Growth of Microalgae for Biofuel Production on High Strength Wastewater

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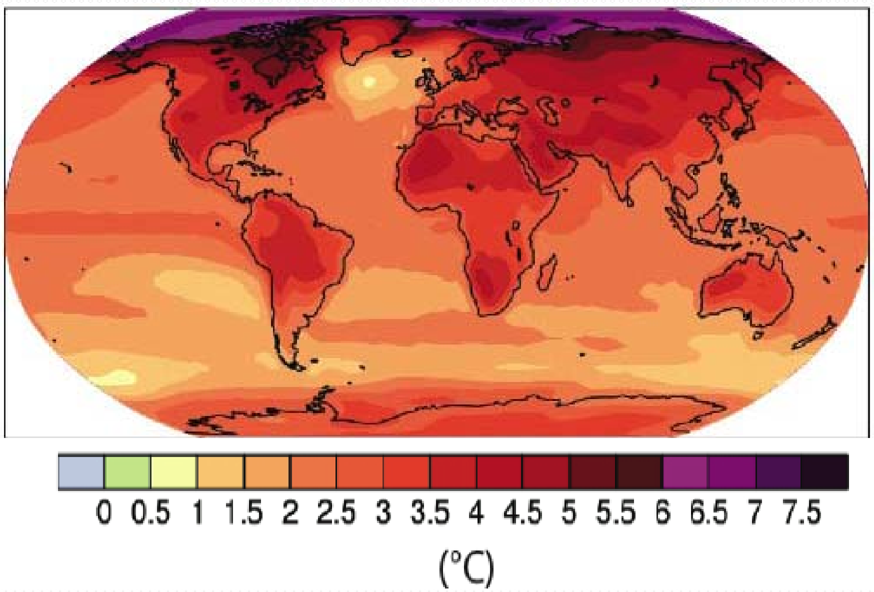
Concerns about climate change

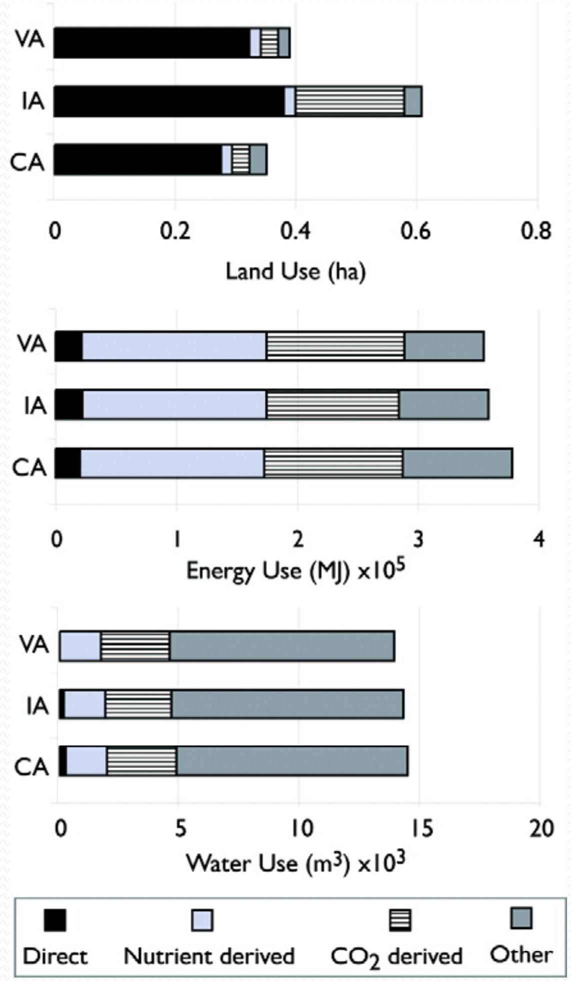
2090's medium Emission Scenario: IPCC, 2007



- Methods proposed for reducing GHGs:
  - Reforestation
  - Increased use of renewable and nuclear energy,
  - Carbon Capture & Storage
  - Increased use of biofuels
    - Corn, sorghum, sugar cane, sugar beets
    - Switch grass, woody biomass
    - Soy, sunflower, palm oil
    - Algae – oil, biogas, other fuels.

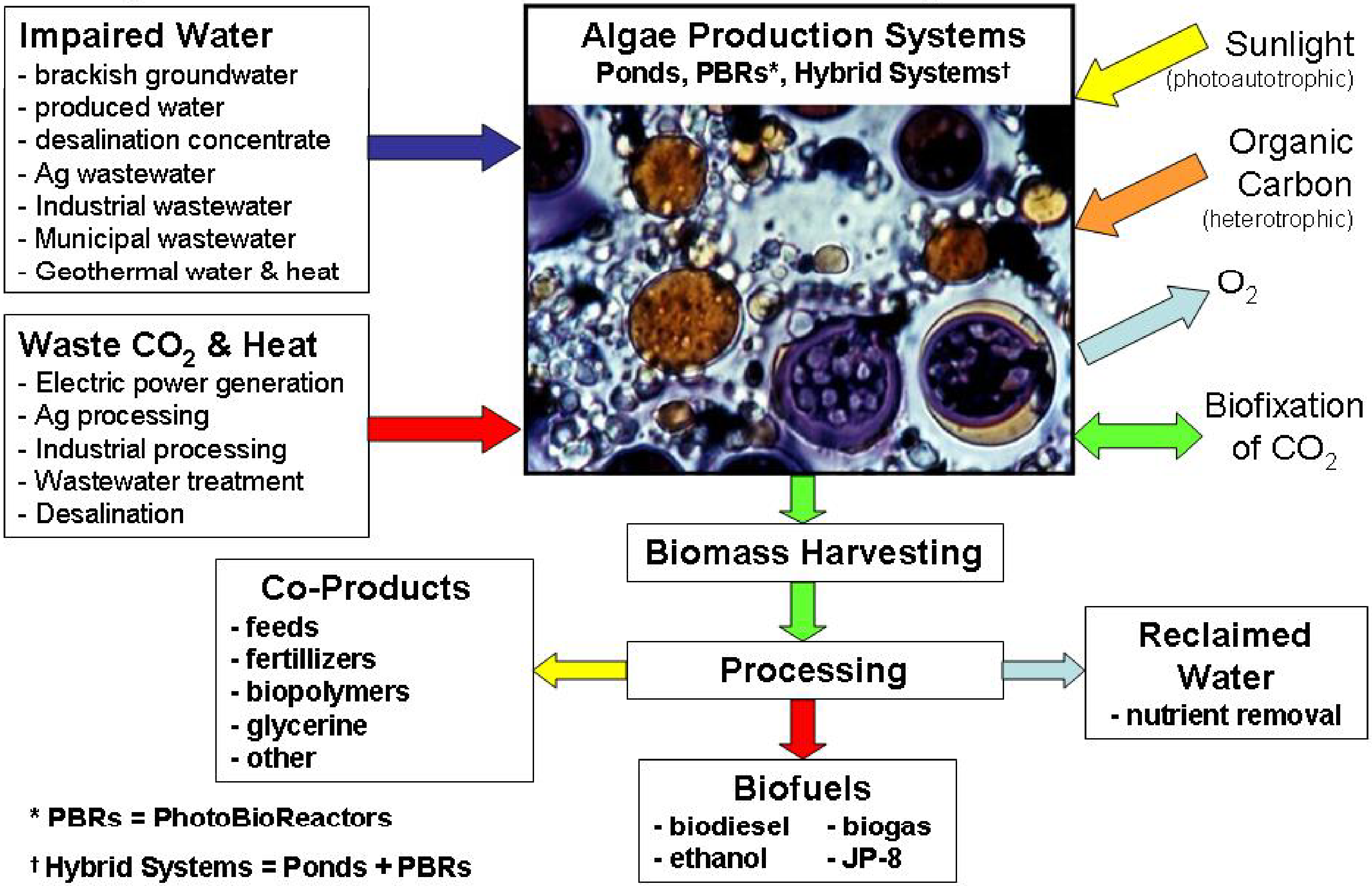
Life cycle costs of algal biofuels

- Clarens et al., 2010:
  - Conventional crops – lower environmental impacts than algae in energy use, GHGs, & water.
  - Algae performed favorably with regard to land use and eutrophication.
  - Use of flue gas and wastewater can offset environmental burdens.



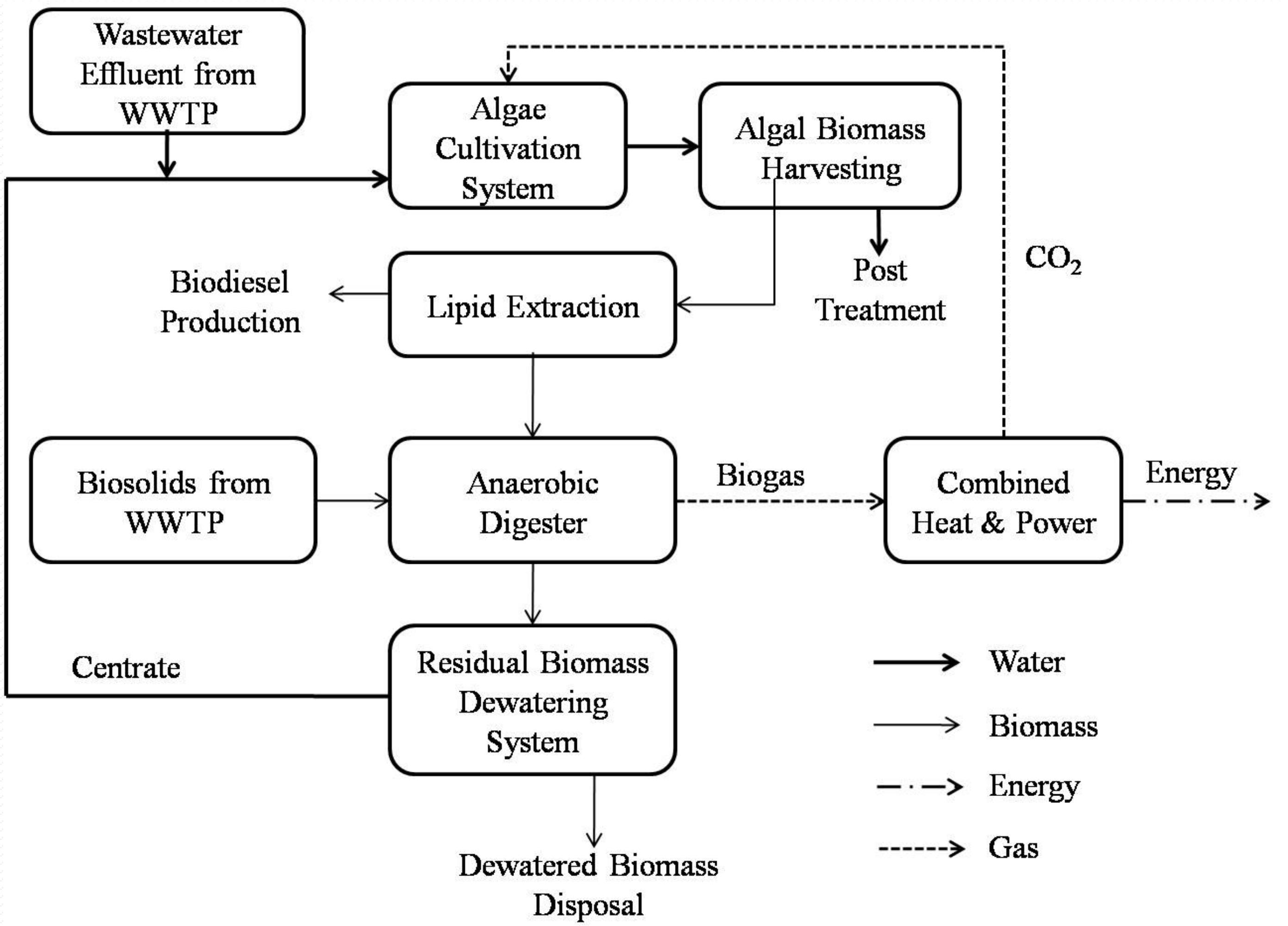
Land, energy, & water impacts for algae production in different locations. Source: *Environmental Science & Technology*

Algae-Based Production of Biofuels, Coproducts, & Services w/ Impaired Waters



Source: Sandia National Laboratories

Algal biofuel integration with WWTP anaerobic digestion infrastructure:



Centrate as an algal growth substrate:

- Opportunities:
  - Centrate carries 15-20% N load in WWTP.
  - Centrate recirculation to headworks can cause upsets in BNR processes.
- Challenges:
  - High NH_4^+ may inhibit algal growth.
  - Little research on algal growth on centrate.

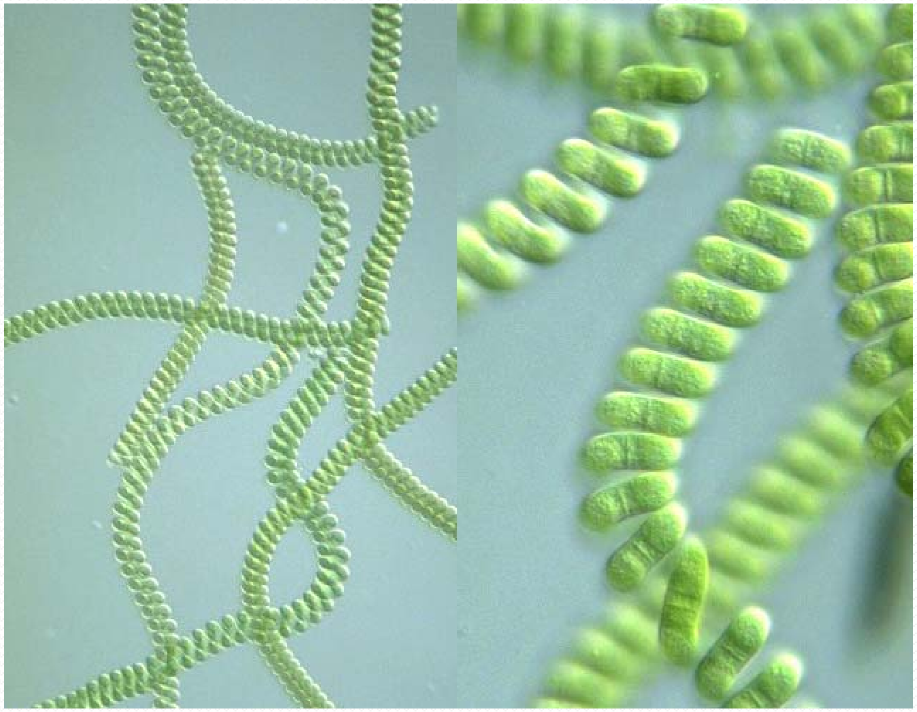
Image from Massachusetts Water Resources Authority

Research approach:

- Algal species – *Spirulina platensis* and *Chlorella sp.*
- Growth media – sludge centrate and mixture of centrate with nitrified effluent.
- Evaluation of algal growth and nutrient uptake rates.
- Harvested algae co-digested with waste activated sludge at varying algae/WAS ratios
- Evaluation of anaerobic digester performance.
- Preliminary investigations of algal harvesting methods.

Spirulina platensis

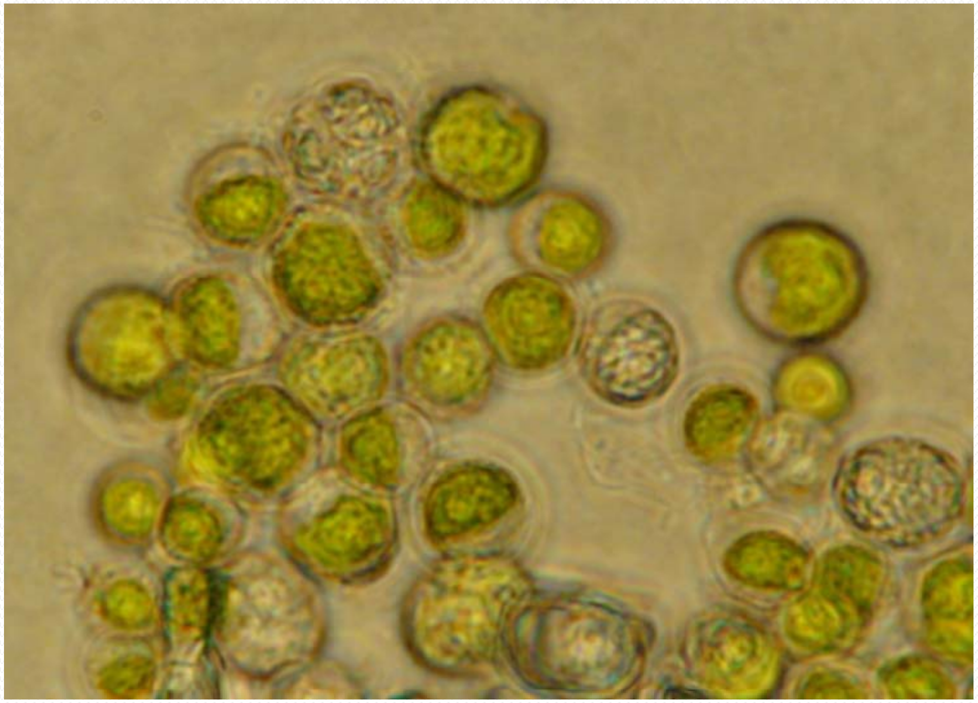
- Cyanobacteria (blue green algae)
- 55% protein, 11% carbohydrates, 8% lipid
- Obtained from U Texas Austin Algal Culture Collection
- Good resistance to free ammonia.



- Multicellular structure – gravity settling works well for harvesting.

Chlorella sp.

- Green (heterotrophic) algae
- 50% protein, 15% carbohydrates, 20% lipid.
- Harvested from Amherst MA WWTP clarifiers.



- Grows well on municipal, industrial and ag WW.

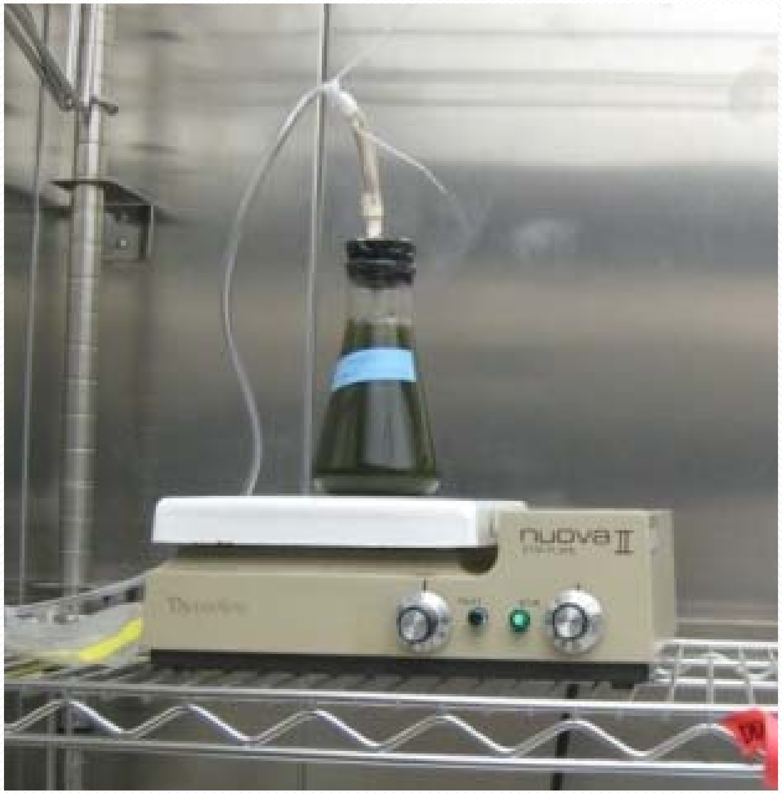
Algal growth and nutrient uptake:

Parameter (mg L^{-1})	Centrate	Centrate/Nite effluent
COD	60-150	50-80
TN	200-400	100-120
NO_3^--N	3-30	20-30
NH_3-N	180-400	80-100
TP	60-120	30-60

- Sparged with 2% CO_2 in air
- Light: 10 klux (400 µmol m^{-2} s^{-1}), continuous & 12 hr light/12 hr dark
- Temperature 20°C.

Anaerobic co-digestion:

- *Chlorella sp.* grown on defined media.
- Washed algae harvested by centrifugation.
- WAS from conventional A-S system.
- Mesophilic temperature: 37 °C
- SRT: 28 d.
- Algae/WAS ratios:
  - 100, 15, 5, 0%.



Algae harvesting:

- *Chlorella sp.*
- Alum and Ferric chloride
- 1 – 40 mg/L with pH adjustment to optimal range
- Rapid mix: 100 rpm 1-2 min
- Flocculation: 25 rpm 20 min
- Sedimentation: 30 minutes
- Turbidity, UV254 absorbance, specific resistance to filtration (SRF) measurements.

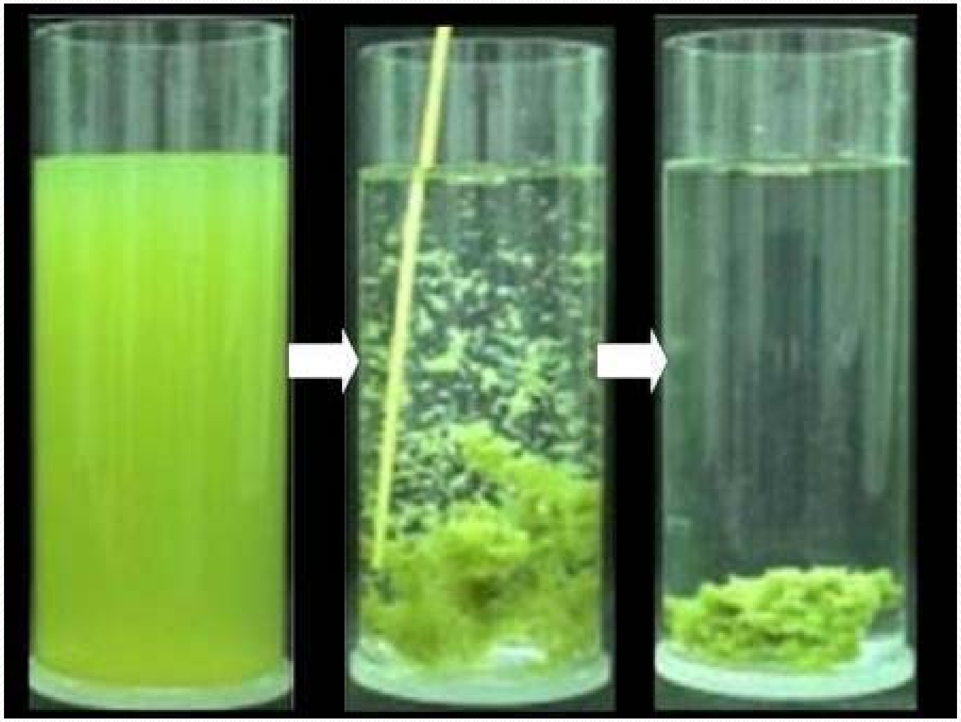
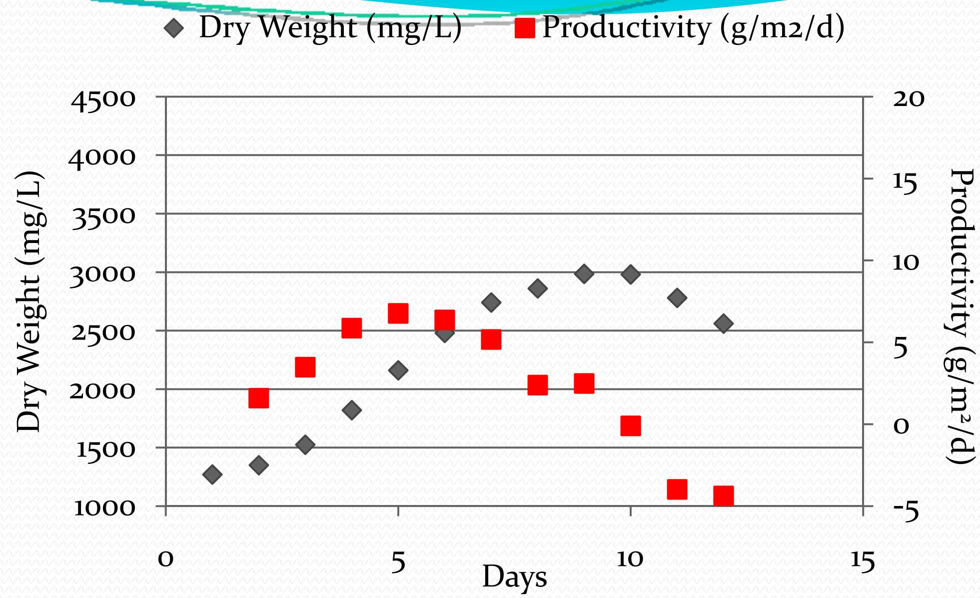
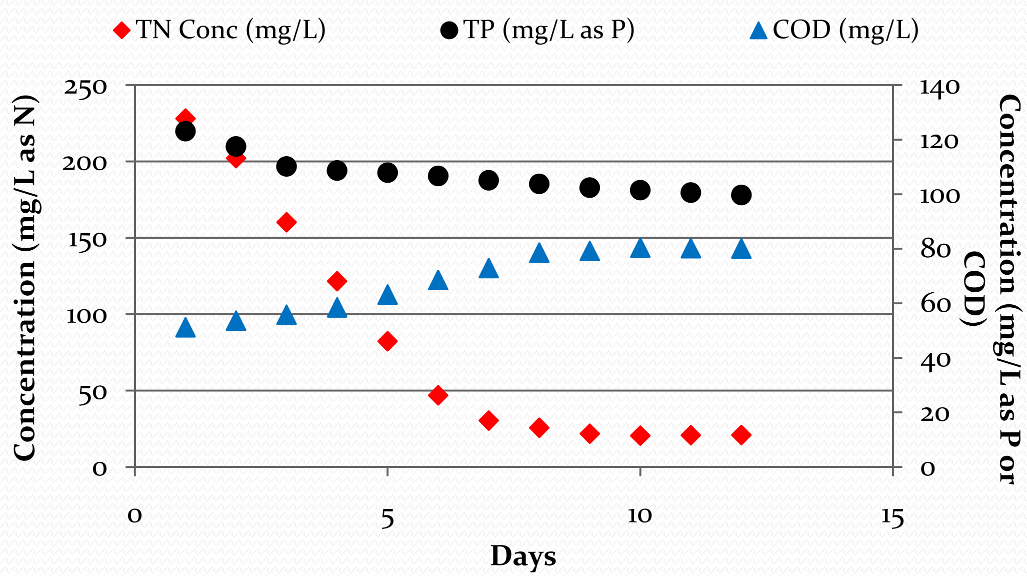


Image from Wageningen University

Algae growth:

- *Chlorella sp.* grew well on both centrate and mixture (Figs).
- *S. platensis* inhibited by centrate but grew well in mixture.
- Light availability limited growth – especially for *Chlorella* on centrate.
- > 90% TN removal, preferential NH_4^+ uptake over NO_3^-
- Some NH_3 loss by volatilization.
- > 20% TP removal.
- Increases in dissolved PO_4^{3-} and COD observed.





Algal growth summary:

Species	***Chlorella sp.***				***S. platensis***	
Medium	Centrate		Mixture		Mixture*	
Light/dark	24/0	12/12	24/0	12/12	24/0	12/12
Max. Productivity ($g/m^2/d$)	15.6	6.8	5.5	4.8	2.8	2.4
Max. TN Uptake Rate ($g/m^3/d$)	49.3	36.5	39.5	35.4	39.1	34.6
Max. TP Uptake Rate ($g/m^3/d$)	7.4	6.5	6.4	5.6	6.9	5.5

*no growth observed for *S. platensis* on centrate.

Comparison with other studies:

Species	Medium	Light intensity (μmol m^{-2} s^{-1})	Mixing/ aeration	Temp. °C	Specific growth rate d^{-1}	Ref.
Chlorella zofingiensis	Anaerobic effluent	NA continuous	Stir bar	23-28	0.49	Córdoba *et al.*, 2008
Chlorella vulgaris	BG11	50 12/12	6% CO_2 bubbling	30	0.22	Chinnasamy *et al.*, 2009
Chlorella vulgaris	Textile wastewater	135-1,139 natural light	Paddle wheel	24-32	0.05-0.39	Lim *et al.*, 2010
Chlorella sp.	Centrate	370-430 12/12 & continuous	2% CO_2 bubbling	20	0.19-0.32	This study

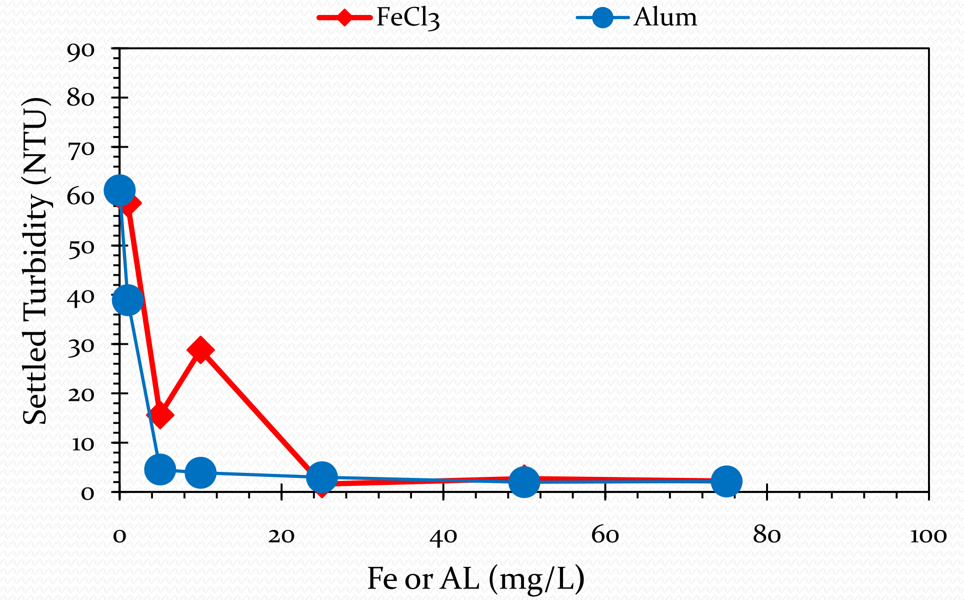
Anaerobic digestion *Chlorella*:

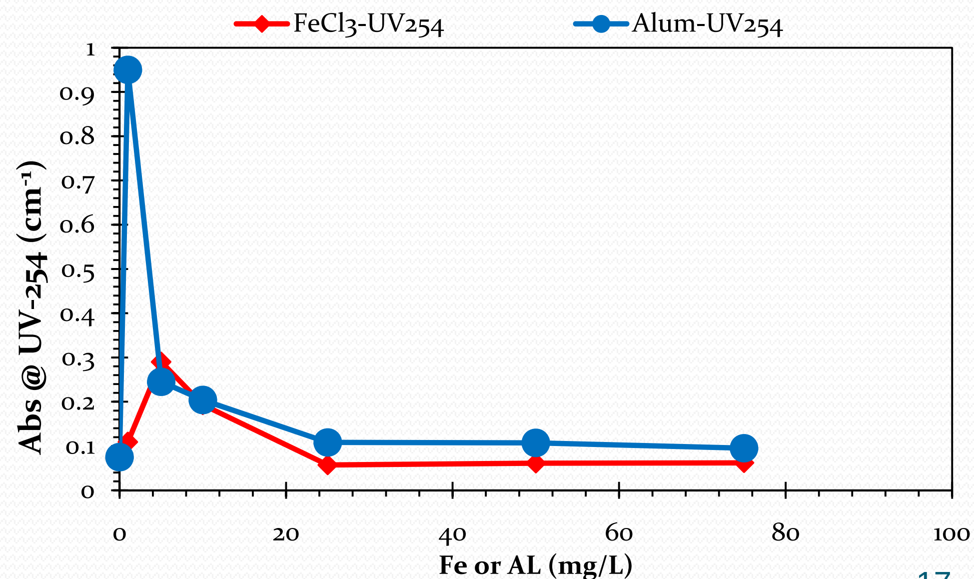
Algae fraction (%)	VSR (%)	Capillary Suction Time (s)	
		Before digestion	After digestion
0	41.1	40	471
5	44.8	29	589
15	45.3	26	862
100	68.1	9.3	390

- Co-digestion of Chlorella with WAS improved degradability but had a negative effect on dewaterability.
- No biogas measurements yet.

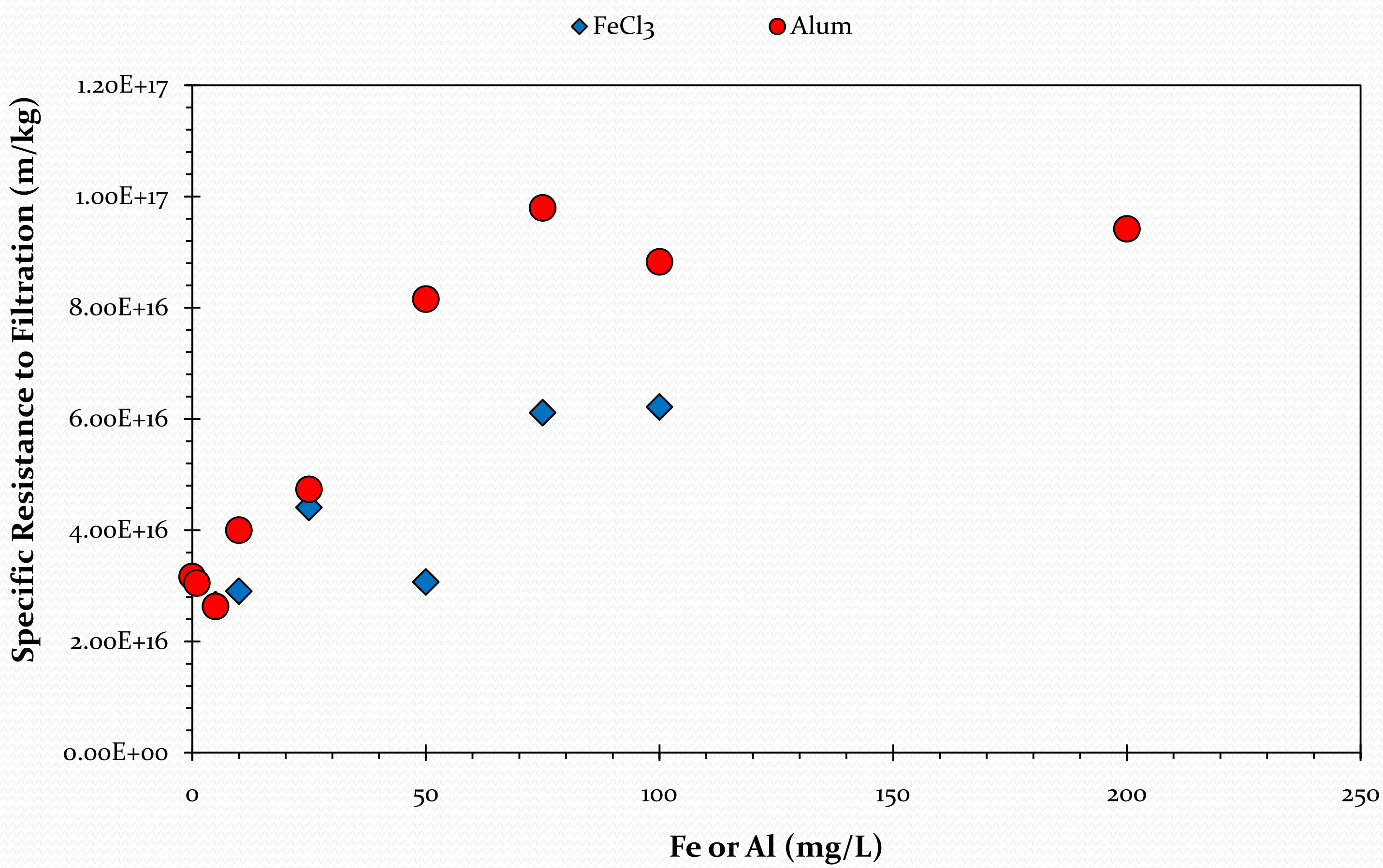
Harvesting results:

- FeCl: Lowest turbidity (1.59 NTU) & UV abs (0.057 cm^{-1}) at 25 mg/L Fe, pH 5.3.
- Alum: Lowest turbidity (1.99 NTU) & UV absorbance (0.056 cm^{-1}) at 50 mg/L Al, pH 6.9.
- Lower SRF values with FeCl.





Specific resistance to filtration:

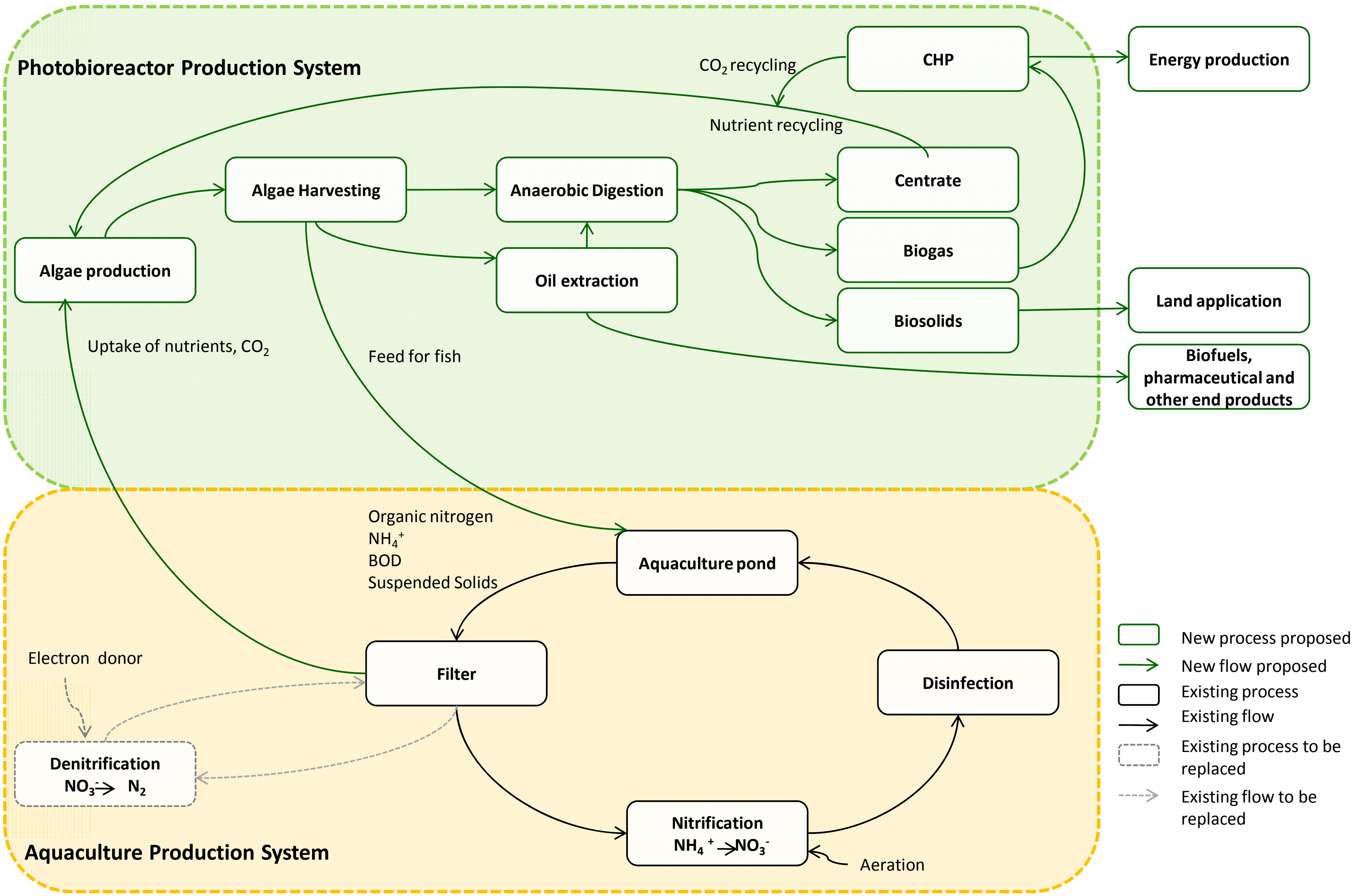


Conclusions:

- High growth, N & P uptake rates with *Chlorella* on centrate.
- Insignificant growth observed with *S. platensis* on 100% centrate.
- Both species grew well on the centrate/nitrified effluent mixture.
- Both species depleted N and P from the medium and preferentially utilized ammonia over nitrate.
- COD concentrations increased slightly, even with heterotrophic *Chlorella* indicating low bioavailability of organics in centrate.
- Algae co-digestion with WAS improved VSR and may possibly result in more biogas generation.
- Co-digestion of *S. platensis* with WAS improved biosolids dewaterability; however, *Chlorella* addition had a negative impact on dewaterability.

Next steps:

- Algal growth experiments: Ergas/Wolan USF
  - Continuous flow reactor studies
  - CO_2 uptake rates
  - Lipid production
  - Aquaculture wastewaters
- Algae co-digestion studies: Chul Park UMass Amherst
  - Effect of substrate and growth stage on digestibility, biogas production and biosolids dewaterability
- Harvesting: Park/Ergas
  - Use of polymers
  - Effects of coagulants on anaerobic digestion
- Life cycle analysis: Qiong Zhang USF



Photobioreactor Production System
CO2 recycling
CHP
Energy production
Nutrient recycling
Algae Harvesting
Anaerobic Digestion
Centrate
Biogas
Biosolids
Land application
Algae production
Oil extraction
Uptake of nutrients, CO2
Feed for fish
Biofuels, pharmaceutical and other end products
Organic nitrogen
NH4+
BOD
Suspended Solids
Aquaculture pond
Electron donor
Filter
Disinfection
Denitrification
NO3- → N2
Nitrification
NH4+ → NO3-
Aeration
Aquaculture Production System
New process proposed
New flow proposed
Existing process
Existing flow
Existing process to be replaced
Existing flow to be replaced

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Image from Pure Energy Fuels Ltd.

Thank you