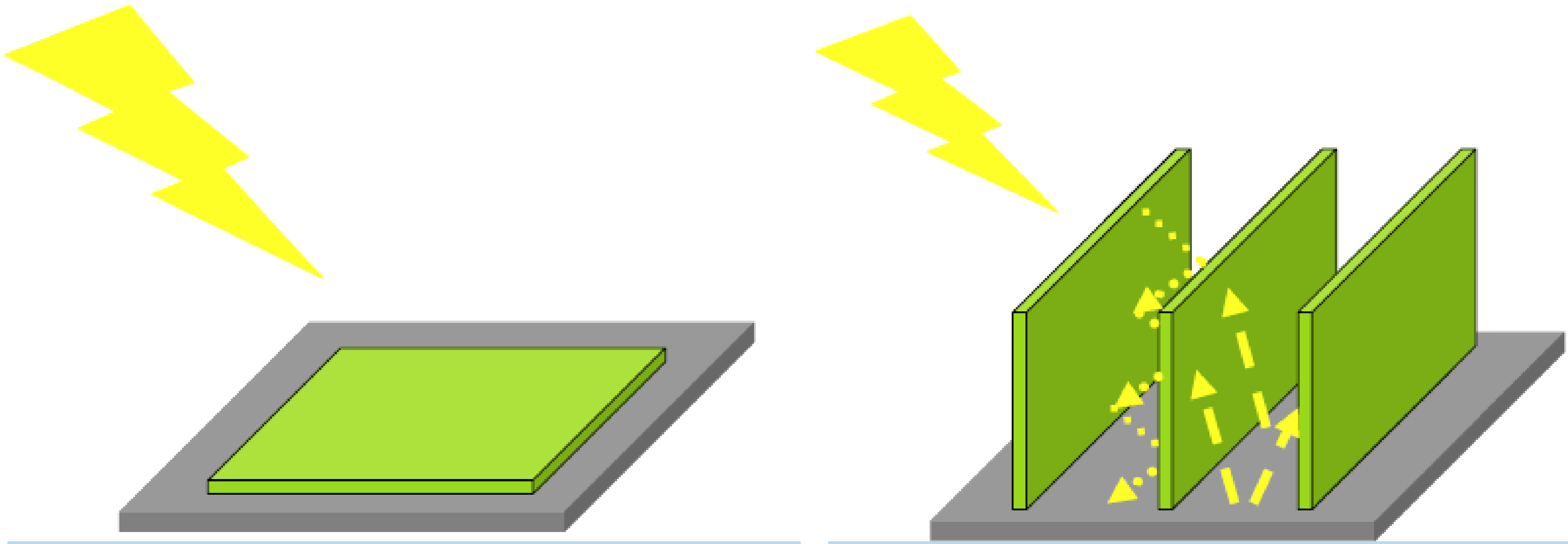
Advantage
- Cheap to build and to operate
- Established technology

Disadvantages
- Prone to contamination
- Water evaporation
- Controllability
- Low biomass concentrations

Advantage
- High controllability
- Closed system
- High biomass concentrations

Disadvantages
- Photo inhibition
- Oxygen built up

# Principal of light dilution– go vertical!



$I_{max}$ : 1800 µmol photons $m^{-2}$ $s^{-1}$
Direct sunlight

$I_{max}$ : 400 µmol photons $m^{-2}$ $s^{-1}$
Dilution effect

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Cuaresma, M et al. (2011). Bioresource Technology **102**: 5129-5137.

# Production systems at AlgaePARC

Flat panels

Vertical stacked tubular reactor

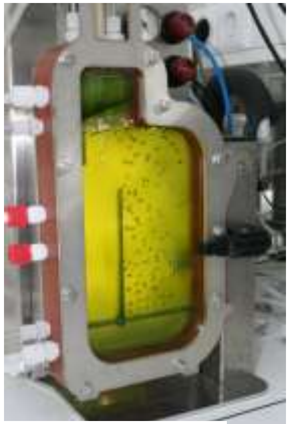
Advantage
- Low material costs
- No need for external cooling
- High biomass concentrations

Disadvantages
- Prone to damage
- Energy costs of air sparging

Advantage
- High controllability
- Closed system
- Light dilution

Disadvantages
- Oxygen built up
- Costs/energy to built

# Example: Screening, testing & optimizing algal species under controlled conditions



Algaemist

## Screening of species

- Mostly done in Erlenmeyer flasks
- With reactors → under controlled condition

## Optimisation in lab scale photobioreactors

- Optimisation of lipid productivity under nutrient limitation for some selected species
- Optimize lipid productivities under mimicked outdoor conditions

## Cultivation outdoors

- testing in 2.4 $m^2$ systems
- proof of principle in 24 $m^2$ systems

PhD student
Giulia Benvenuti

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# Development of a lab scale flat plate commercial photobioreactor

Maria Cuaresma

Rouke Bosma

Marcel Janssen

Marco Siemerink

Marc Buevink

AlgaePARC

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INFORS HT
Benelux

# Why a commercial flat panel reactor ?

On the market only (stirred) vessel type reactors were available

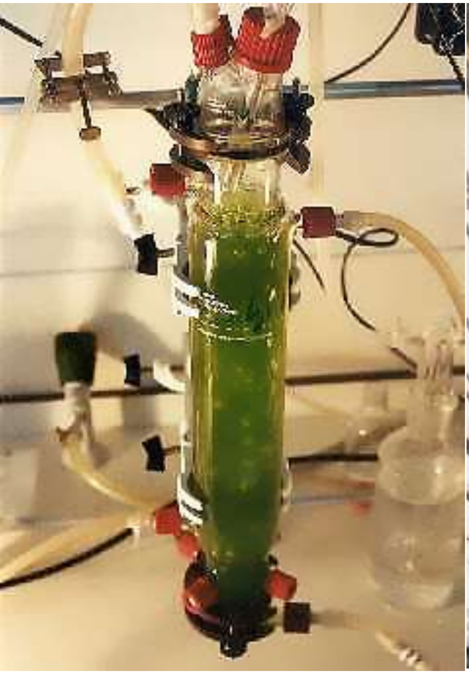
**Advantages of flat panel over vessel type**

- Shorter optical path
- Light absorption can be easily quantified
- Increased volumetric productivities
- Photosynthetic yield can be determined

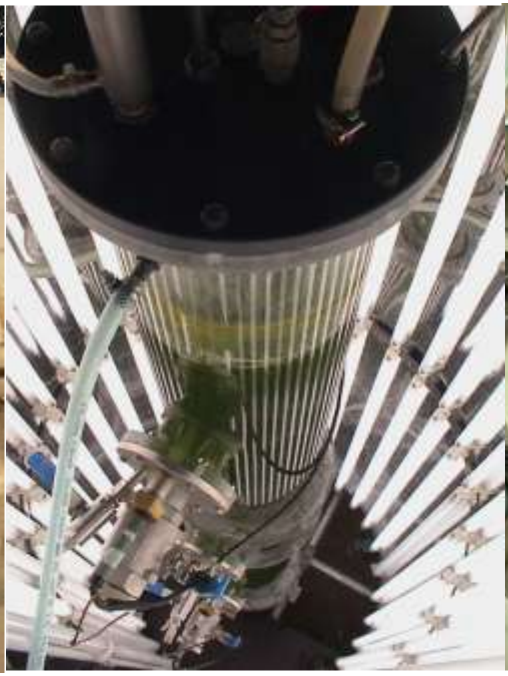
**In addition, requirements for research**

A versatile laboratory reactor in which we can simulate outdoor conditions.

# Development inside Wageningen UR



1998



2000

2003

2007

Final flat panel design → ready for commercialization

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# Reactors on the market

**Sartorius**

**BIOSTAT® PBR 2S**


**Photon Systems Instruments**

**FMT-150**


Tubular photobioreactor + stirred tank

- Slow mixing

Illumination: Fluorescent lights

- Low light intensities
- In-homogenous
- Light absorption not quantifiable

Flat panel mixed by gassing

- Low volume (400 mL)

Illumination: LEDs

- High light intensity

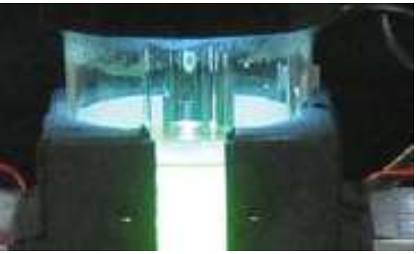
Robustness?

Software not flexible

# Reactors on the market

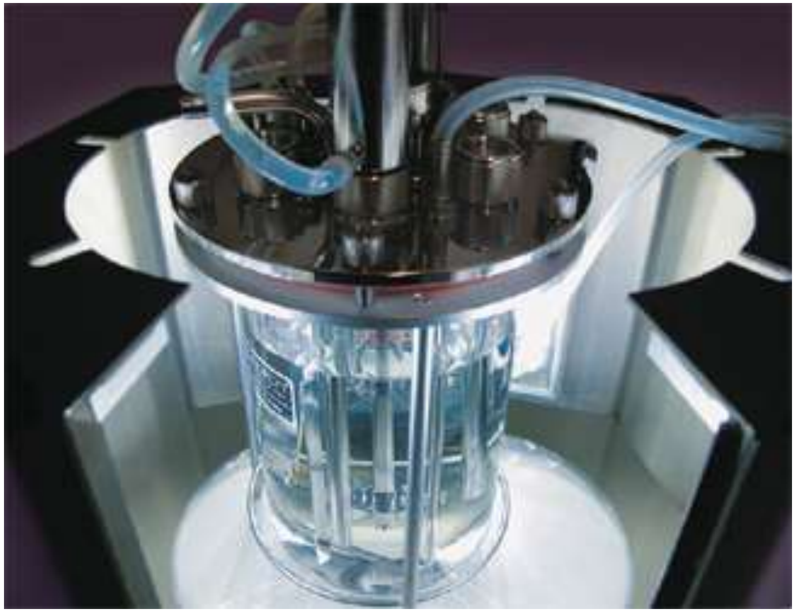
**Phenometrics Inc.**

**ePBR photobioreactor**



**Applikon**

**Photobio**



Vessel shaped reactor mixed by gassing

Illumination: LEDs

- Long optical path
- In- homogenous
- Light absorption difficult to quantify

- Sterilisable?

Vessel shaped reactor mixed by stirring

Illumination: Fluorescents? LEDs (future)

- Long optical path
- Low light intensity
- Light absorption difficult to quantify

# Infors HT flat panel system


**High-power LED lighting**

- Warm white leds (4000 K colour)
- Energy efficient
- Supply 2400 µmol m$^{-2}$ s$^{-1}$ (400-700 nm)
- Homogenous light (unidirectional)

**Controllable light intensity from 0-100%**

- Simulate sunlight

**Optical path (diameter) : 2 cm**

- High algal concentrations

**Airlift system**

- Gentle mixing
- Mixed in about 20 s

**Asymmetrical shape (round corners)**

- No stagnant zones

# Infors HT flat panel system


**Working volume: 1.8 L**

**Sterilisable (121 °C, 15 minutes)**

**Easy to dismantle (click system)**

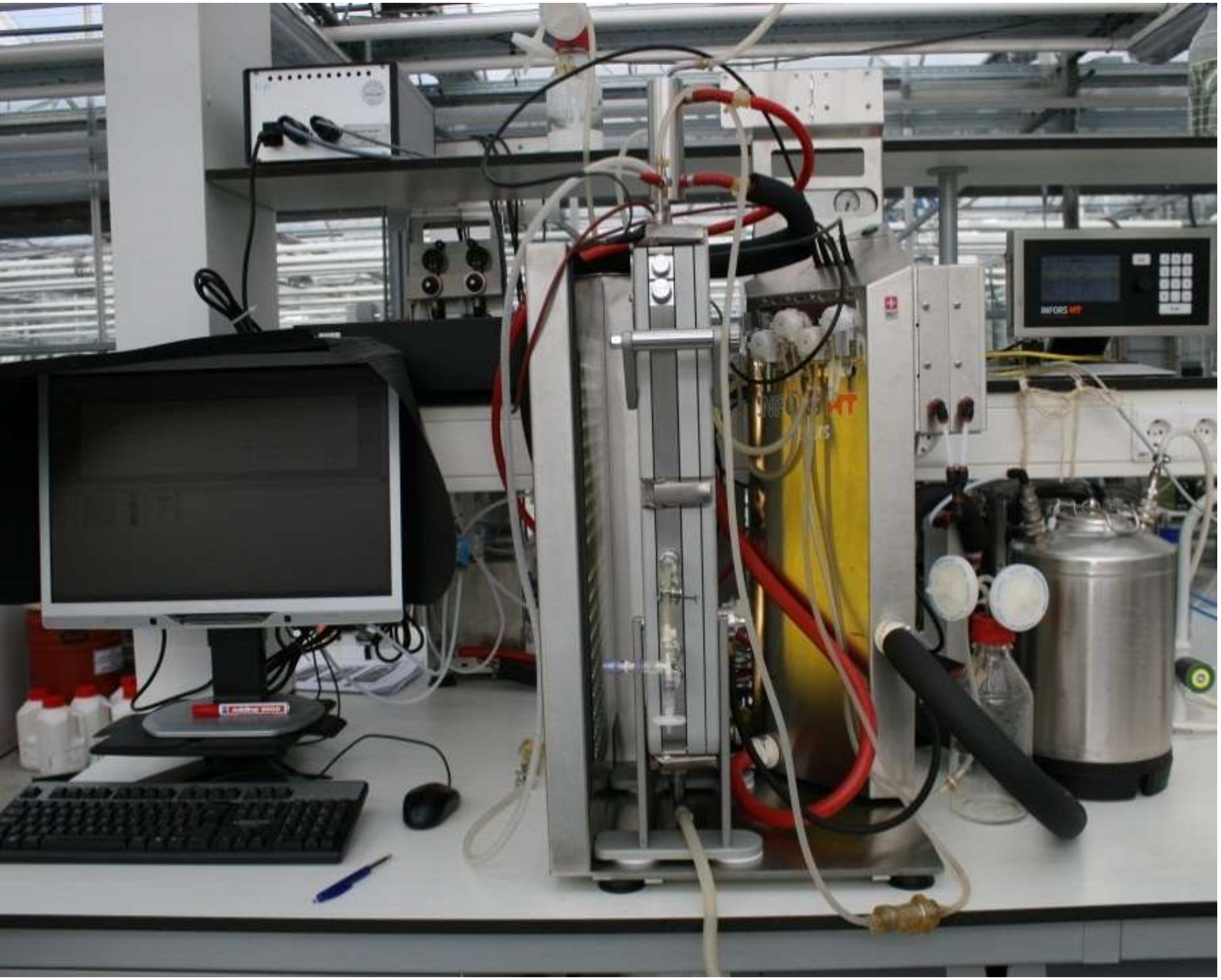
**pH control by**

- $CO_2$ addition
- Pumping acid/base

**Easy to program**

- Implement new control strategies
- Mimicking outdoors conditions

# Photobioreactor set-up



**Labfors 5 Lux Unit**

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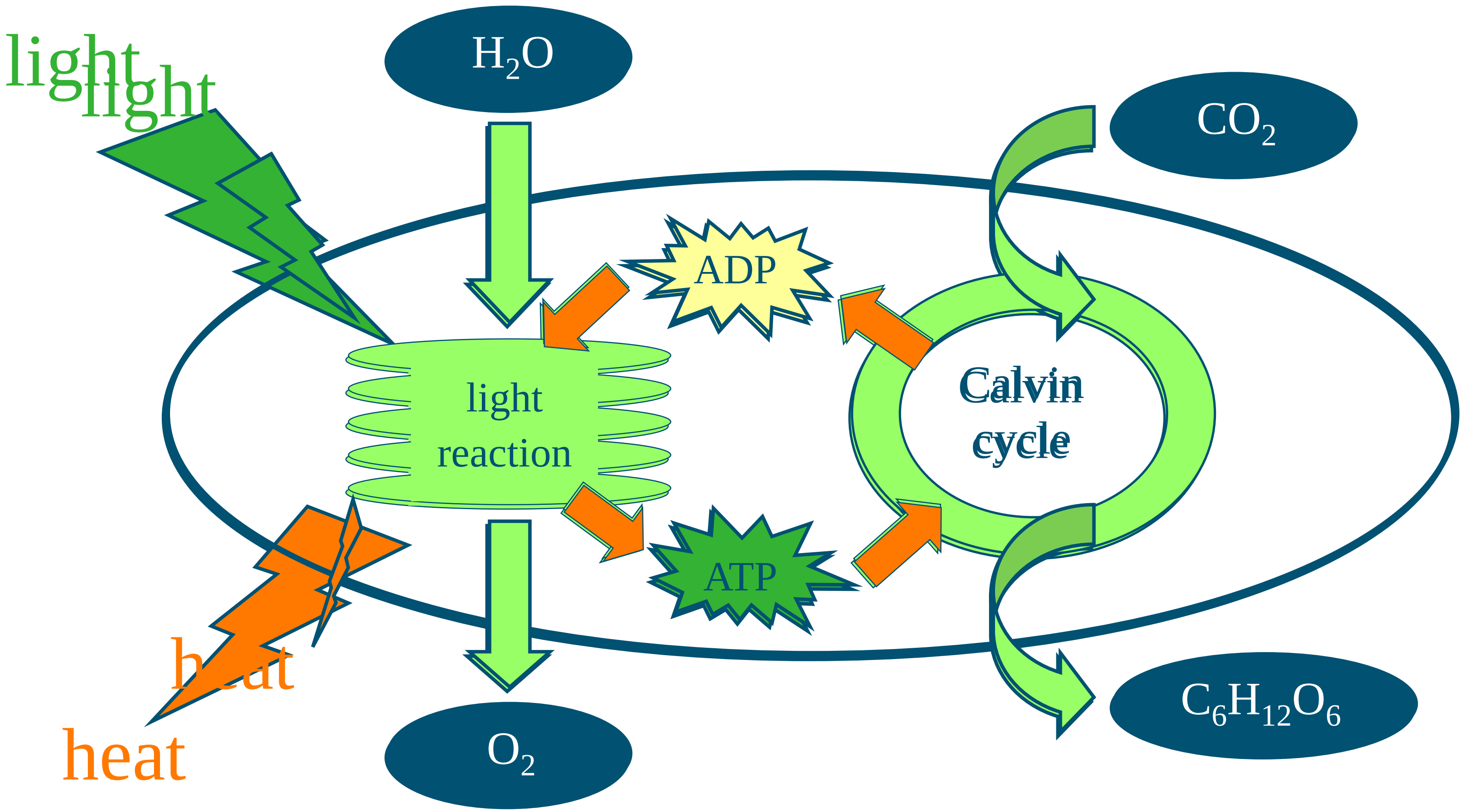
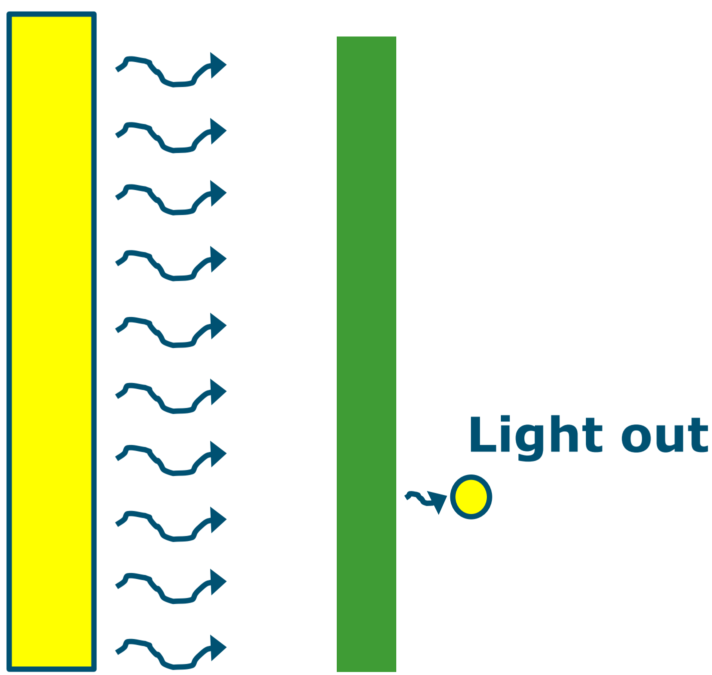
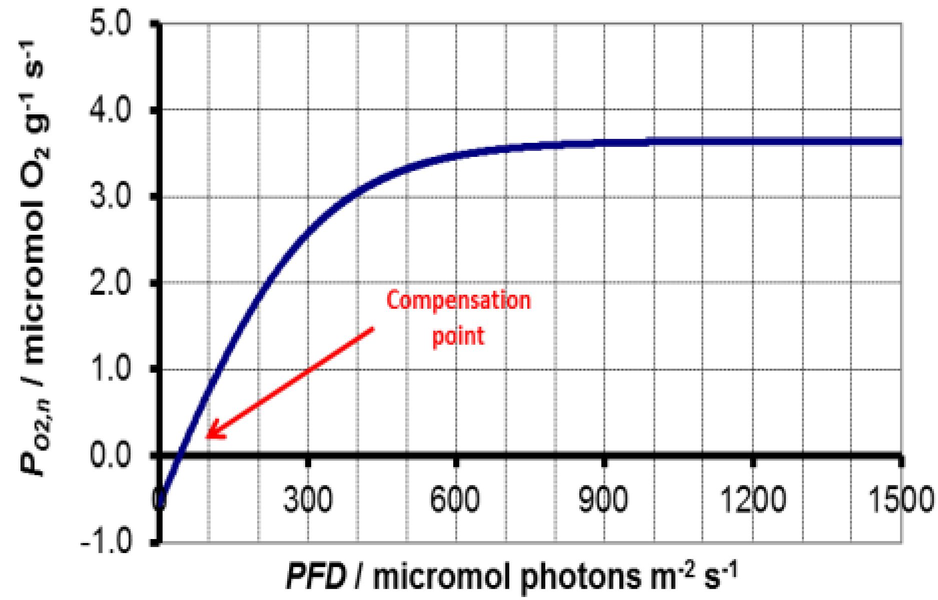
# Schematic of photosynthesis



# Luminostat control

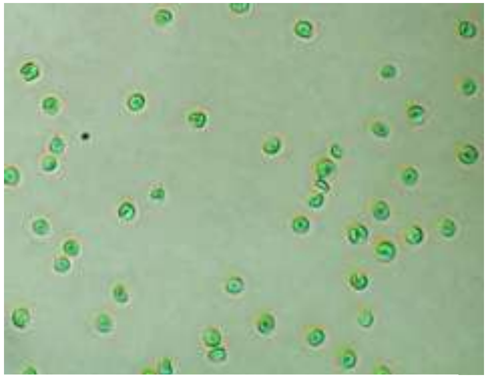
- Keeping the light at the back constant (30 $\mu$mol $m^{-2}s^{-1}$)
- Preferably light out should be the compensation point



# Strain/experimental conditions

*Chlorella sorokiniana* CCAAP 211/8K
- freshwater microalgae
- fastest growing microalgal species
- Doubling time: 2.6 hr ($\mu_{max}$ 0.27 $h^{-1}$)



*C. Sorokiana* 400 x

| Parameter | Setpoint |
|---|---|
| Temperature | 37°C |
| pH | 6.7 |
| Medium | M8-a |

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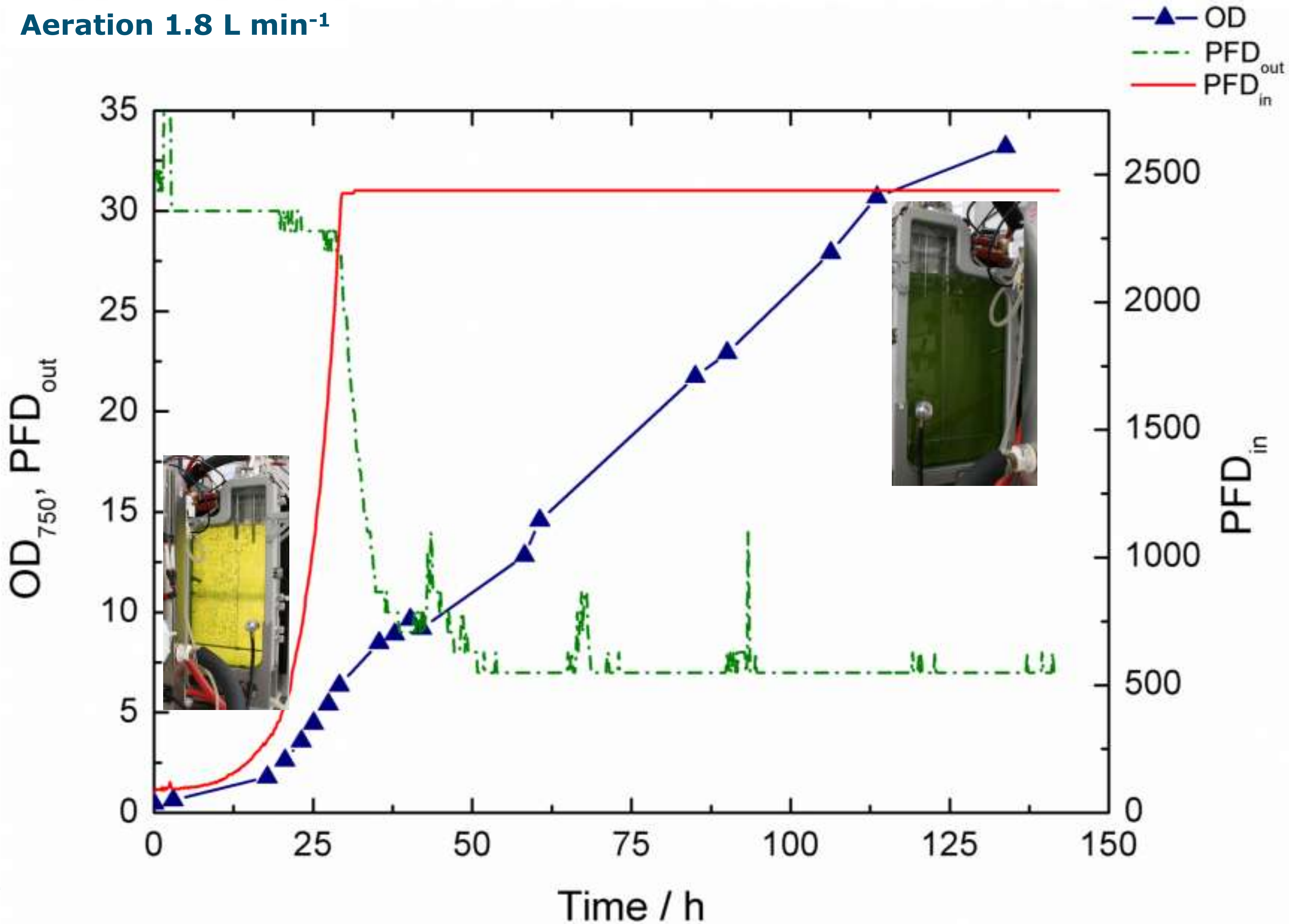
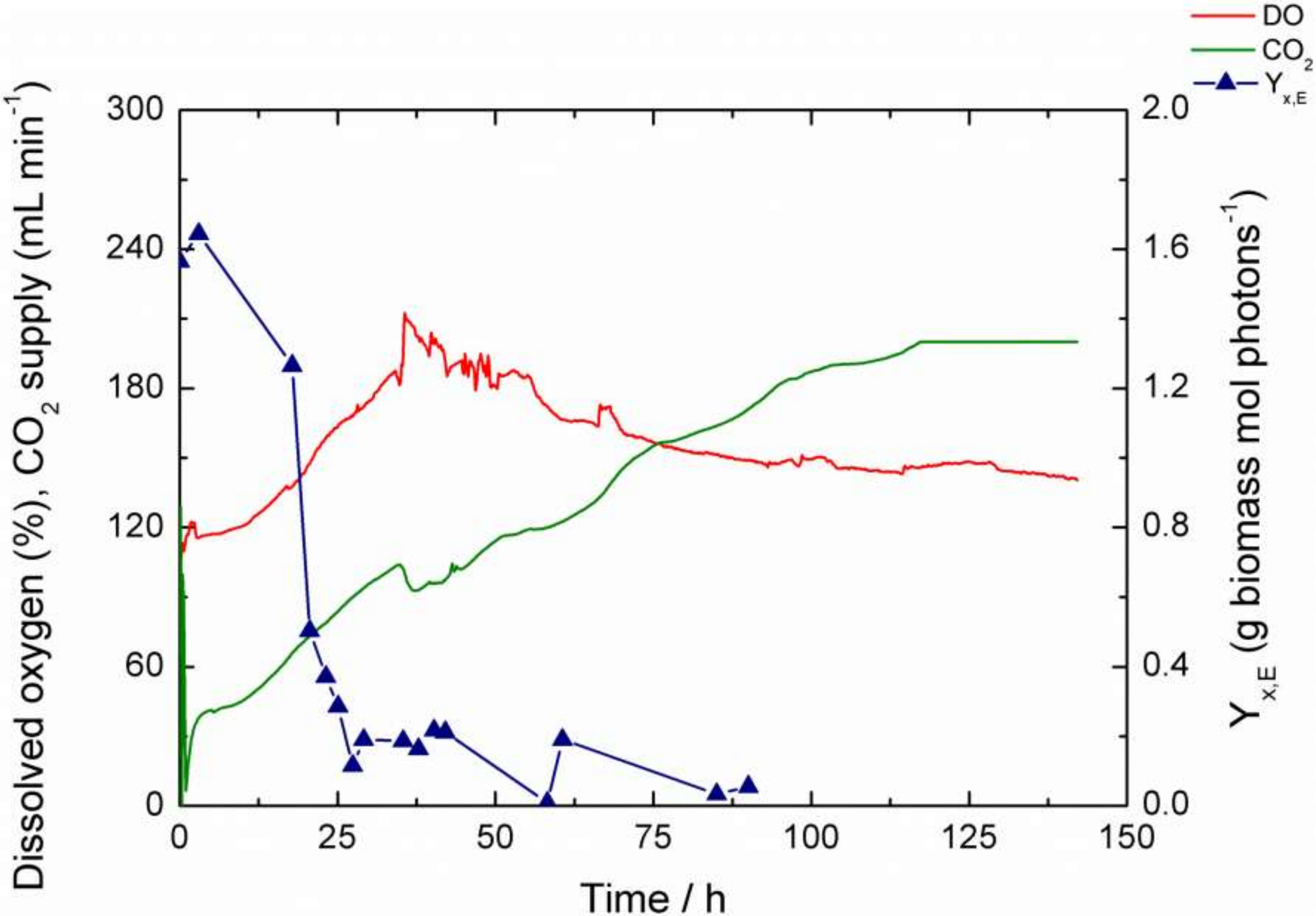
*Cuaresma, M et al. 2009. B&B **104**(2): 352-359*

# Luminostat run, E3, biomass



# Luminostat run, E3, DO build up



# Luminostat 3 runs, different Airflows

| Experiment | E1 | E2 | E3 |
|---|---|---|---|
| Airflow (L $min^{-1}$) | 1 | 1.5 | 1.8 |
| Max. Cx (g $L^{-1}$) | 9.5 | 9.5 | 11.3* |
| Reached Max Cx (h) | 210 | 110 | 120 |
| Doubling time (h) | 13.1 | 8.2 | 5.5 |
| Spec. growth rate ($h^{-1}$) | 0.053 | 0.085 | 0.126 |
| $DO_{max}$ reached (%) | 305 | 310 | 210 |

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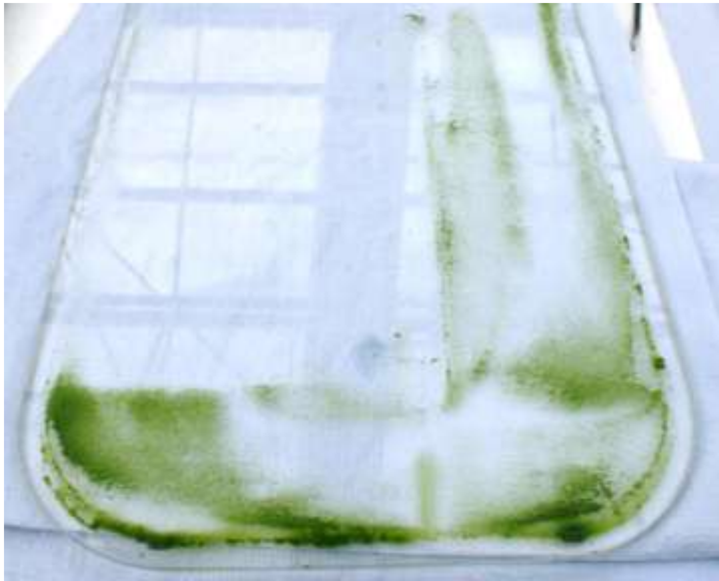
** Stopped because of lamp failure*

# Improvements

- Biofouling
  - Testing cleaning magnets
  - Extra holes could also be an option

- Reactor design
  - Baffle length
  - Ratio riser/downcomer
  - Curvature round corners

→ Computational fluid dynamics



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# Improvements

- Safety pressure release valve

- Problem, water cooling LED
  - Aluminium oxide blocks cooling circuit

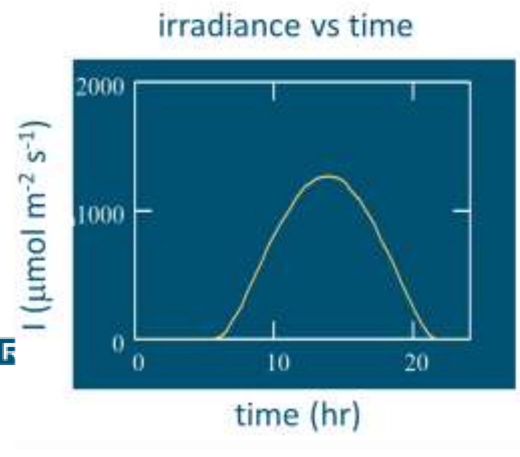
- Cooling lamp automatic off when not used
  - Prevents condensation inside panel

- LED improvement
  - Design new light sources
  - Customer awareness

# Further experiments

**Chemostat / turbidostat experiments**

- Continuous operation
- Optimize lipid productivity by nutrient stress
- Compare productivity under low and high light intensities
- Compare constant light vs. light/dark cycles
- Compare constant cycles vs. real outdoor conditions

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# AlgaePARC

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www.algaeparc.com

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