



Presentation at ReWater

Braunschweig, November 7th 2013

Nutrient Recycling from Wastewater in Algae-to-Energy Systems

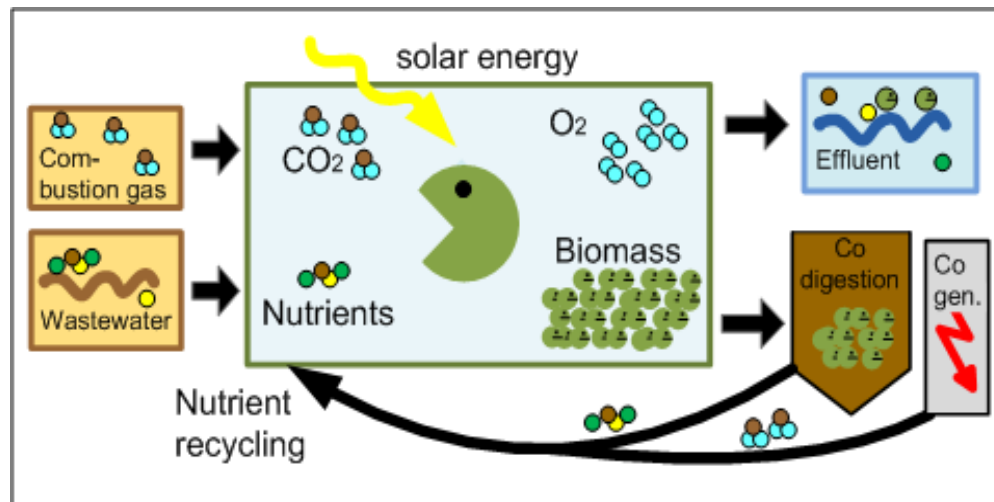
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Introduction

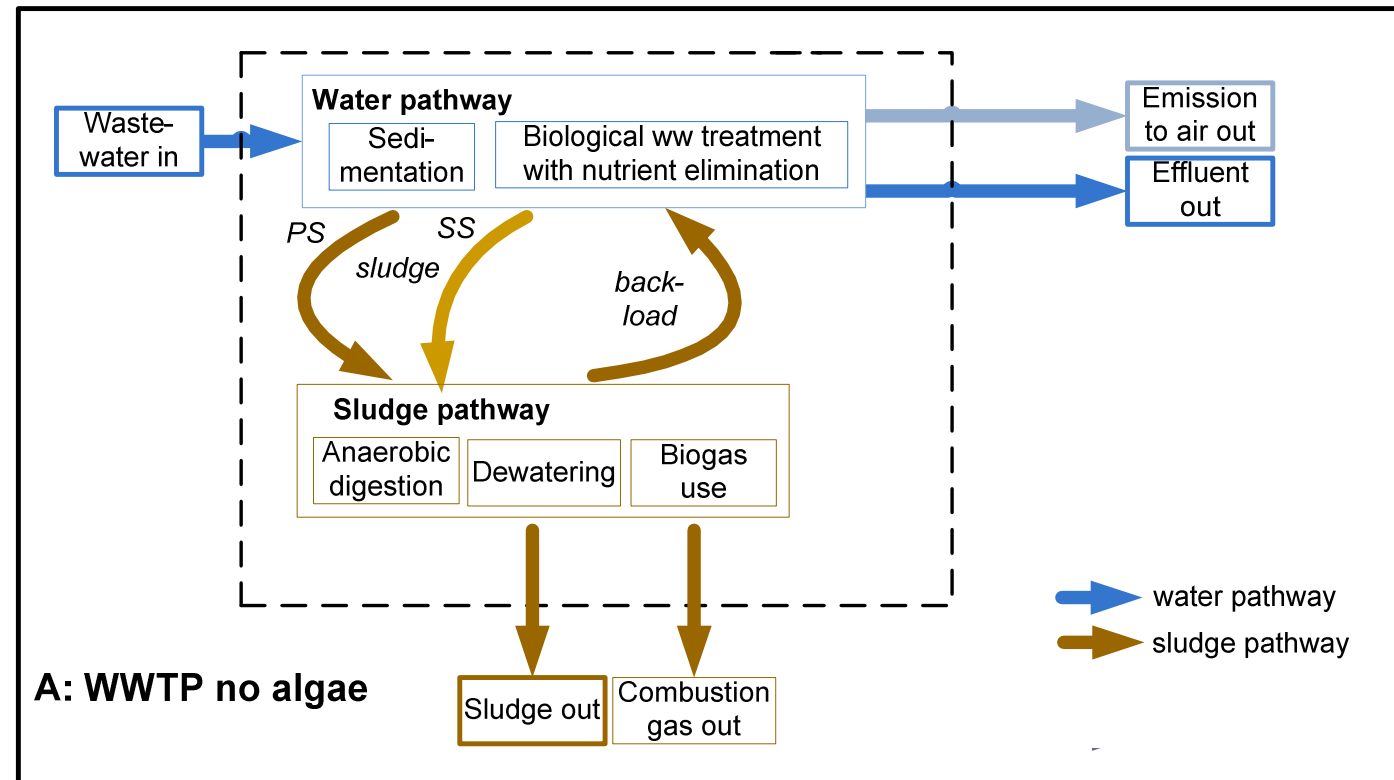
- Algae systems for reuse of CNP from wastewater → **bioenergy**
- Ponds or photobioreactors
- High areal productivity (> energy crops)
- High demand for nutrients per unit biomass (esp. N)
- Biomass generation in “closed” system → no emission of AMPs
- Potentially increased elimination of AMPs from effluent → transfer to biomass



Lundquist
2011

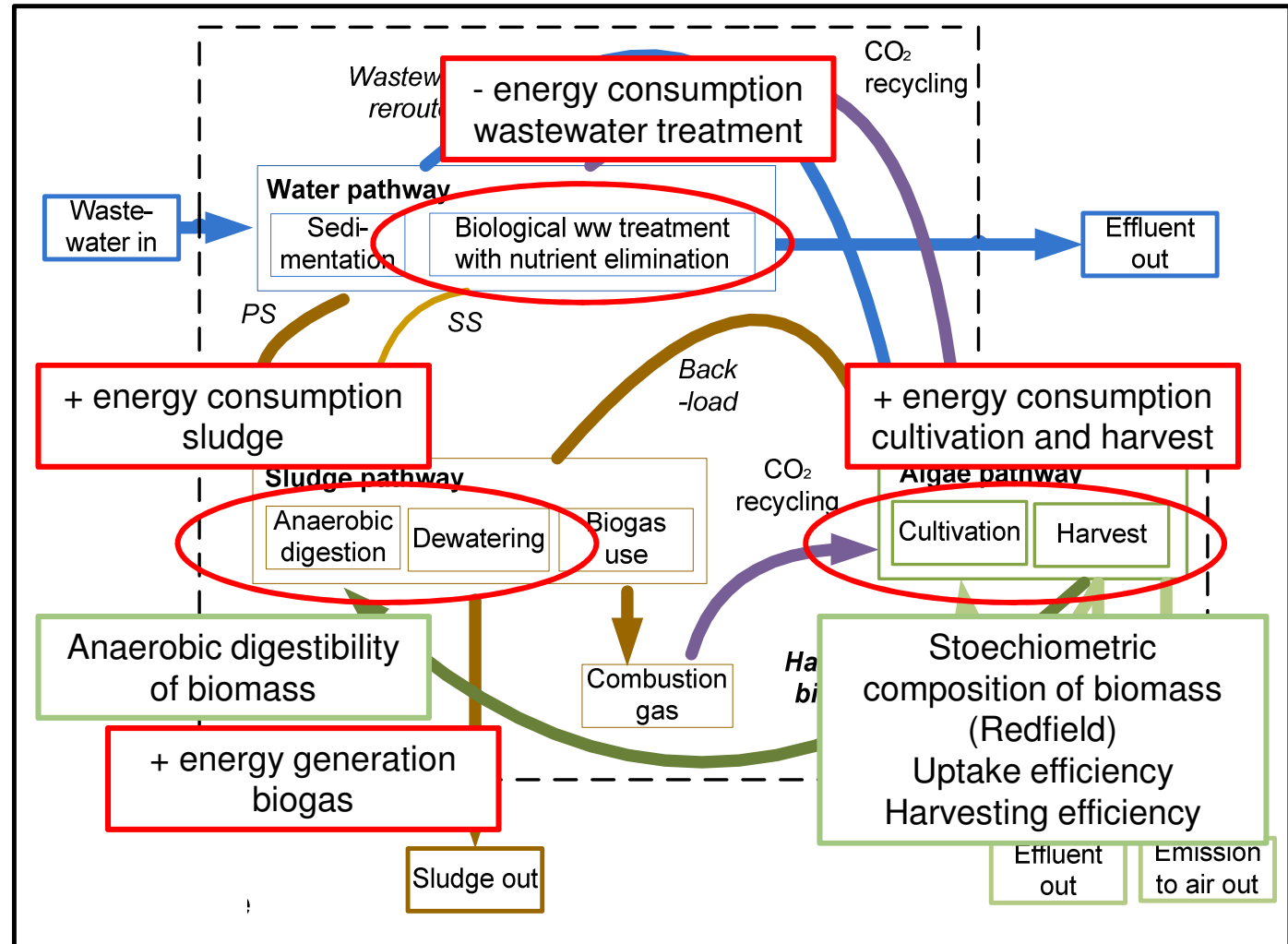
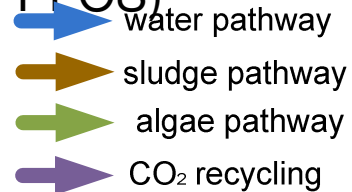
Technical setup

- Proposed process design for integration of algae systems at MWWTP → no external input
- SFA: Δ loads to different steps → Δ energy and emission balance (fate of CNP and PFOS)

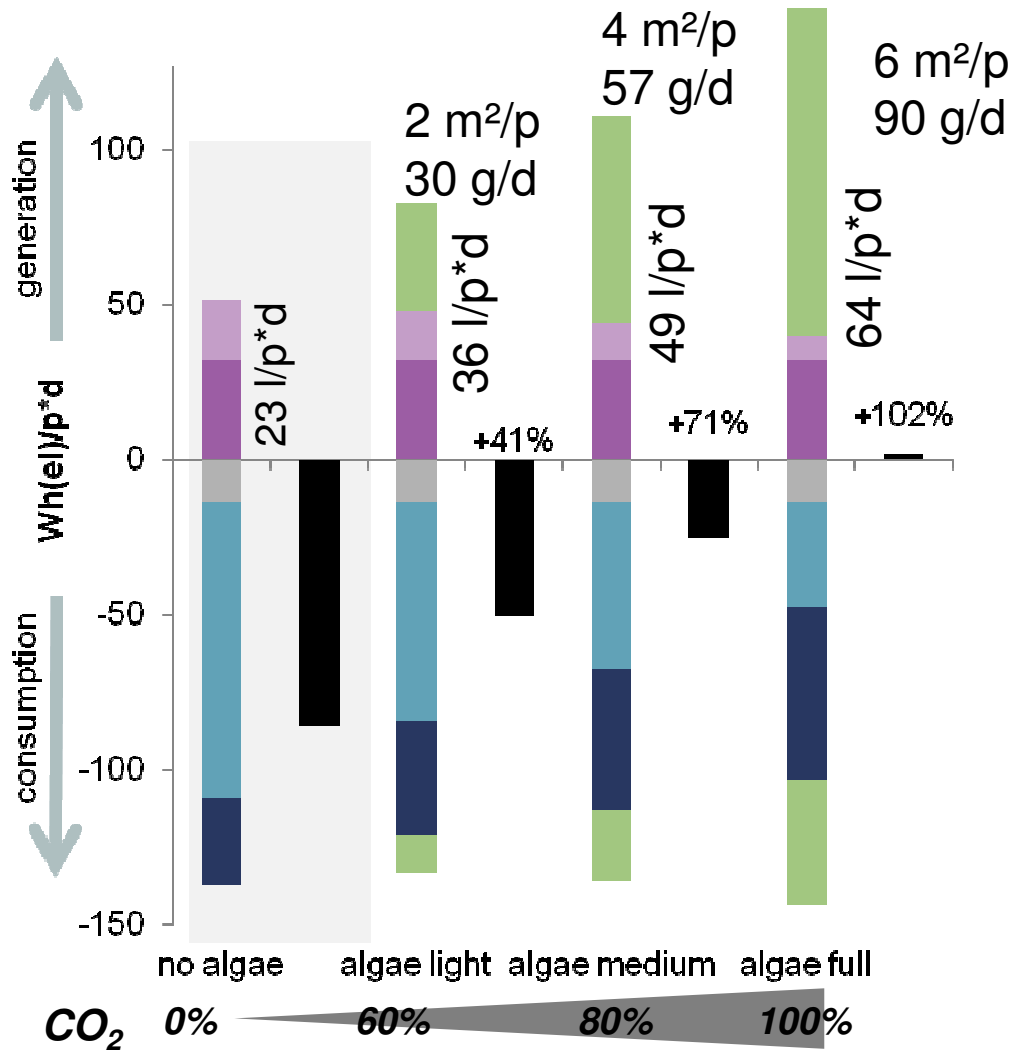


Technical setup

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Energy balance



Additional energy generation from biogas from algae biomass

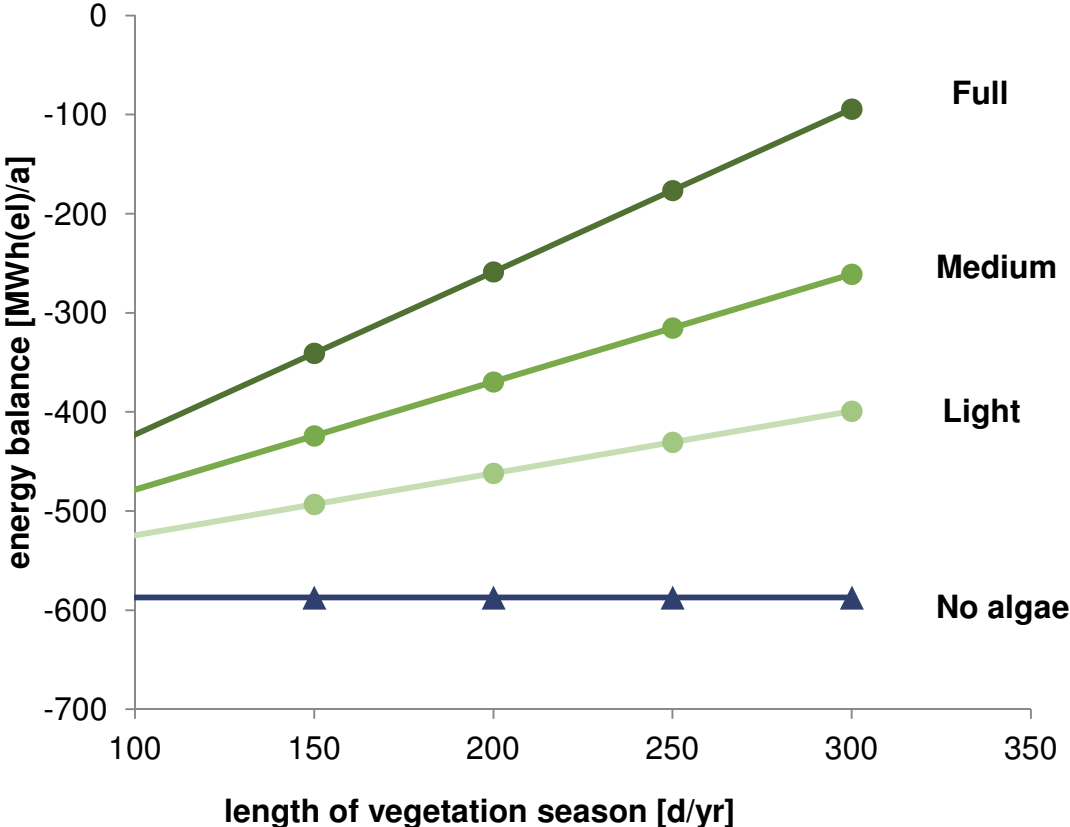
Reduced energy consumption for wastewater treatment

Additional energy consumption for sludge handling

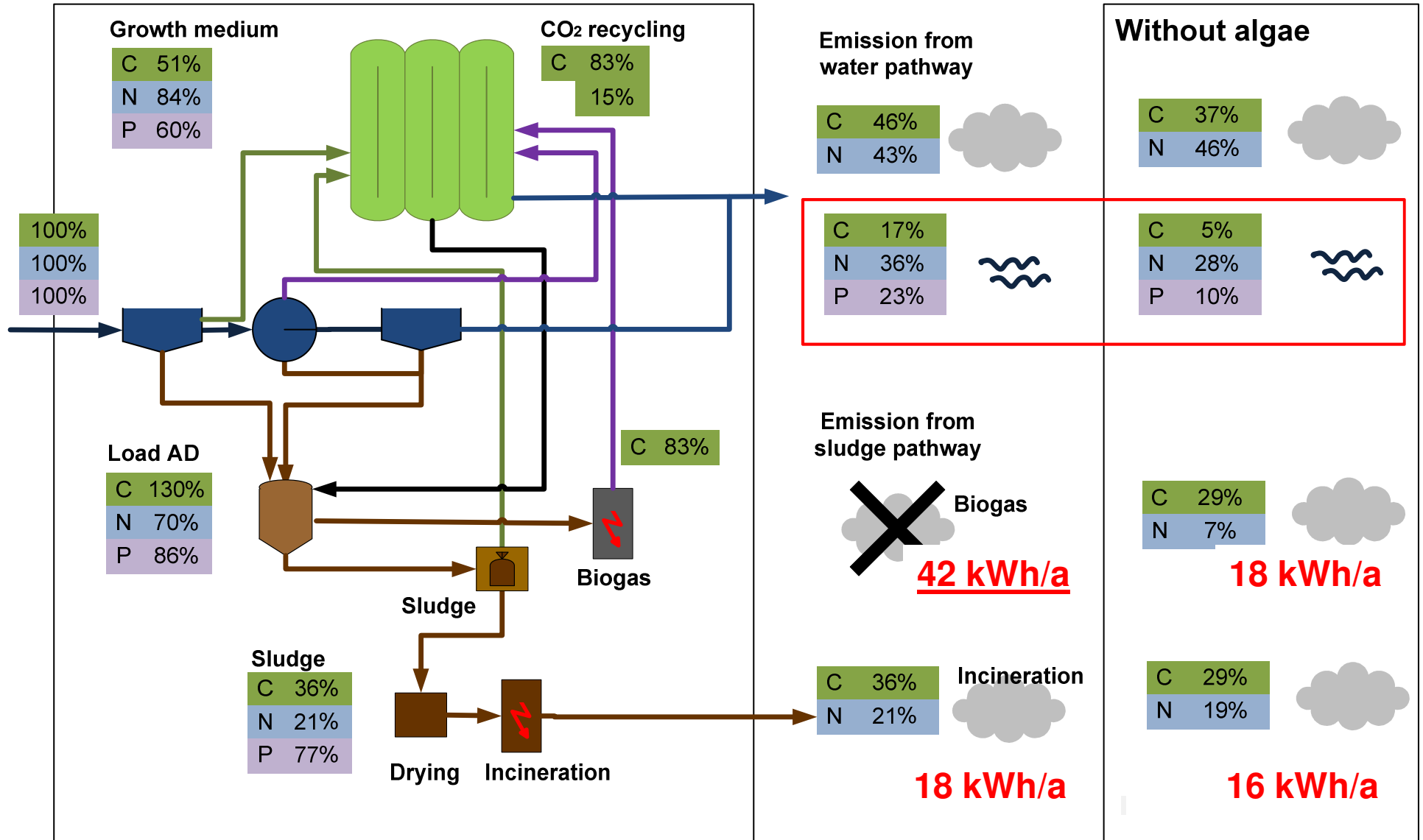
Additional energy consumption for algae cultivation and harvest

Energy balance

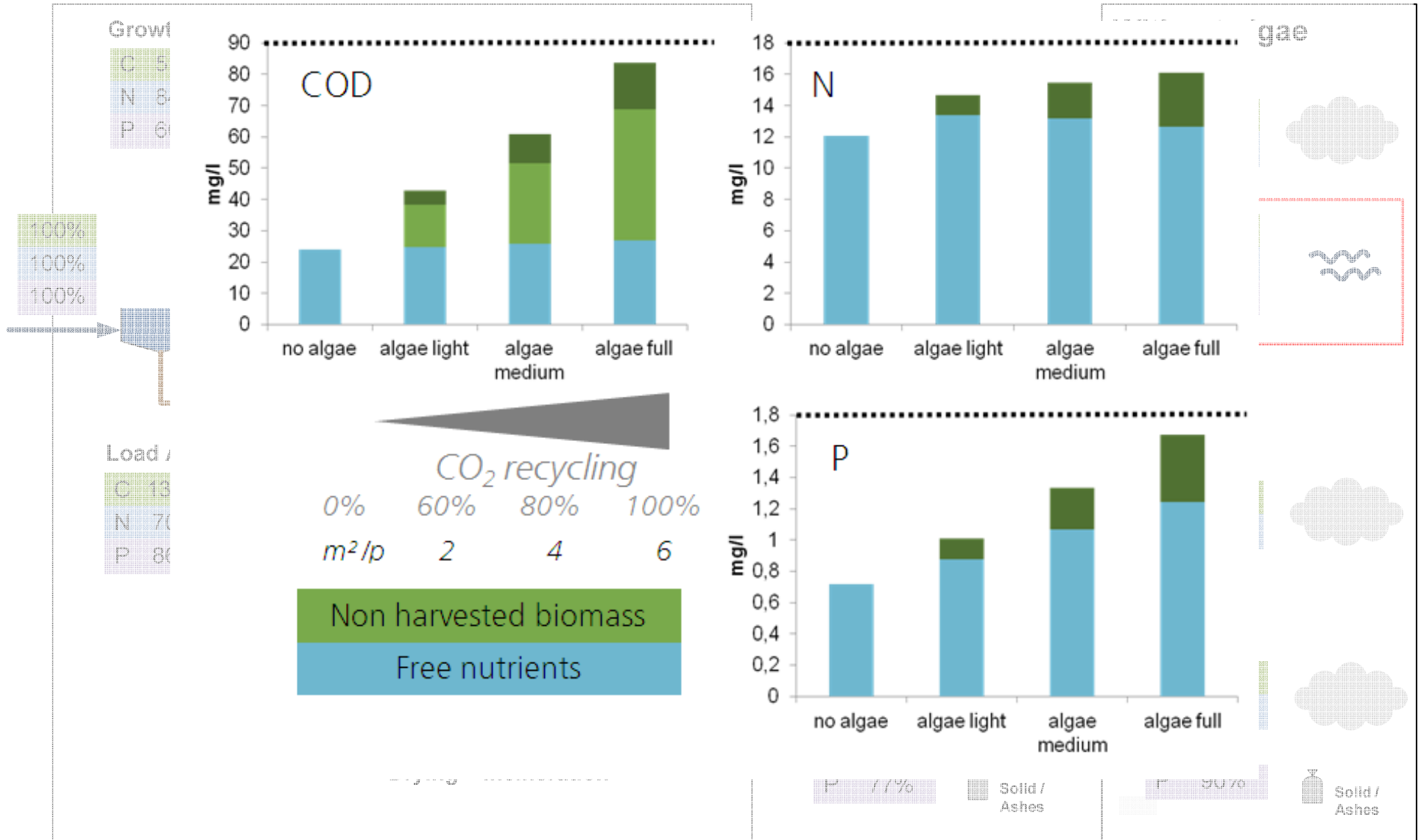
- On an annual base, energy balance depends on length of growing season



SFA

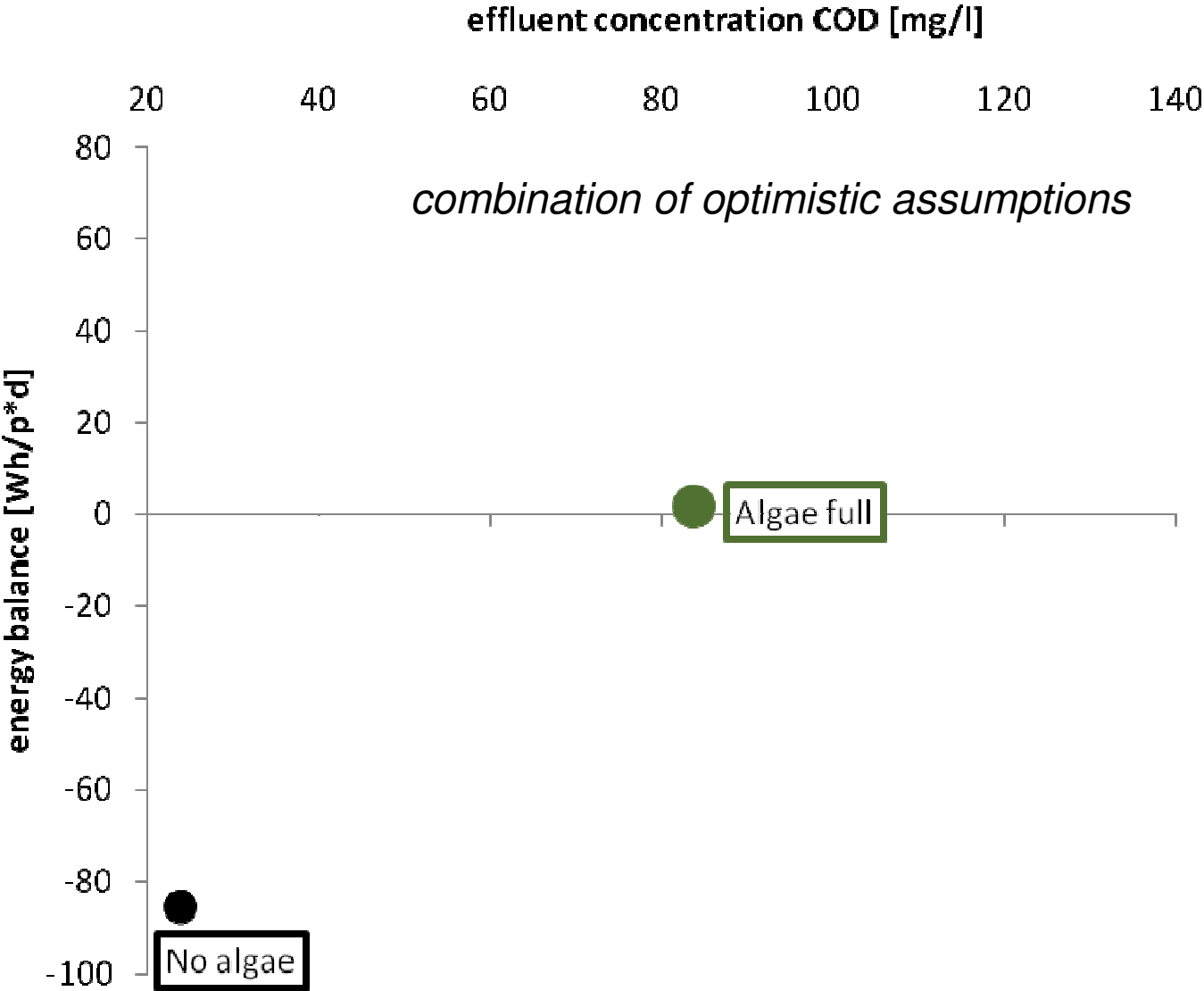


SFA



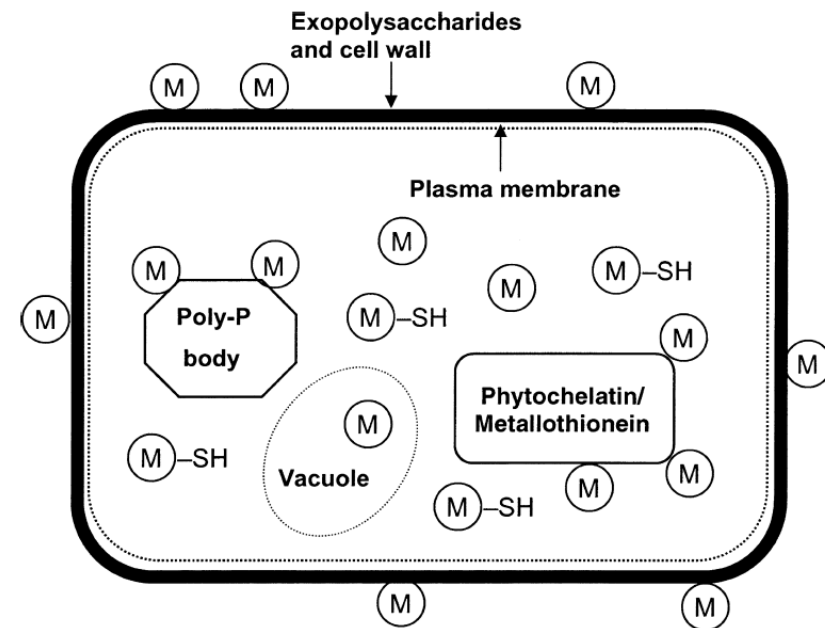
Key parameter

- Harvesting efficiency $88 \pm 10\%$
/Post treatment 66% removal
- > Anaerobic digestibility $70 \pm 10\%$
- > Energy demand algae $70 \text{ kWh/ha} \cdot \text{d} \pm 25\%$
/Productivity $18\text{-}25 \text{ g/m}^2 \cdot \text{d}$

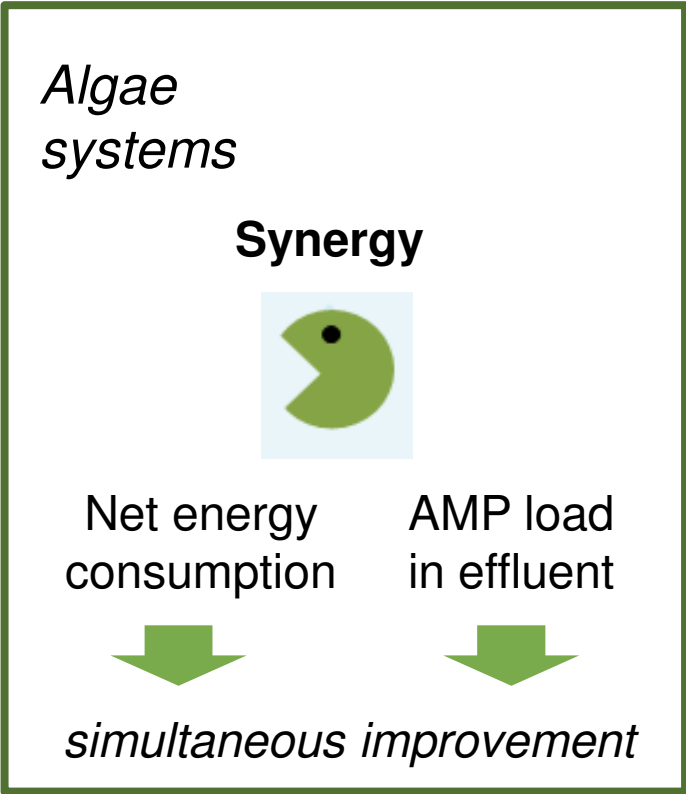
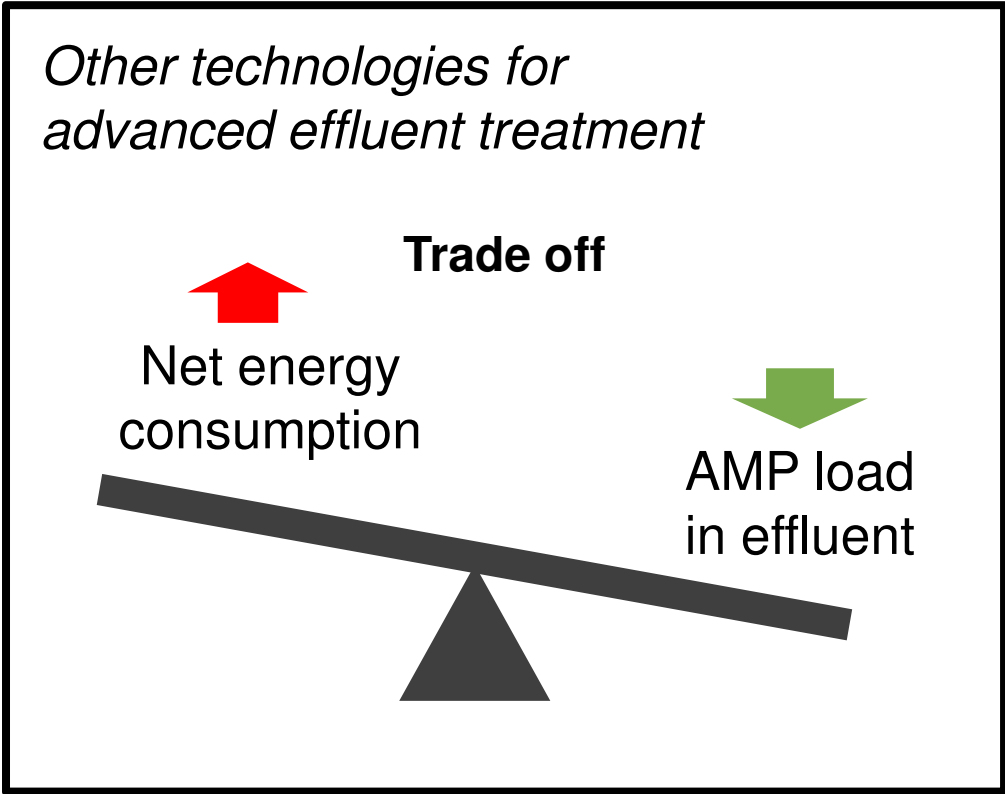


Anthropogenic micropollutants

- Anthropogenic micropollutants (AMPs) e.g. impregnation agents, biocides, pharmaceuticals or heavy metals
- Estimate: 100 -1000 different AMPs in effluent (concentrations in the ng to µg range - 10-50% of the C load; Schlupe *et al.* 2006)
- Wastewater → chemical “cocktail” as mirror of society
- Introduction of 4th treatment stage discussed
- Algae can increase the elimination rate of many AMPs (cross substance effect)
 - long retention time (~3 days)
 - large active surface for sorption and assimilation
- Double function of area dedicated to algae systems: bioenergy + AMP elimination
- Solution for smaller WWTPs



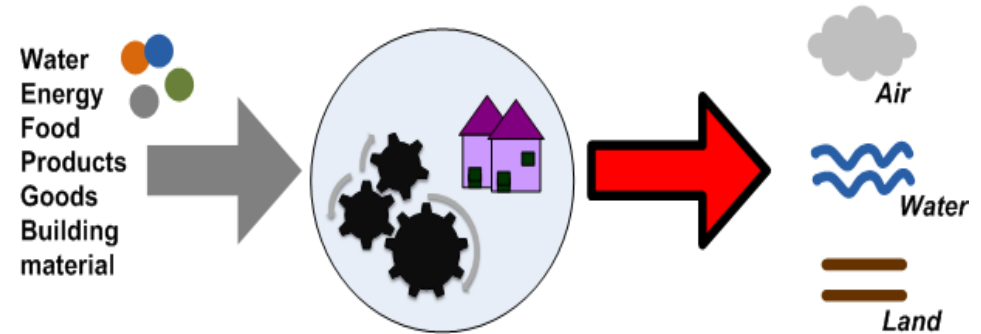
Anthropogenic micropollutants



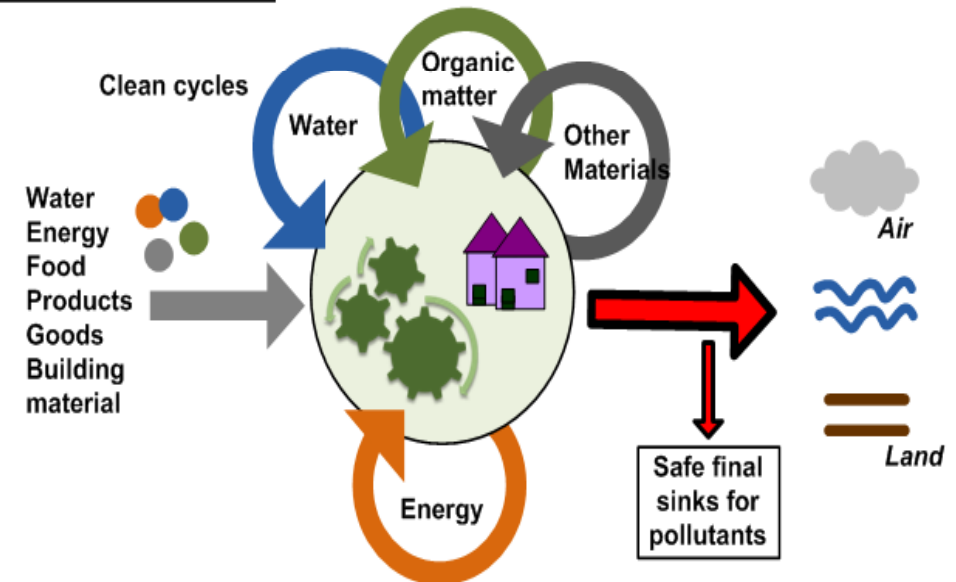
Conclusion

- Today: mainly **linear** system
 - function depends on resource availability and
 - capacity of hinterland to absorb *waste*
- Future: **circular** metabolism mirroring natural ecosystems
- The urban water and wastewater infrastructures are an important part of the urban metabolism
- Algae systems can increase the metabolic efficiency while reducing the emission of AMPs
→ **clean cycles**


Linear urban metabolism




Circular urban metabolism



Conclusion

Restructuring
energy systems 

Reusing nutrients
C N P

Mitigating the chemical
pollution problem 



Important for cities today → further increase of importance in the future

Strong drivers for algae systems



Clean cycles in algae systems provide no full solution for any of these challenges
→ but can play an important role in all of them



Thank You for Your Attention

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Table 1. Summary of SFA Results for the WWTP without and with MAS (PTW: Primary Treated Wastewater)

| | no algae | algae light | algae medium | algae full |
|--|----------|-------------|--------------|------------|
| Microalgae Systems (MAS) | | | | |
| harvested biomass [g/p·d] | | 30 | 57 | 90 |
| area needed (cultivation) [m ²] | | 1,9 | 3,6 | 5,7 |
| PTW diverted to MAS [%] | | 11 | 32 | 57 |
| Biological Wastewater Treatment (BWT) | | | | |
| loading of C [% of incoming] | 73 | 60 | 46 | 29 |
| loading of N [% of incoming] | 110 | 81 | 62 | 39 |
| loading of P [% of incoming] | 100 | 80 | 61 | 39 |
| Anaerobic Digestion (AD) | | | | |
| loading of C [% of incoming] | 65 | 87 | 107 | 131 |
| biogas produced- total [l/p·d] | 23 | 36 | 49 | 64 |
| contribution of harvested biomass [%] | | 42 | 60 | 73 |

Table 2. Emission Balance: Emission to Water, To Air and in Sludge for the WWTP without and with MAS

| | no algae | algae light | algae medium | algae full |
|---|----------|-------------|--------------|------------|
| Water | | | | |
| elimination efficiency C/COD [%] | 95 | 91 | 87 | 83 |
| elimination efficiency N [%] | 72 | 67 | 66 | 65 |
| elimination efficiency P [%] | 90 | 86 | 81 | 78 |
| Sludge | | | | |
| total stabilized sludge [g/p-d] | 60 | 64 | 66 | 69 |
| additional sludge [%] | | 7 | 10 | 14 |
| load of C in sludge [% of incoming] | 29 | 31 | 33 | 36 |
| Air | | | | |
| load of C to air [% of incoming] | 66 | 59 | 54 | 46 |
| CO ₂ emission on site (renewable) [g/p-d] | 93 | 84 | 76 | 66 |
| CO ₂ intensity of bioelectricity production [kg/kWh] | 1.8 | 1.0 | 0.7 | 0.5 |

Challenges for Algae Systems

- **Large area demand**
 - General problem of bioenergy systems
 - Area demand for algae reported lower than for other energy crops
 - Ecological design with other plants integrated
- **Smell**
 - adapt culture conditions, cover of cultivation area
- Production of **algae toxins** during growth
 - adapt culture conditions, apply post treatment
- **Growing season** too short due to cold climate
 - wastewater, sludge water and combustion gas have relatively high temperatures that can prolong growing season
- No **know how**, new business area
 - Information, pilots, technical guidance documents

Challenges for Algae Systems

- Low **Reliability / Robustness** of process
- Low growth rates due to changes in wastewater composition or **inhibitory substances** in wastewater
- Algae do not reach assumed efficiencies
 - for nutrient uptake
 - for AMP elimination
 - for areal productivity
- **Harvesting efficiency** low, high energy use
- **Anaerobic digestibility** low → too much sludge and too little biogas
- Problems with **conditioning of sludge** (dewatering, drying)
- adapt culture conditions
- **Extensive infrastructures** required (growth medium, CO₂, ponds, covers, harvesting) with high ecologic burdens and cost
- lean design, short distances