Predictive modelling of large scale algal biomass production

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Need for fuels from renewable resources

- EU directive (2020):
  - 20% renewable energy
  - 10% biofuels

Country		Share of renewable energy 2005	Share of renewable energy 2020
AT	Austria	23.3	34.0
BE	Belgium	2.2	13.0
BG	Bulgaria	9.4	16.0
CY	Cyprus	2.9	13.0
CZ	Czech Republic	6.1	13.0
DE	Germany	5.8	18.0
DK	Denmark	17.0	30.0
EE	Estonia	18.0	25.0
EL	Greece	6.9	18.0
ES	Spain	8.7	20.0
FI	Finland	28.5	38.0
FR	France	18.3	23.0
HU	Hungary	4.3	13.0
IE	Ireland	3.1	16.0
IT	Italy	5.2	17.0
LT	Lithuania	15.0	23.0
LU	Luxembourg	0.9	11.0
LV	Latvia	34.9	42.0
MT	Malta	0.0	10.0
NL	Netherlands	2.4	14.0
PL	Poland	7.2	15.0
PT	Portugal	20.5	31.0
RO	Romania	17.8	24.0
SE	Sweden	39.8	49.0
SI	Slovenia	16.0	25.0
SK	Slovakia	6.7	14.0
UK	United Kingdom	1.3	15.0
EU-27	**EU 27**	**8.5**	**20.0**

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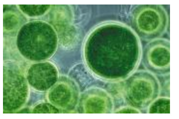
Algae as source for biodiesel



- Algae are promising
  - Photosynthetic cell factories
  - High lipid contents & productivity
- Challenge: make it economically feasible & sustainable

Techno-economic studies use generic information

Used estimates:
50-110 ton ha^{-1} yr^{-1} in ponds*
40-80 ton ha^{-1} yr^{-1} in closed systems**

- How realistic?
  - Often not performed under outdoor conditions
  - Large uncertainties in assumptions
  - Lack specific information on e.g. daily production cycles and location

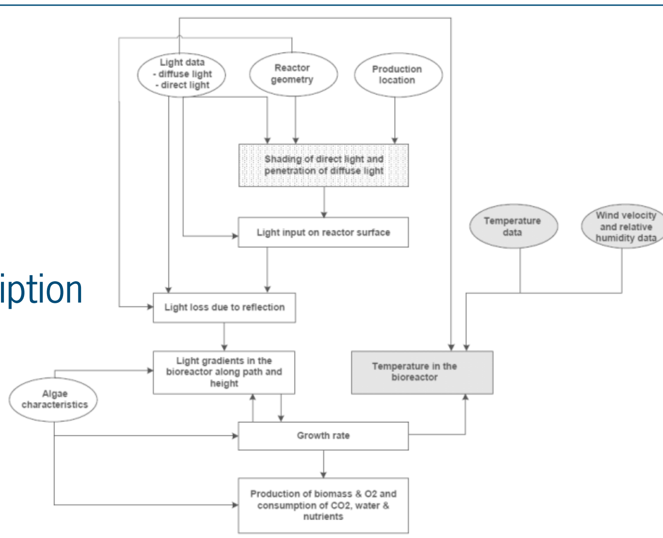
*Campbell *et al.* (2011), Bioresource Technology
**Wijffels *et al.* (2010), Biofuel Bioprod Bioref:4(3);287

Focus of this presentation

- Predictive model for biomass production has been developed
  - Open ponds
  - Flat panel reactors

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

- Model description



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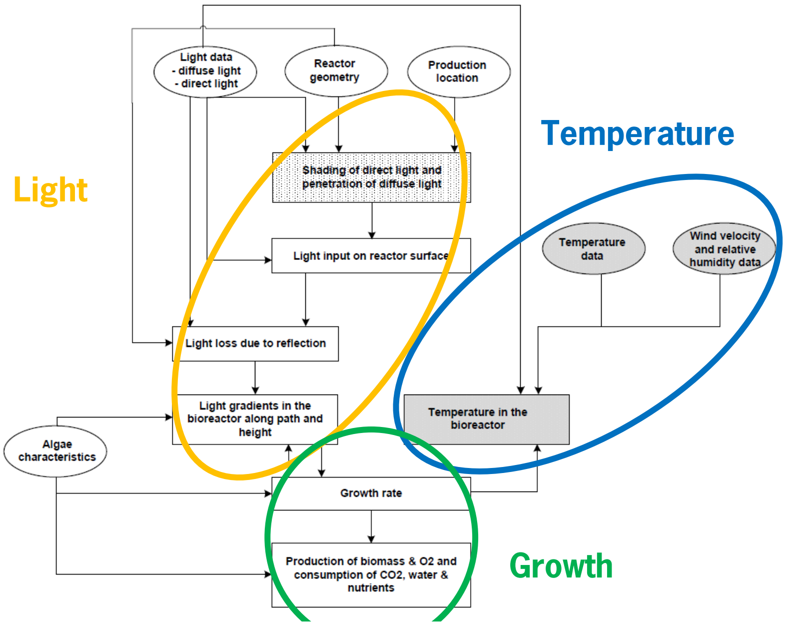
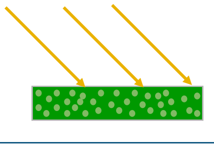
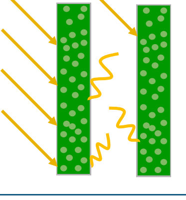
Model structure

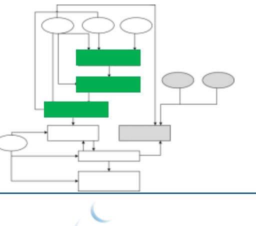


1. Quantifying the light falling on reactor wall

$$I_{surf}(t) = f(I_{sun}(t), design\ variables, dayhour)$$
$$I_{sun}(t) = f(location, weather)$$

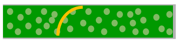


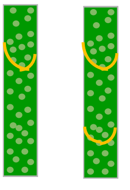


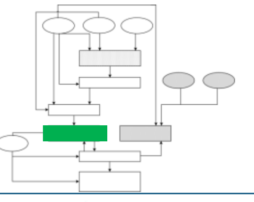


2. Light gradient in reactor volume

$$I(y,z,t) = I_{surf}(t) * \exp(-\mathrm{K_a C_x(t) z})$$





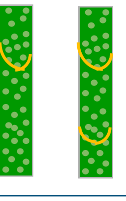


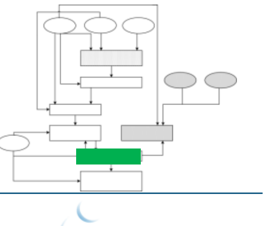
3. Algae growth according to local light gradient

Optimal growth temperature

$$\mu(y,z,t) = f(\mathrm{I(y,z,t)}, algae\ characteristics) - \mathrm{r_m}$$

Based on pl-curves (Geider, 1997)





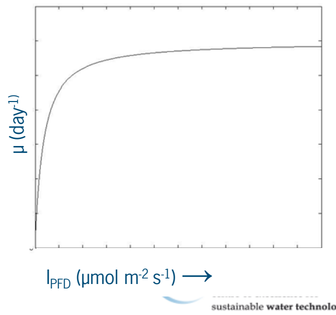
3. Algae growth according to local light gradient

Optimal growth temperature

$$\mu(y,z,t) = f(\mathrm{I(y,z,t)}, algae\ characteristics) - \mathrm{r_m}$$

Based on pI-curves (Geider, 1997)

$$\mu(y,z,t) = P_m^c\left(1 - \exp\left(\frac{-\alpha I_{PFD}(y,z,t)\Theta(z,t)}{P_m^c}\right)\right)$$



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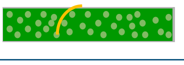
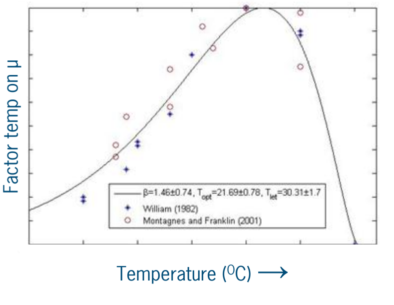
3. Algae growth according to local light gradient and water temperature

Based on pI-curves (Geider, 1997) & Blanchard, 1996.

$$\mu(y,z,t) = \mu(I(y,z,t) * f(T)$$

$$f_T = \left(\frac{T_{let} - T_w}{T_{let} - T_{opt}}\right)^{\beta} \exp(-\beta\left(\frac{T_{let} - T_w}{T_{let} - T_{opt}} - 1\right)$$





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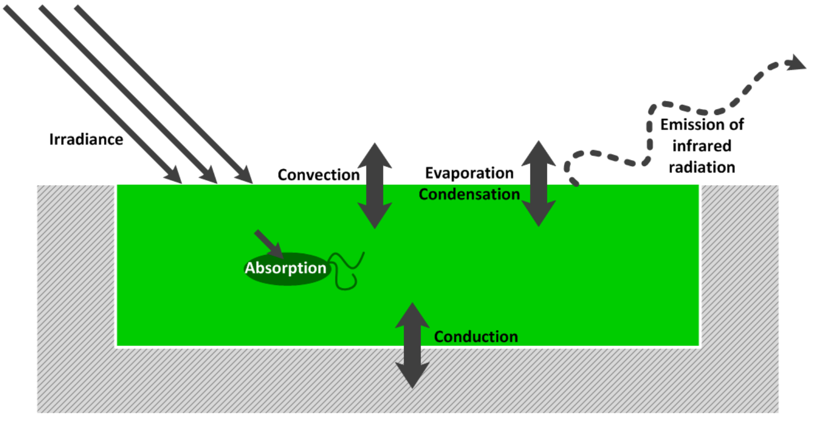
Fluxes influencing water temperature

$$V_w \rho_w C p_w \frac{dT}{dt} = Q_{irradiance} - Q_{absorption} - Q_{evaporation} - Q_{convection} - Q_{conduction} - Q_{radiation}$$



- Results

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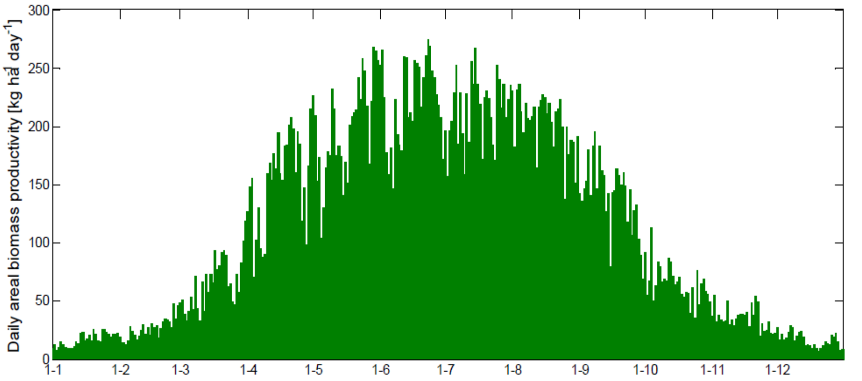
Production in Netherlands



- *P. tricornutum*
- 30 cm deep pond – dynamic temperature

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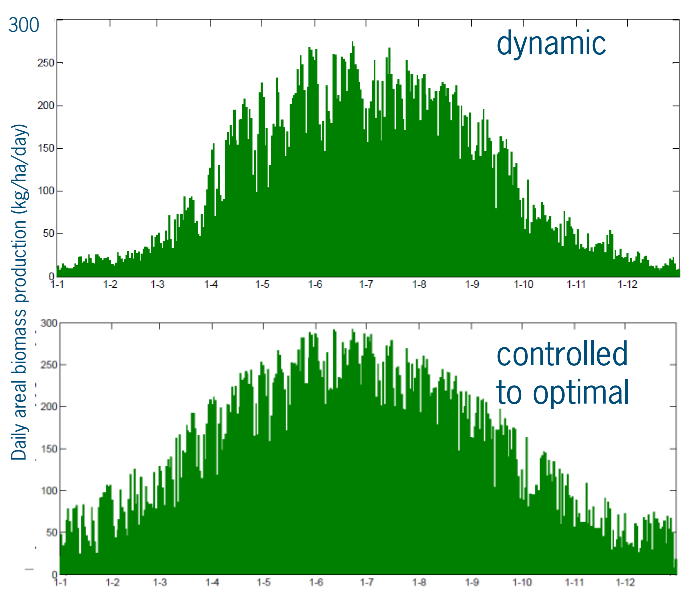
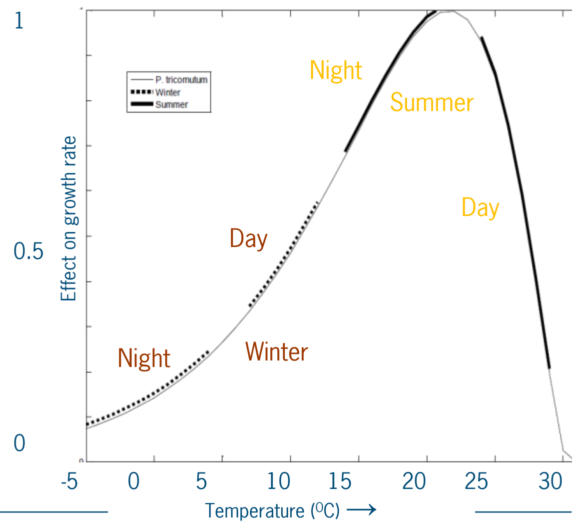
Effect of dynamic water temperature



Effect temperature on growth

- During day light and temperature limit growth
- During night temperature has a beneficial effect -> reduced maintenance



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Production with dynamic temperature

P. tricornutum	Source	Average prod. (ton ha^{-1} year^{-1})
Netherlands 52 °N	Model	41.5
Algeria 22.8 °N	Model	63.7

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Production with dynamic temperature

P. tricornutum	Source	Average prod. (ton ha^{-1} year^{-1})
Netherlands 52 °N	Model	41.5
Algeria 22.8 °N	Model	63.7
England 50-54°N	Ansell, 1963 (40cm deep)	29.0
California 32.5°N	Thomas, 1984 (temp. controlled)	80.0

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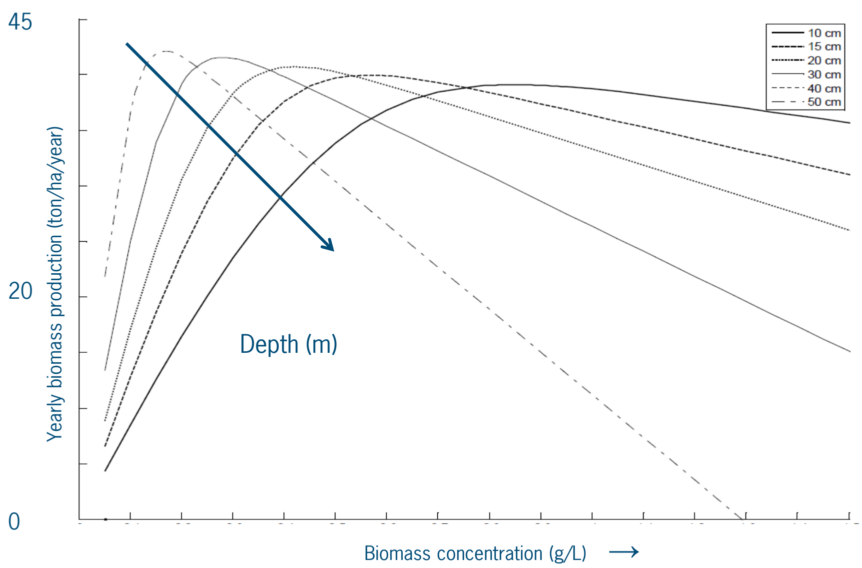
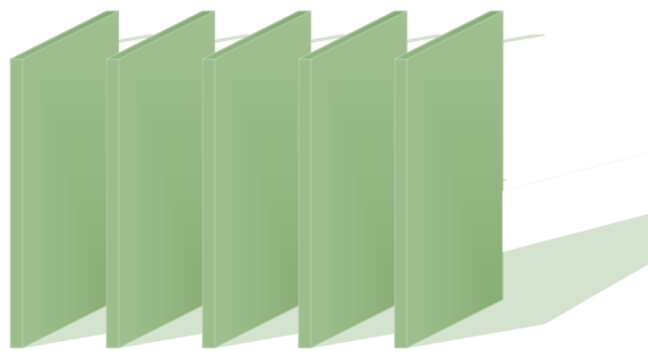
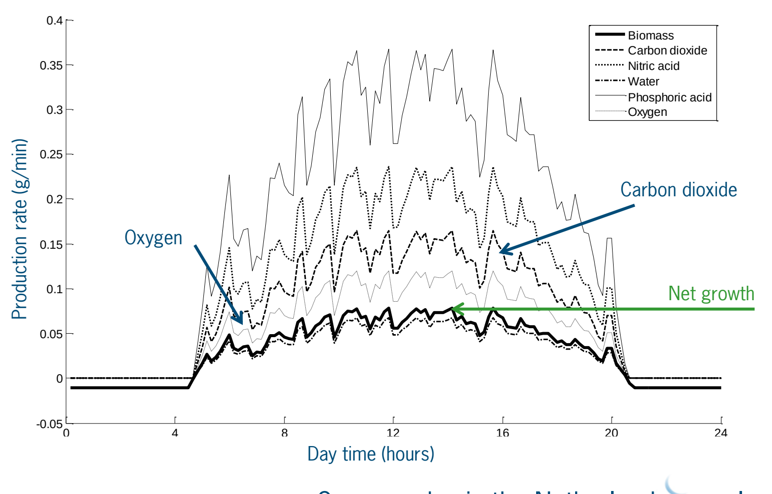
Achieving yearly peak production using a constant biomass concentration (during the year)



- Results



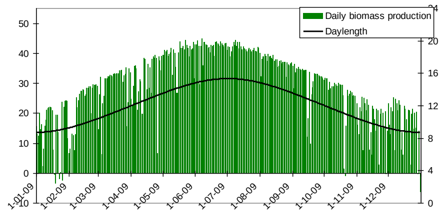
Daily production fluctuations are linked with nutrient consumption & oxygen production



Summer day in the Netherlands, panels of 1*1*0.03 m

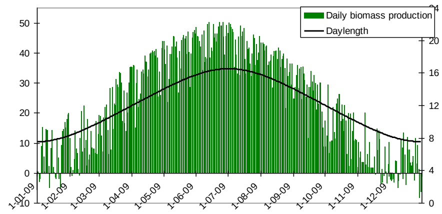
Predicted daily biomass production for one year

France



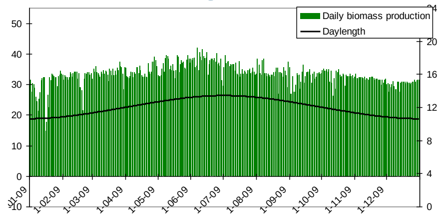
Netherlands

Daily areal biomass production (kg/m2/day)



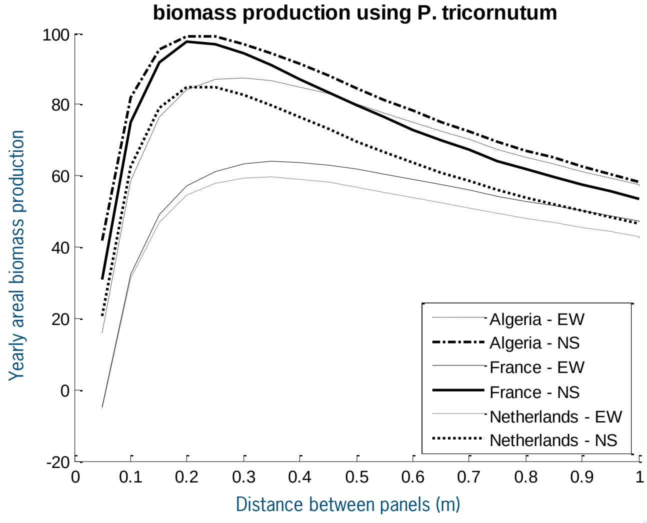
1 Jan. 31 Dec.

Algeria



Effect panel distance and orientation

Effect of panel distance on areal yearly biomass production using P. tricornutum



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Conclusions

- We are able to predict year round biomass production
  - Dynamic sun light input (incl. shading)
  - Dynamic water temperature
  - Design parameters and location
- More insight on influence decision variables: better opportunities for higher productivities
- Model is a good basis for further LCA and TE analysis

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Questions?

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