Microalgae for production of bulk chemicals and biofuels

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www.algae.wur.nl
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Biodiesel from microalgae

- **Botryococcus**
  - Alkanes (C34)
  - High concentrations (40-70%)

- **Other algae**
  - 20-60% lipids

- **High productivity**
  - Palm oil: 6,000 l/ha/year
  - Algae: 20,000-80,000 l/ha/year
  - No competition with food
  - Salt water
Feasibility study

Delta nv

Raceway ponds

Horizontal tubes

Flat panels
Tubular reactor

- Centrifuge
- Harvest tank
- Monitor and Control Unit
- Nutrient Inlet
- pH
- DO
- Stack tank
- Biomass Inlet
- pH
- Degasser
- 25% Headspace
- Solar collector
- Stack gas /CO2
- Pump
- CO2
- Solar collector
- CO2
Biomass production cost

1 ha

Labor 28%  Power 22%

10.62 € / kg biomass

100 ha

Power 42%

4.02 € / kg biomass

89% decrease

0.4 € / kg biomass
15 €/GJ

Potential

Centrifuge westfalia separator AG
Medium Feed pump
Seawater pump station
Installations costs
Buildings
Carbon dioxide
Power
Maintenance

Centrifuge Feed Pump
Medium preparation tank
Automatic Weighing Station with Silos
Instrumentation and control
Polyethylene tubes Photobioreactor
Media Filters
Labor
General plant overheads

Medium Filter Unit
Harvest broth storage tank
Culture circulation pump
Piping
Culture medium
Air filters
Payroll charges
Conclusions Delta report: economical viability

- Power input is the main constrain in photobioreactors
- Sensitivity analysis show that biomass production costs can be further decreased from 4 to 0.4 €/kg
- Parameters that need improvement
  - Mixing system / efficiency
  - Photosynthetic efficiency
    - reactor design
    - cultivation conditions
    - strain improvement / screening
  - Integrate processes
- Positive energy balance still needs to be reached
Economical Viability: Process integration and valorisation

Bulk chemicals and biofuels in 1,000 kg microalgae

- 400 kg lipids
  - 100 kg as feedstock chemical industry (2 €/kg lipids)
  - 300 kg as transport fuel (0.50 €/kg lipids)
- 500 kg proteins
  - 100 kg for food (5 €/kg protein)
  - 400 kg for feed (0.75 €/kg protein)
- 100 kg polysaccharides
  - 1 €/kg polysaccharides
- 70 kg of N removed
  - 2 €/kg nitrogen
- 1,600 kg oxygen produced
  - 0.16 €/kg oxygen
- Production costs: 0.40 €/kg biomass
- Value: 1.65 €/kg biomass
Research programs

- Photosynthetic Cell Factories (NWO)
- Solar-H and Solar-H2, SUNBIOPATH (EU)
- Sealand Sole (Min. Agriculture, province Sealand, companies)
- SUNLIGHT (University of Ghent)
- CO₂ fixation (TNO)
- Reactor design (Proviron, University Huelva, Wetsus)
- AlgiCoat (Akzo, Ingrepro, Essent)
- Wetsus (17 companies)
- AlgaePARC (15 companies)
Wageningen research agenda

- Control of primary metabolism
- Photobioreactor design
- $O_2$ removal and $CO_2$ supply
- Biofilms for post-treatment wastewater
- Harvesting and Oil extraction
- Biorefinery
- Design scenarios
- AlgaePARC
Control primary metabolism
– Annette Kliphuis, Anne Klok, Packo Lamers

- Research reactor to apply wide range of cultivation conditions
- On-line monitoring of production and consumption rates (CO₂, O₂, N, biomass)
- Metabolic network model and flux calculations to predict rates in primary metabolism
- Objective: control metabolism
Photobioreactor design

Maria Cuaresma, Lenneke de Winter, Jan-Willem Zijffers, Rouke Bosma, Niels Henrik Norsker, Carsten Vejrazka

- Translate laboratory experiments to practice, study daily variations:
  - day to day changes in light
  - day/night changes in light
  - Temperature

- Development of control strategies:
  - Mixing
  - Biomass density - harvesting
O₂ removal and CO₂ supply

Claudia de Sousa, Ana Santos, Sayam Raso, Michiel Michels

- High Oxygen partial pressure inhibits photosynthesis
  - Maximal tolerable O₂ partial pressure
  - Strains more resistant to O₂
  - Develop new technology to remove O₂

- Energy efficient CO₂ supply
  - Conditions: high pH, high salt
  - Selection of lipid accumulating strains
Biofilms for post-treatment wastewater – *Nadine Boelee, Kanjana Tuantet*

- biomass is easier to harvest
- no suspended matter in effluent
- low energy requirement (no mixing)
- vertical placement is possible (giving higher photosynthetic efficiency due to light dilution)
Harvesting and oil extraction

Sina Salim, Dorinde Kleinegris

- Reduction of cost & energy demands
  - No additional chemicals
  - Ensure medium reuse

- Bio- & auto-flocculation
  - Microalgae with high lipid content
  - Characterization of algae
  - Mechanistic study
  - Kinetics of harvesting

- Milking of microalgae
Isolation of pure and native protein from microalgae for food applications

Characterization and fractionation of the isolated protein

Test techno-functional properties of isolated protein fractions and its possible applications as a food ingredient
Objective
- Develop scenarios for production of energy carriers at very large scale

Why
- Logistics: complexity and energy use of supply of materials

Research issues
- Which scale is most economic? 1-10-100-…>10,000 ha?
- Logistics of a large scale facility are very complex
- Energy
- Mixing, degassing, CO₂ supply, harvesting, materials
- Industrialized areas, desert, floating, local
- Day/night/summer/winter
- Storage
AlgaePARC: Algae Production and Research Center

- Development of a process chain
- Experience with systems
- Information for design of full scale plants
- Comparison of systems
- Comparison of strains
- Comparison of feeds (nutrients, CO$_2$, sunlight…)
- Supply of biomass for further processing
- Further processing
AlgaePARC

- Research plan
- 4 outdoor systems of 25 m² each
  - Open pond: reference
  - Horizontal tubular system: high light intensity, oxygen accumulation
  - Vertical tubular system: low light intensity, oxygen accumulation
  - Flat panel system: low light intensity, no oxygen accumulation
- 4-8 systems of 2.5 m²
- Specific requirements: extra systems
2.5 m² systems

- Phase between lab and pilot
- Test things where you are not sure of
- Different strains
- Different feed stocks
- Adaptations in design
- New systems
- If successful
  - To 25 m² scale
- If not successful
  - More experiments
  - Reject
Conclusions

- Microalgae are promising for production of bulk chemicals and biofuels
- Microalgal technology is immature
- Development of technology requires large research programs
- Combination with biorefinery important
- Join forces
Collaborative research programs

- **Wetsus**
  - AF&F, Dow Chemicals, Delta, Eneco Energie, Essent, Friesland Campina, De Alg (Hednesford), Hubert, Ingrepro, Neste Oil, Liandon (Nuon), Rosendaal Energy, STOWA, Syngenta, Unilever

- **AlgaePARC**
  - LOI of 15 companies, Ministry of Agriculture, Biosolar program, province of Gelderland

- **Biorefinery**
  - Combination of end users (for the different biomass fractions) and technology suppliers
Program coordinators:

- Marcel Janssen: photobioreactors and CO$_2$ transfer
- Marian Vermue: harvesting, biorefinery and O$_2$ effects
- Dirk Martens: metabolic flux modelling
- Maria Barbosa: AlgaePARC