Design Scenarios for Large Scale Micro-Algae Production

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Microalgae

- Photosynthetic cell factories
- Promising for the production of
  - Omega fatty acids
  - Pigments
  - Pharmaceuticals
  - Feed/Food
  - Chemicals
  - Biofuels
Systems analysis and design scenarios

- Reach economical and sustainable production process
  - Integrate production process and production chain
  - Make efficient use of environment of algae plant

- Design scenarios
  - Quantify effect of different system designs, location, algae species
  - Identify critical points in algae cultivation
  - Specify development directions

LCA and TE are important assessment tools

- Analyse economic feasibility and sustainability
- Outcomes vary between different studies
  - Analysis border
  - System design
How realistic are the outcomes?

- Often not performed for outdoor conditions
- Large uncertainties in assumptions
- Lack specific information on e.g. daily production cycles

- Additional steps needed to analyse system under local conditions
  - Location
  - System design
  - Algae species

Predictive model for biomass production has been developed

1. Insight in dynamics of algae and their needs during the day/year
2. Effect of algae species
3. Quantify the effect of location and design variables
4. Determine settings for peak biomass production
Model overview

Reactor design

Location (Climate conditions, elevation sun)

Light regime

Water temperature

Biomass production

Light regime

1. Quantify the light falling on reactor wall
   Reactor geometry, reflection, alteration diffuse light

2. Quantify light regime in reactor volume
   \[ I(y, z, t) = I_{surf}(t) \times \exp(-K_aC_x(t)z) \]
Water temperature

- Dynamic water temperature for open ponds

\[ V_w \rho_w C_{pw} \frac{dT}{dt} = Q_{irradiance} - Q_{absorption} - Q_{evaporation} - Q_{convection} - Q_{conduction} - Q_{radiation} \]

Biomass production

- Growth as function of light and temperature

\[ \mu(y, z, t) = \mu(l(y, z, t)) \ast f(T) \]

- Based on pl-curves (Geider, 1997)

\[ \mu(y, z, t) = \frac{P_c}{m} \left( 1 - \exp \left( -\frac{aF(y, z, t)O(z, t)}{P_c/m} \right) \right) - r_m \]

- Based on equation by Blanchard, 1996.

\[ f(T) = \left( \frac{T_{let} - T_w}{T_{let} - T_{opt}} \right)^\beta \exp(-\beta \left( \frac{T_{let} - T_w}{T_{let} - T_{opt}} - 1 \right) \]
Biomass production

Based on equation by Blanchard, 1996.

\[ f(T) = \left( \frac{T_{let} - T_W}{T_{let} - T_{opt}} \right) ^ \beta \exp(-\beta \left( \frac{T_{let} - T_W}{T_{let} - T_{opt}} - 1 \right) \right) \]

Results

Based on measured meteorological data
Daily fluctuations in production

Summer day in the Netherlands

- Biomass
- Carbon dioxide
- Nitric acid
- Water
- Phosphoric acid
- Oxygen

Production rate (g/min) vs. Day time (hours)

Effect temperature on growth (Netherlands)

- During day light and temperature limit growth
- During night temperature has a beneficial effect -> reduced maintenance
Production in 30 cm deep pond (*P. tricornutum*)

![Graph showing daily and monthly biomass productivity for *P. tricornutum* in the Netherlands.]

Production with dynamic temperature

<table>
<thead>
<tr>
<th><em>P. tricornutum</em></th>
<th>Source</th>
<th>Average prod. (ton ha(^{-1}) year(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Netherlands 52 °N</td>
<td>Model</td>
<td>41.5</td>
</tr>
<tr>
<td>Algeria 22.8 °N</td>
<td>Model</td>
<td>63.7</td>
</tr>
</tbody>
</table>
Production with dynamic temperature

<table>
<thead>
<tr>
<th>Algae Species</th>
<th>Source</th>
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</tr>
</thead>
<tbody>
<tr>
<td>P. tricornutum</td>
<td>Slegers et al, 2011 Model</td>
<td>41.5</td>
</tr>
<tr>
<td><strong>Alaska</strong></td>
<td><strong>32.5°N</strong></td>
<td><strong>63.7</strong></td>
</tr>
<tr>
<td><strong>England</strong></td>
<td><strong>50-54°N</strong></td>
<td><strong>29.0</strong></td>
</tr>
<tr>
<td><strong>California</strong></td>
<td><strong>40°N</strong></td>
<td><strong>80.0</strong></td>
</tr>
</tbody>
</table>

Algae species affect potential productivity
Achieving yearly peak production
using a constant biomass concentration during the year

Conclusions

- We are able to predict year round biomass production
  - Dynamic sun light input
  - Dynamic water temperature
  - Design parameters and location

- Effect of design and decisions are visible

- Model is a good basis for further LCA and TE analysis
Production in 30 cm deep pond (*P. tricornutum*)

**Netherlands**

**Algeria**