Non Sea Algae Methanization

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GRENOBLE INP UGA

Specific biomass to treat

$$a\ \textit{photons} + b\ CO_2 + c\ \textit{nutrients} + d\ H_2 \rightarrow e\ CO_{0.48}H_{1.83}N_{0.11}P_{0.11} + f\ O_2 + g\ H_2O$$

The nutrient requirements can vary depending on the species of microalgae. However, nutrients need to be continuously supplied to optimize its growth.

- Carbon: supplied in the form of carbon dioxide.
  - 1.83 kg for 1 kg of algal biomass on a dry mass basis.

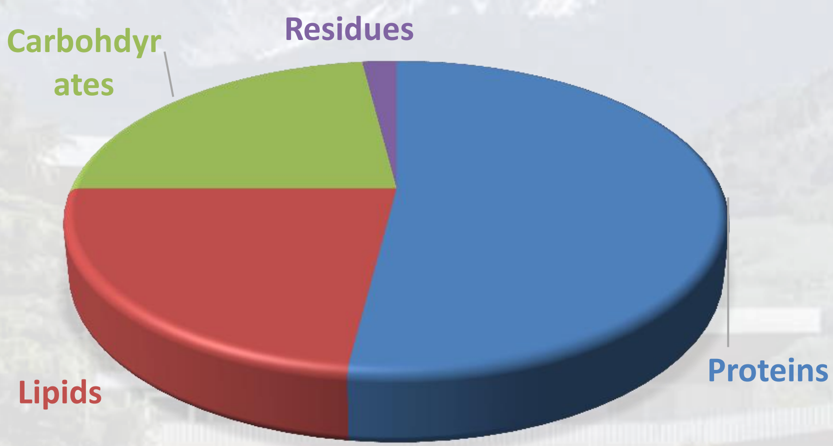
- Nitrogen: supplied as nitrate, ammonia, or urea.
  - 0.07 kg for 1 kg of algal biomass on a dry mass basis.

- Phosphorus: supplied as phosphate.
  - 0.01 kg for 1 kg of algal biomass on a dry mass basis.

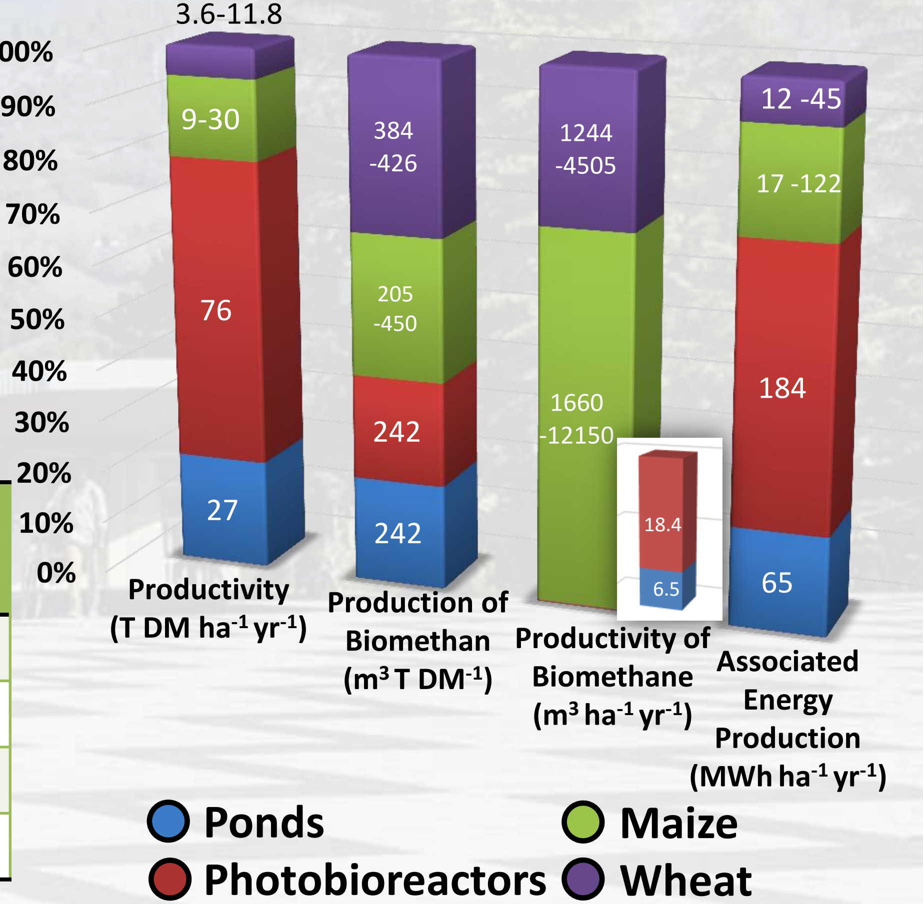
- Other nutrients are essential in trace amounts: iron, magnesium, manganese, nickel, zinc, molybdenum, cobalt, boron, vanadium, and copper.
    - However, if their concentrations are too high,
    - these elements can be toxic to the culture.

Specific biomass to treat

$$a \text{ photons} + b\, CO_2 + c \text{ nutrients} + d\, H_2 \rightarrow e\, CO_{0.48}H_{1.83}N_{0.11}P_{0.11} + f\, O_2 + g\, H_2O$$



TYPES OF BIOMASS



	Proportion %	Calorific power (MJ kg^{-1})
Proteins	6-52	15.5
Lipids	7-23	38.3
Carbohydrates	5-23	13.0
Ratio C: N : P	106:16:1	

Methanization process

2.1 Hydrolysis

- Hydrolysis is the first and main step in the biotransformation of various complex organic raw materials.

2.2 Acidogenesis

- This is the second stage of the process in which two groups of microorganisms **decompose soluble organic** molecules such as monosaccharides and amino acids **through facultative bacteria**.
- Alcohol, hydrogen, acetic acid, formic acid, and carbon dioxide are produced once this reaction is complete.
- **Faster kinetics than hydrolysis**

2.3 Acetogenesis

- The third step of the process converts alcohol, butyric acid, propionic acid, valeric acid, etc. into hydrogen, carbon dioxide, acetic acid through acetogenic bacteria.
- A very low partial pressure of hydrogen is required to form acetate from propionic acid, valeric acid, or butyric acid.

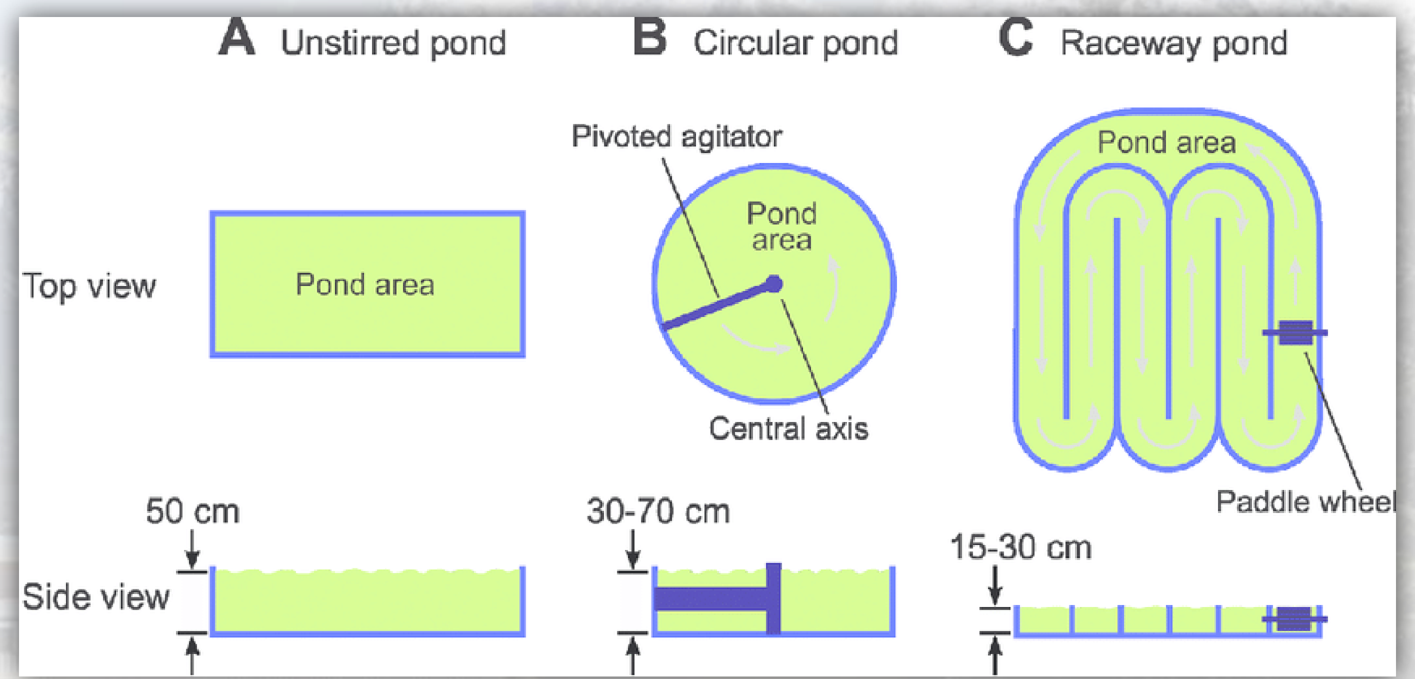
$$CO_2 + 4\,H_2 \rightarrow CH_3COOH + 2H_2O$$

2.4 Methanogenesis

- This stage is the final step that summarizes the methanogenesis process.
- 70% → $CH_3COOH \rightarrow CO_2 + CH_4$ 30%→ $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$

Different types of cultivation systems

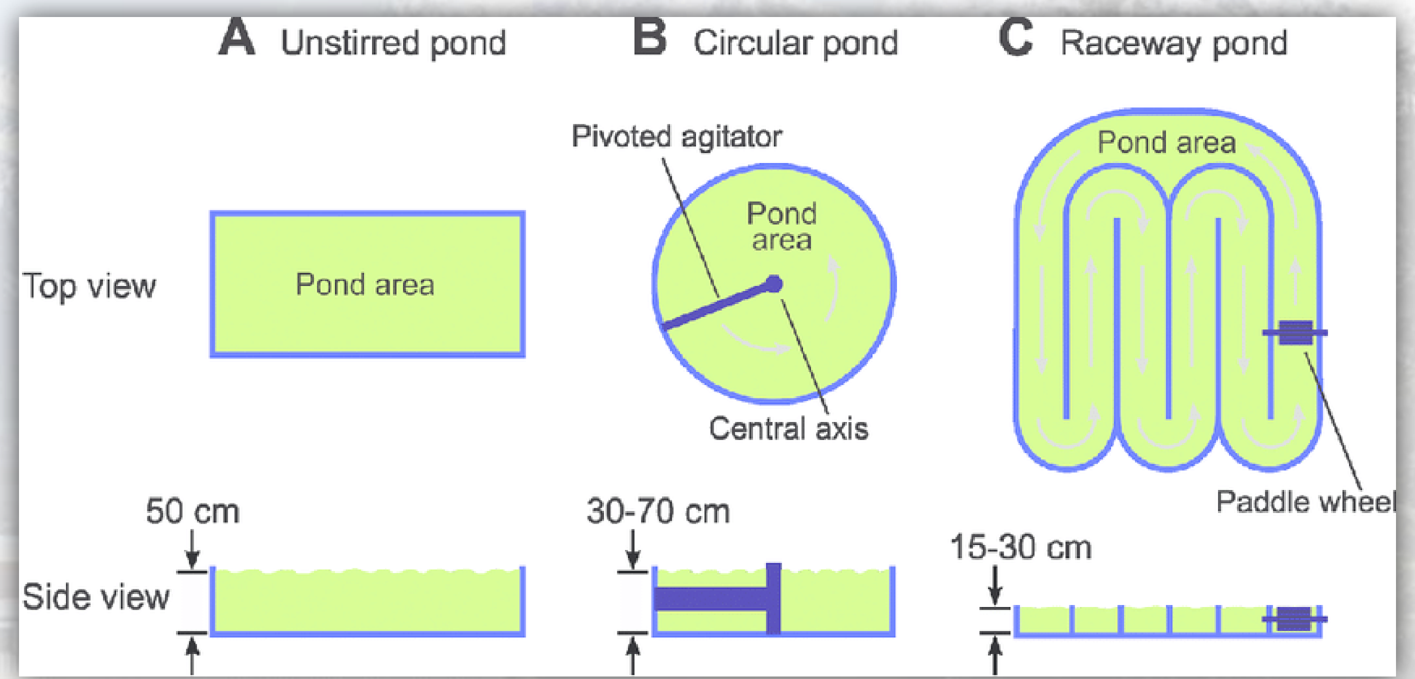
Different Types of Open Ponds



- The average volumetric productivity of this system is 0.06 – 0.42 g L^{-1} day^{-1}.
- The effectiveness of the system will depend on **the composition of the pond** and **the type of algae growing.**

Different types of cultivation systems

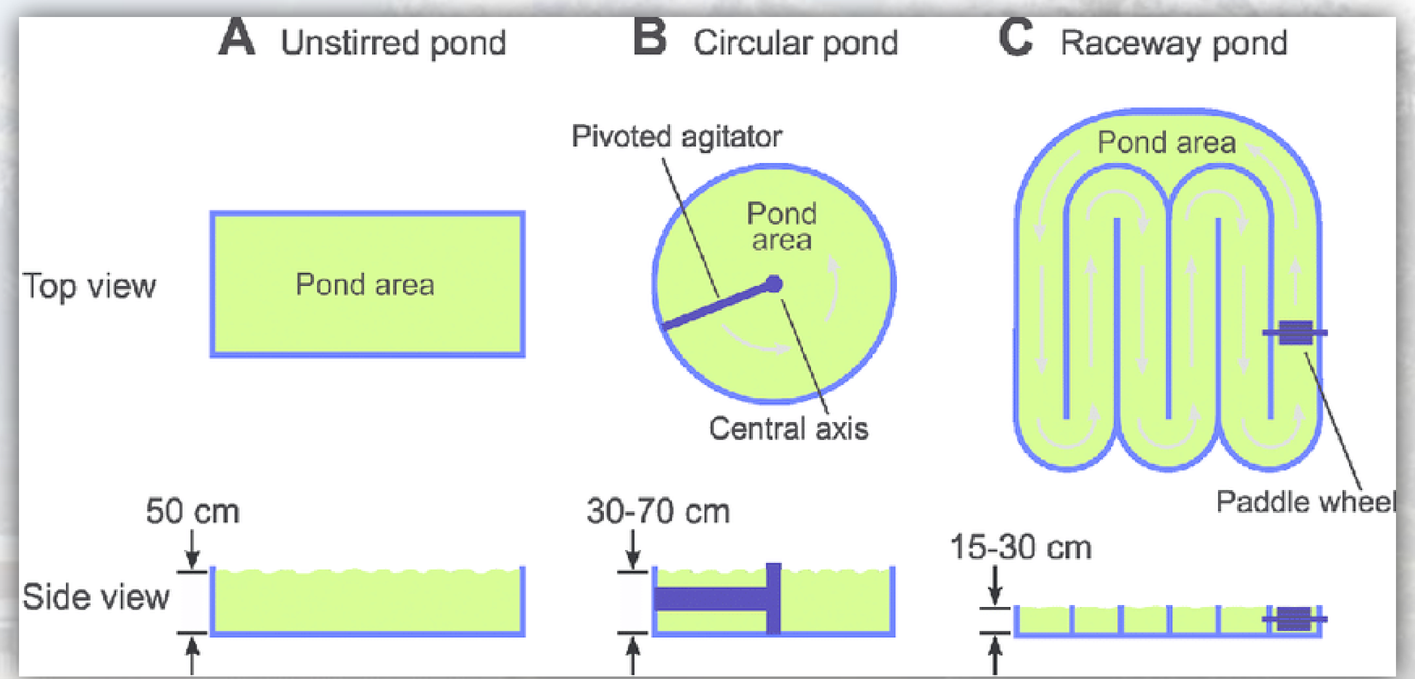
Different Types of Open Ponds



- Open reservoirs or naturally existing bodies of water (ponds, lakes, lagoons, etc.) are commonly known as open ponds and are easy to construct and operate. These ponds are kept shallow to allow solar radiation to penetrate easily. Water and nutrients circulate continuously in the crop.

Different types of cultivation systems

Different Types of Open Ponds



- **Pond productivity** is measured by calculating the biomass produced per unit area per day.
- The area of the round pond and the road can be about 1 hectare and the area of the large pond can be about 200 ha.

Different types of cultivation systems

Different Types of Open Ponds

Unmixed Ponds

- ✓ no control over the factors

Circular Ponds

- ✓ 1st design commercially for growing algae.
- ✓ Cons: limited to radius of 1000 m ^{2}
- ✓ Voltages in this range will cause the main rotary mixer to **become uncontrollable.**

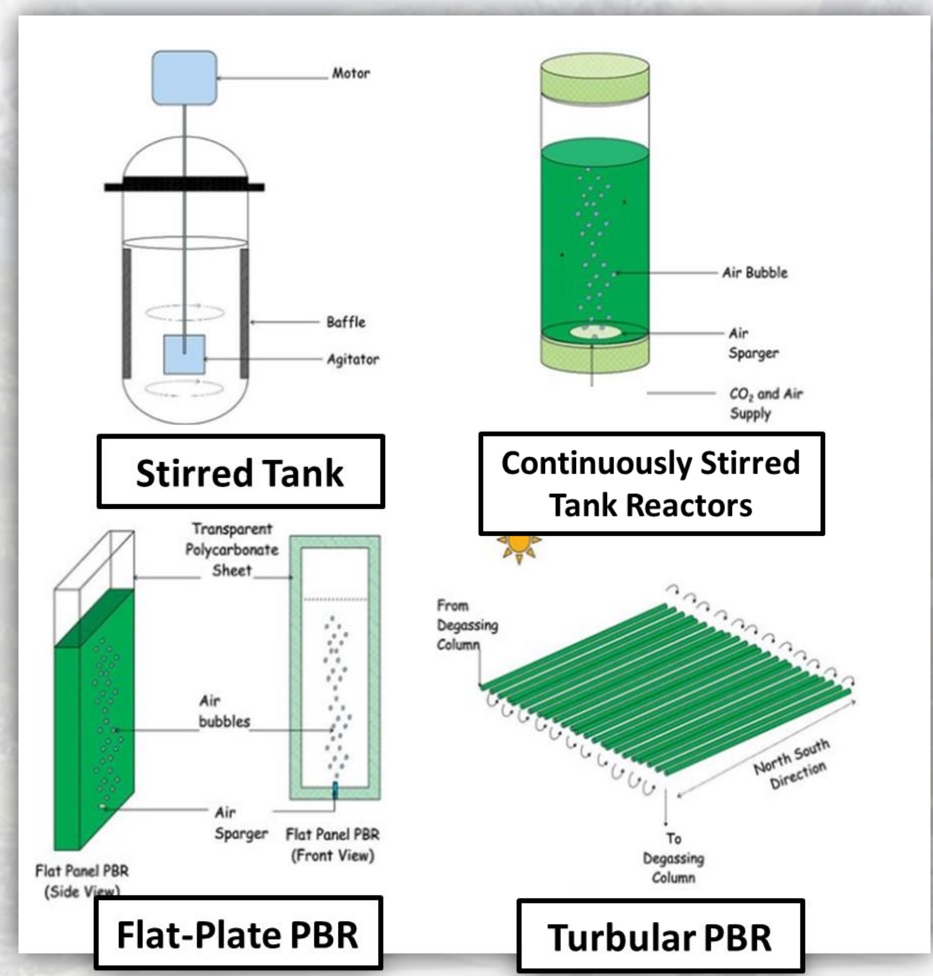
Raceway ponds

- ✓ by maintaining a symbiotic relationship between **aerobic bacteria** and **algae**.
- ✓ With **paddles**, the circulation of broth and nutrients is carried out in loop-shaped channels.
- ✓ The pond is made of concrete, PVC or clay and is about 0.2 to 0.5 m deep, **allowing sunlight**

X: Problems with infestation and unwanted bird species.

Closed Photobioreactors

Different Types of Closed Ponds



- Photobioreactor (PBR) system yields range from <u>0.02 – 3.22 g $L^{-1}day^{-1}$</u>.

Pros:

1. **Not allow exposure of the birds to the external environment.**
2. **Compared to open pond systems, algae cultures in PBR are effectively protected from all types of pollution and losses due to low evaporation.**

Different types of cultivation systems

Different Types of Closed Ponds

Continuously Stirred Tank Reactors	Column PBR

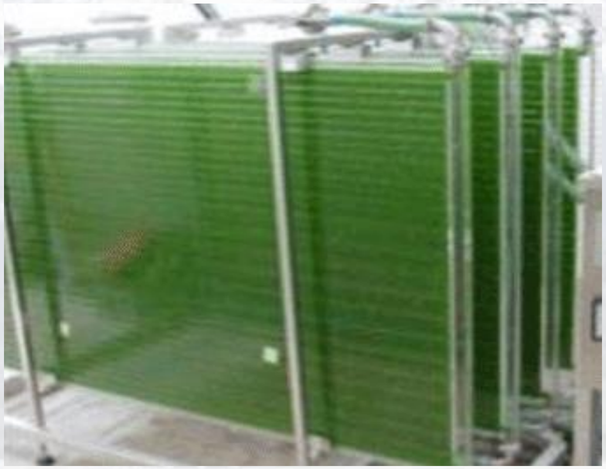
- Wide and hollow-shaped tank to work both inside and outside a closed cylindrical channel with mixing and lighting features. Drainage systems and gas injectors are located in

O: The risk of contamination of the culture is very low.

- ... **growth** ... and **prevents contamination** of the culture.
- Culture parameters (nutrients, temperature, pH, etc.) can be effectively controlled.

O: Cheap, easily install, best mixing, easily controlled culture conditions, and the highest volumetric mass transfer rate.

Different Types of Closed Ponds



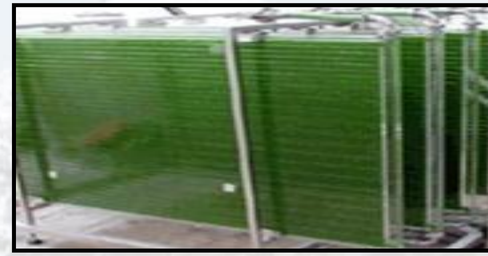
Flat-plate PBR

Turbular PBR

- **O: They are more suitable for cultivation because they have less accumulation of dissolved oxygen and photosynthesis is more efficient.**
- **X: there are issues such as temperature control and algae adhesion to the reactor walls.**

- Tubular PBR is made by installing linear **X: The problem with tubular PBRs is algae build-up at the bottom of the tube.** nces.
- **→However, sinking can be avoided by using lifting propellers to maintain a highly**
- **turbulent flow.** s the largest size, with an area of up to 750 m^3 .

Comparison of POND and PHOTOBIOREACTOR



	POND	PHOTOBIOREACTOR
PRINCIPLE	The ponds are large open basins, with the majority being of the 'racecourse' type. The circulation and ventilation of the crop are carried out mechanically.	**Closed systems** where the conditions of mixing and material transfer are optimized
ALGAL BIOMASS CONCENTRATION	0.1 – 0.5 g DM L^{-1}	2 – 8 g DM L^{-1} *(DM = dry mass)*
AVERAGE SURFACE YIELDS	10 – 50 T ha^{-1} yr^{-1}	30 – 150 T ha^{-1} yr^{-1}
CURRENT PRODUCTIVITY	27 T DM ha^{-1} yr^{-1}	76 T DM ha^{-1} yr^{-1}
PRODUCTIVITY *ESTIMATED 2050*	56 T DM ha^{-1} yr^{-1}	116 T DM ha^{-1} yr^{-1}
COSTS	€ 10 - 40 m^{-2}	€ 100 - 300 m^{-2}

Comparison of POND and PHOTOBIOREACTOR

POND

PHOTOBIOREACTOR

Advantages – POND

- ✓ Easy to build and operate
- ✓ Low cost
- ✓ System suitable for mass production of microalgae
- ✓ Low energy consumption

Advantages – PHOTOBIOREACTOR

- ✓ High surface productivity
- ✓ Better control of cultivation conditions
- ✓ Optimization of material and light transfers

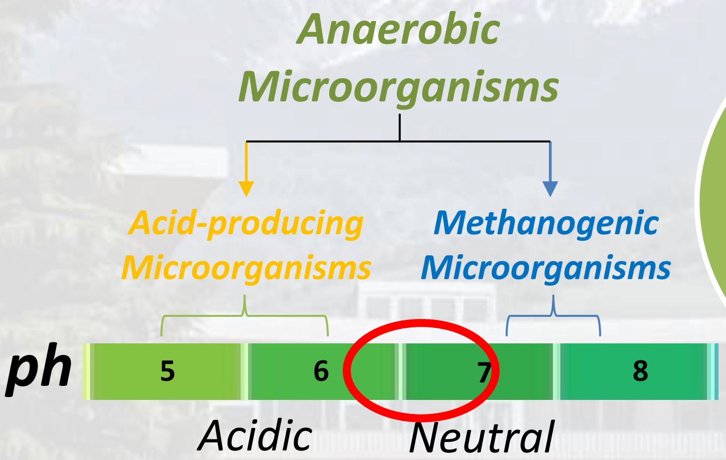
Disadvantages – POND

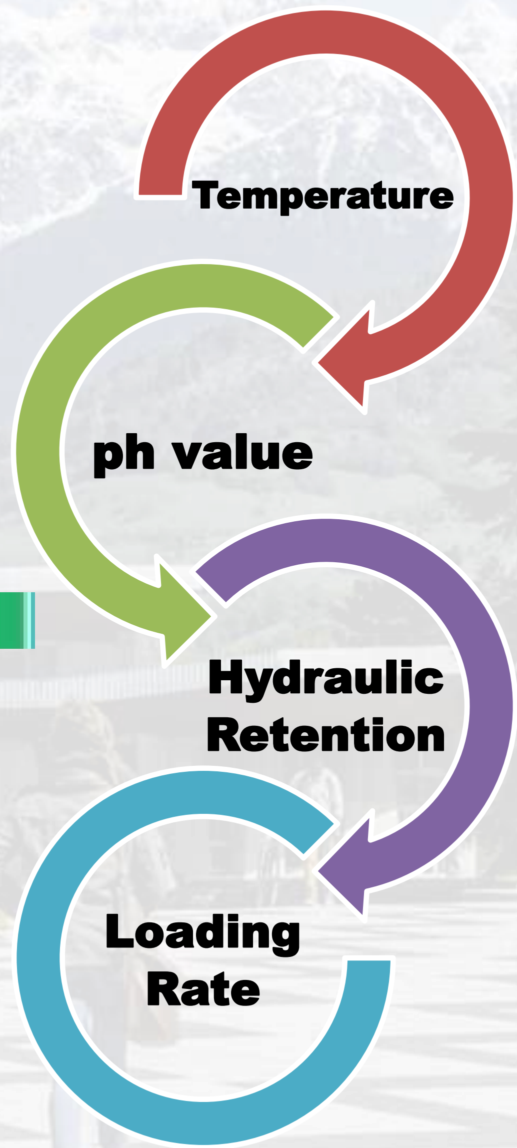
- ☐ High risk of contamination
- ☐ Low surface productivity
- ☐ Limited optimization of material transfers
- ☐ Evaporation

Disadvantages – PHOTOBIOREACTOR

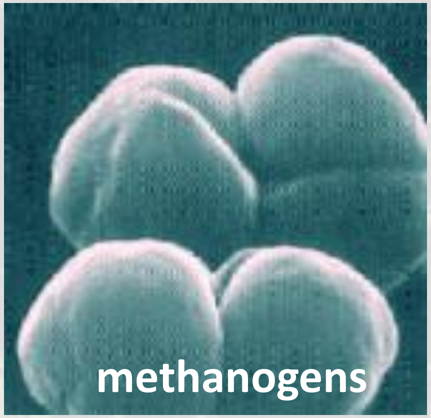
- ☐ High cost
- ☐ Accumulation of O_2 in the reactor
- ☐ Temperature regulation required
- ☐ Generally high energy consumption

Operating parameters



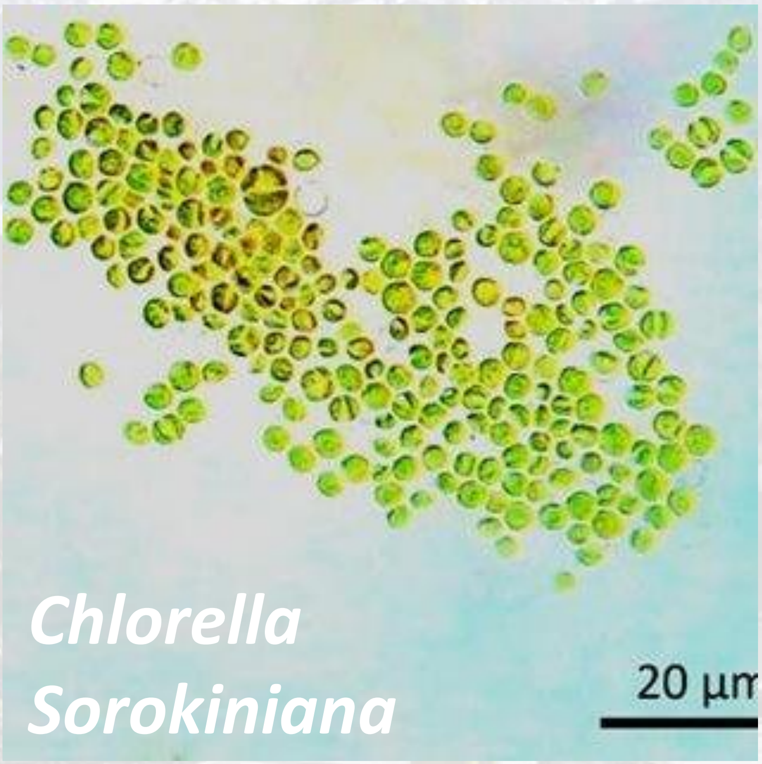


Optimal time for biogas production: ***35 ˚C***

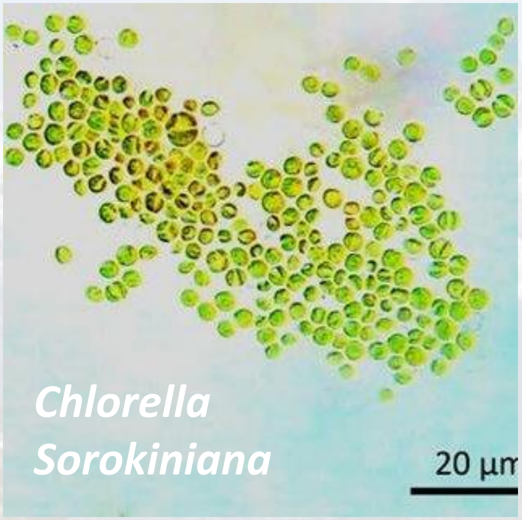


HRT: to stimulate a dynamic population of microorganisms

Large-Scale Production of Algal Biomass: Photobioreactors



Large-Scale Production of Algal Biomass: Photobioreactors



Property	Value
Light intensity	800 *µmol* photons $m^{-2}\ s^{-1}$
Temperature	30 $^{\circ}C$
Aeration rate	1.3 $L\ min^{-1}$
CO_2 % supply	2.0 *%*
Foam suppression	2*%* foam suppressant
ph value	7.0 ± 0.05

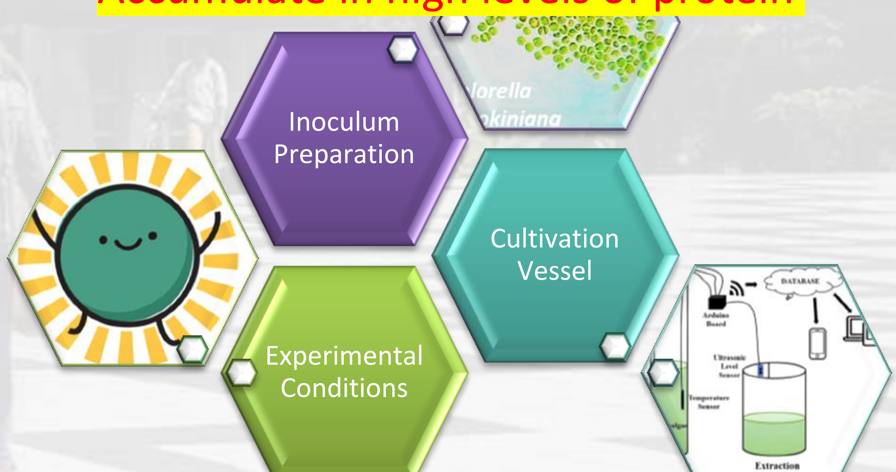
In synthetic media

NH_4^+ (N) concentration: **360 *mg L*$^{-1}$**
concentrations of chlorophylls:
180 ± 7.5 *mg L*$^{-1}$
carotenoids: **26 ± 1.4 *mg L*$^{-1}$**

In unsterilized domestic wastewater

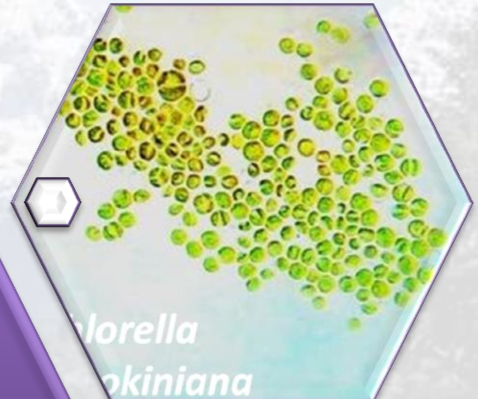
Growth rate: 0.73 *day*$^{-1}$
Biomass productivity: 0.21 *g L*$^{-1}$ *day*$^{-1}$
100% NH_4^+ (N) removal

Adptability in various medias
Accumulate in high levels of protein



Large-Scale Production of Algal Biomass: Photobioreactors

Add antibiotics:
reduce contamination



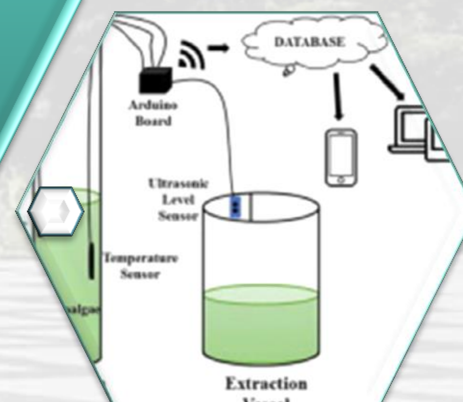
Chlorella
Sorokiniana

Inoculum Preparation

Cultivation Vessel

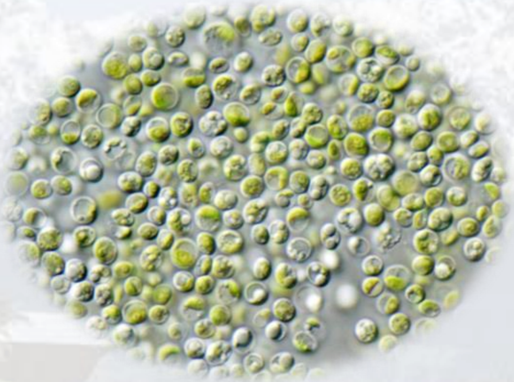
Experimental Conditions

- a. Glass vessel
- b. LED lamps
- c. PAR meter
- d. Temperature control
- e. Aeration
- f. CO2 supply control
- g. Foam suppressant
- h. pH control



growth characteristics
biomass yield
biochemical composition of the cells

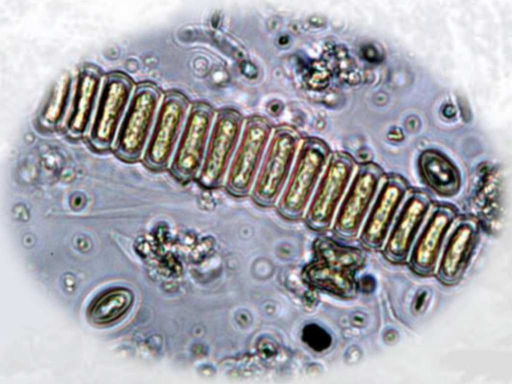
Large-Scale Production of Algal Biomass: Raceway Ponds



Chlorella

rapid growth

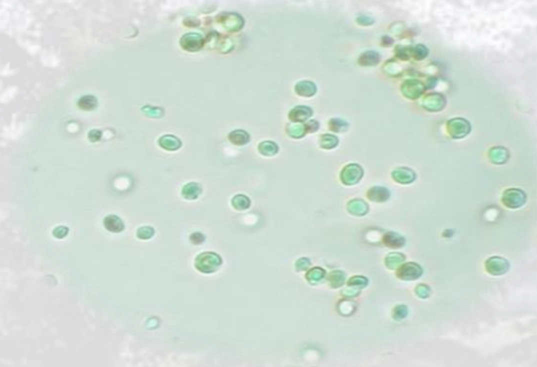
high lipid content



Scenedesmus

adaptability

potential for biofuel production



Nannochloropsis

high lipid content

biodiesel production

CHOOSE

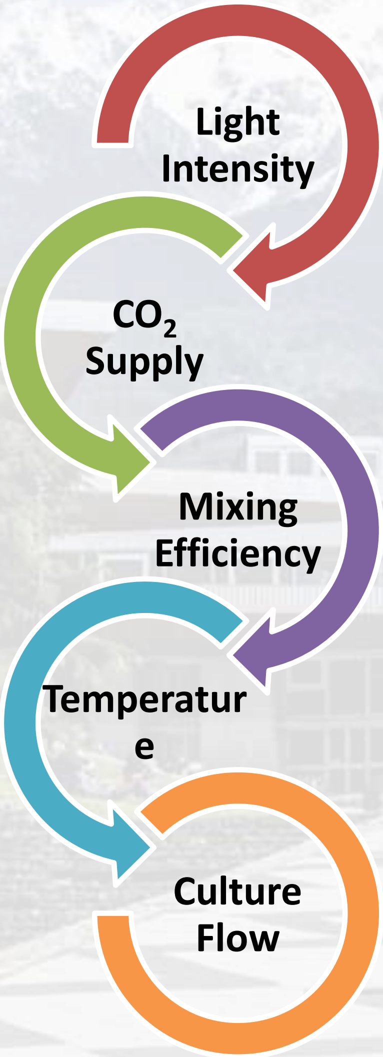
- ✓ lipid content
- ✓ growth rate
- ✓ adaptability to environmental conditions

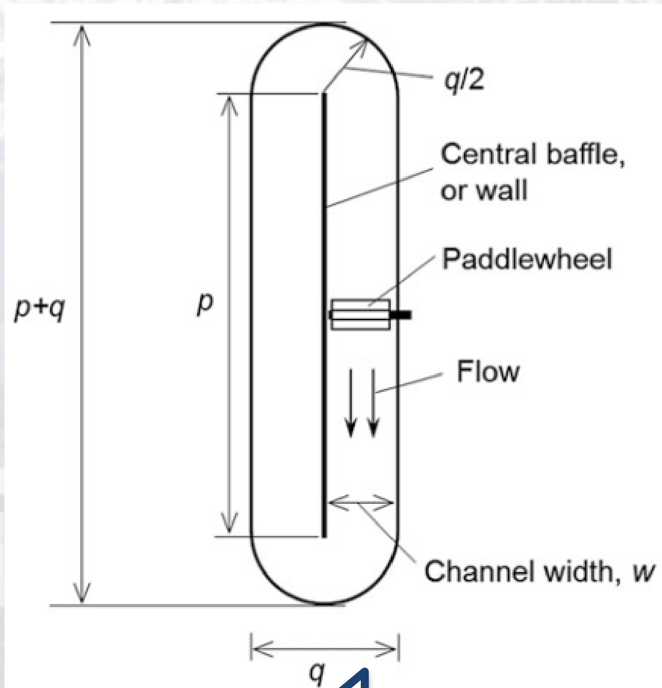
→ the specific requirements of the intended application whether it's water treatment, biofuel production, or other purposes.

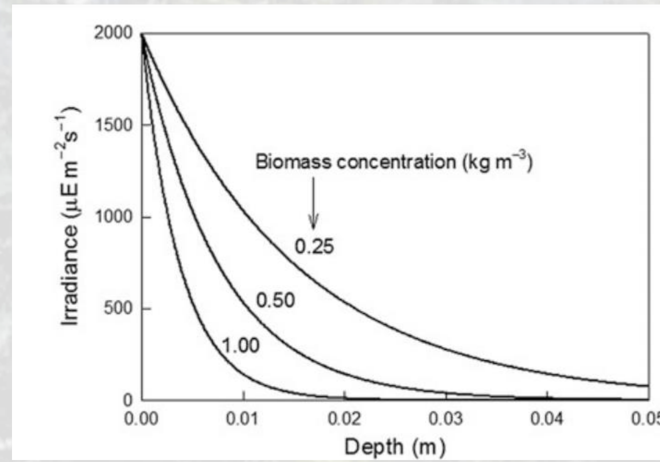
Reactor sizing and operation

$$A = \frac{\pi * q^2}{4} + p * q$$

$$V = A * h$$







Simulation: prevent sedimentation and dead zones
Lowering the channel flow velocity
⇒ reduce power consumption

Paddle Wheel

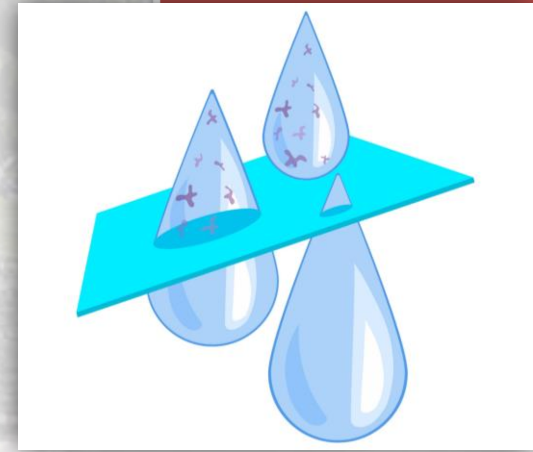
Energy Consumption

mixing efficiency
power consumption

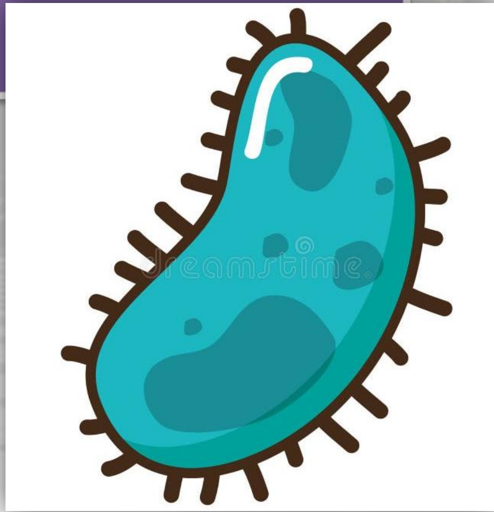
Possible contamination culture

Predator Control

Contamination Management



Bacterial Contamination



Contamination Source

Large-Scale Production of Algal Biomass: Raceway Ponds

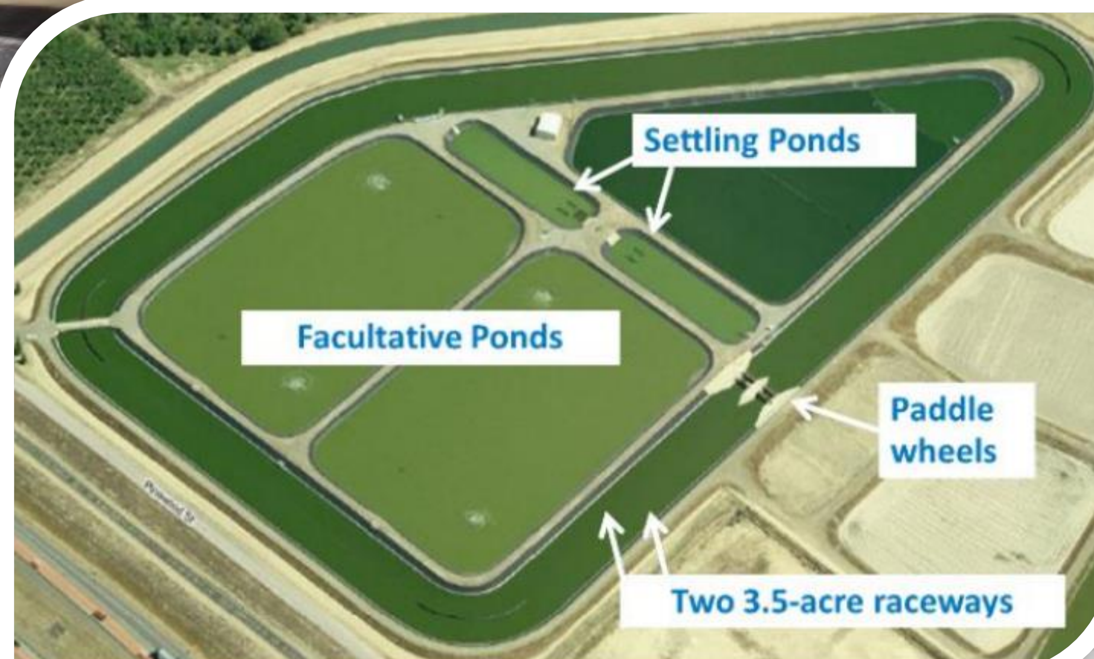
PROS

Cost-effective
Simple to construct and operate
Large surface area exposure to light

CONS

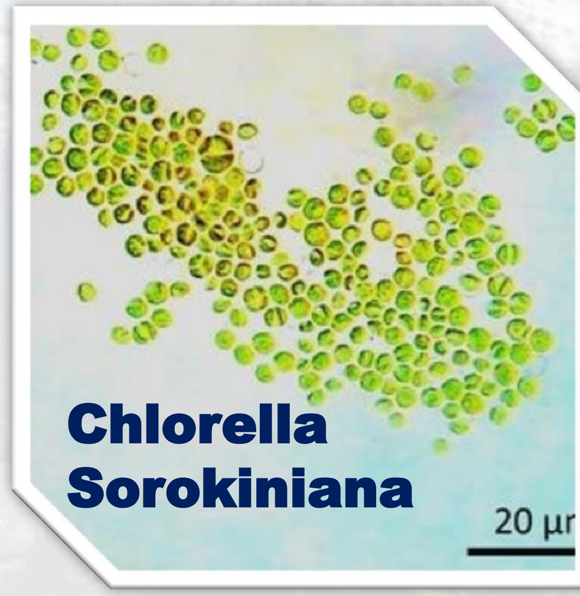
Sedimentation
Dead zone
pH value
CO_2 supply

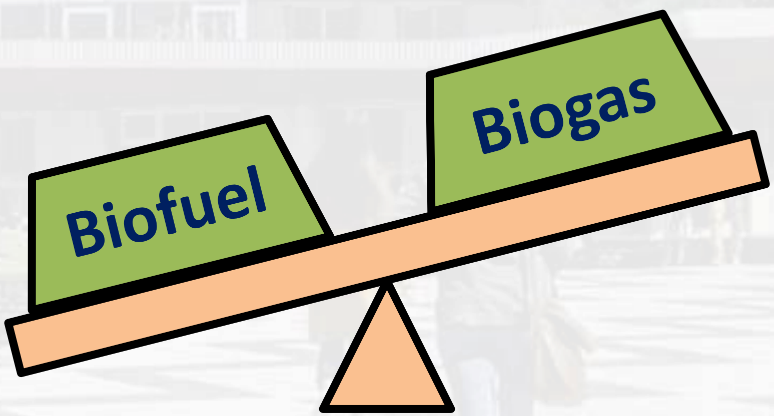
Real Example: Scale-up of Algal Biofuel Production Using Waste Nutrients



GRENOBLE INP UGA

Introduction





Algae Biomass Production

Process Scheme – Real example scale up

Pilot system to maximize the productivity
0.6 M gallon per day wastewater

- ✓ oxygen production
- ✓ nutrient removal

Process Scheme – Real example scale up

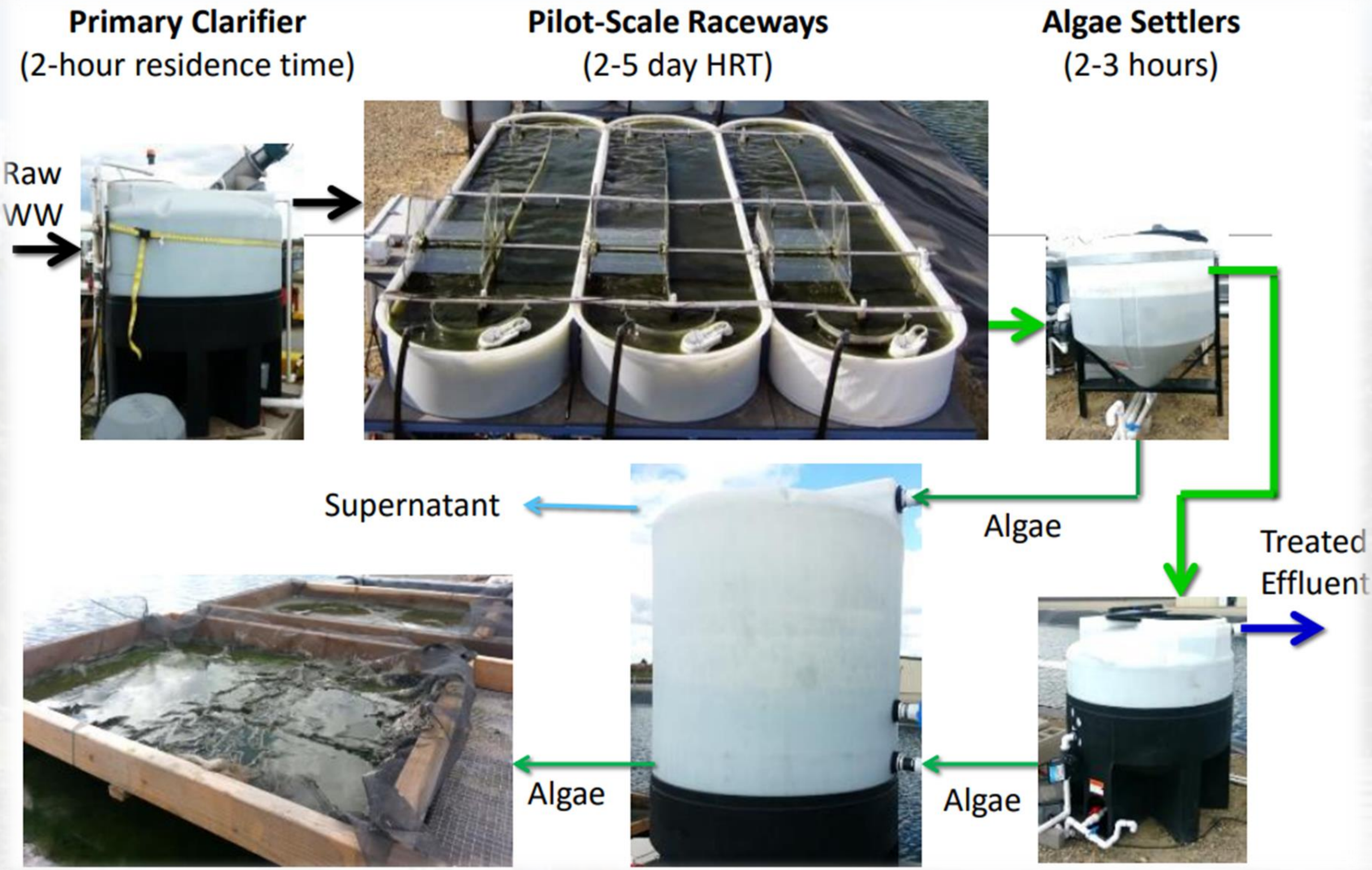
Pilot system to maximize the productivity
0.6 M gallon per day wastewater

<u>Manipulated Variables</u>

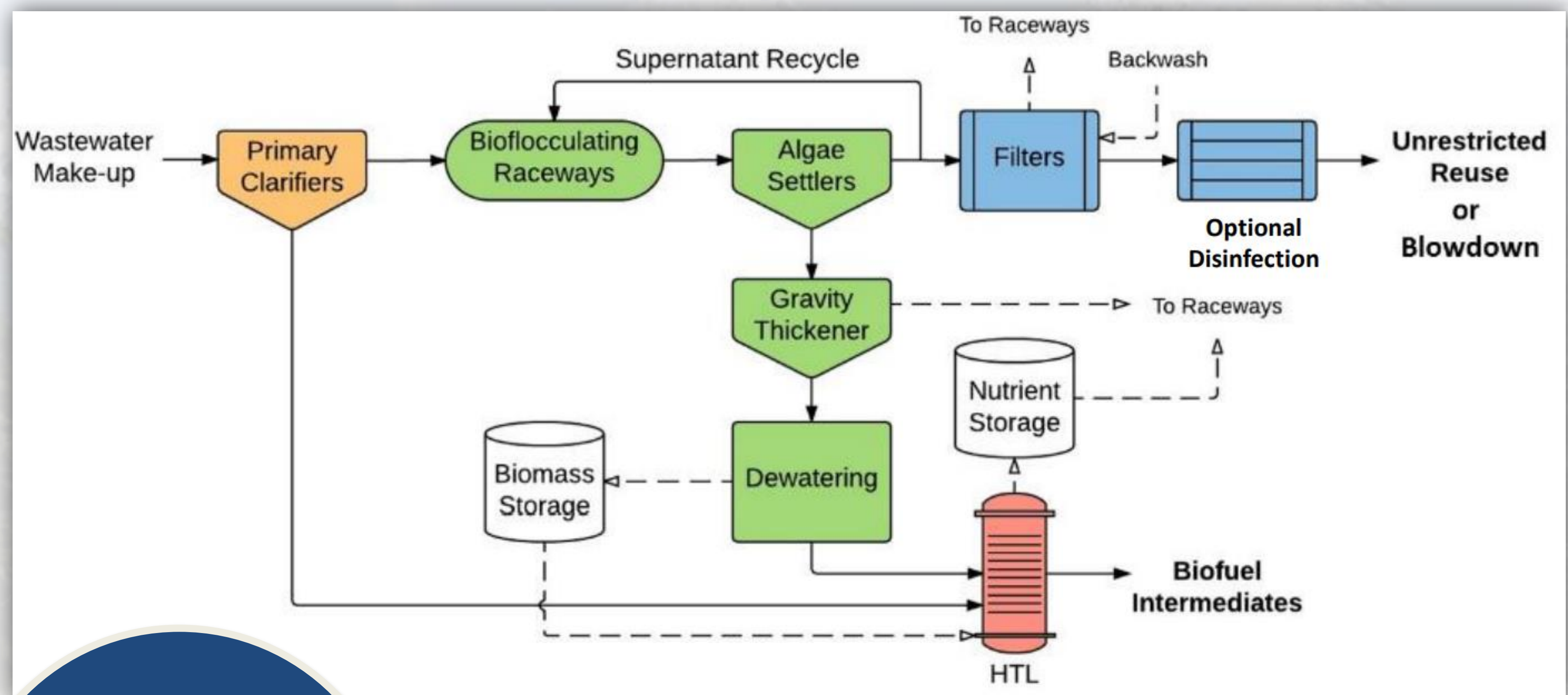
Residence time

Influent water source

CO_2 addition


Primary Clarifier
(2-hour residence time)
Pilot-Scale Raceways
(2-5 day HRT)
Algae Settlers
(2-3 hours)
Raw WW
Supernatant
Algae
Treated Effluent
Algae
Algae

Process Scheme – Scale-up Process Flow



Waste Water

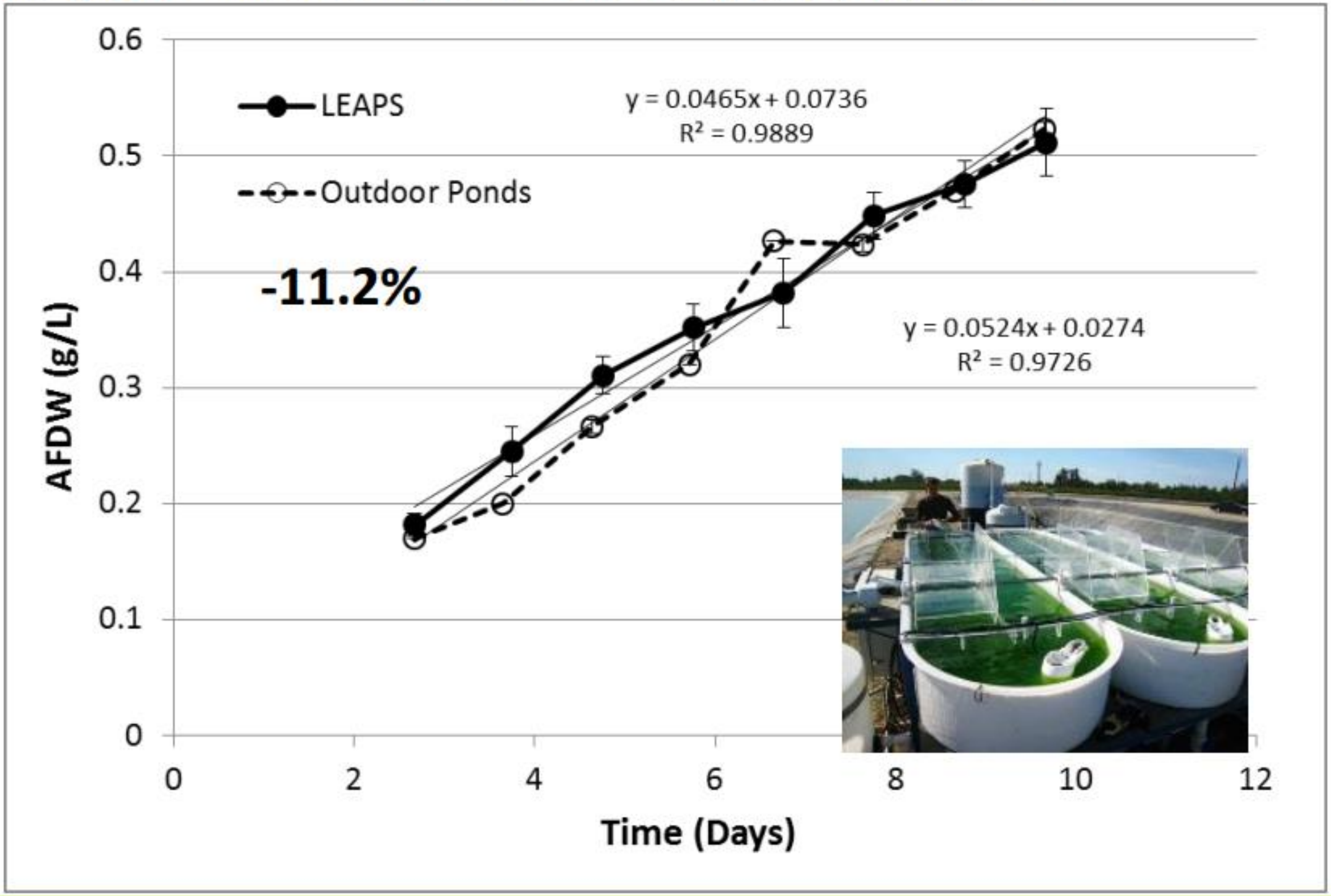
Algae Biocrude

Water

For reuse

Process Scheme – Scale-up Process Flow

The LEAPS Successfully Simulates *Chlorella sorokiniana* Outdoor Ponds (Dehli, CA, July). The Biomass growth model over predicts biomass productivity by 23%.



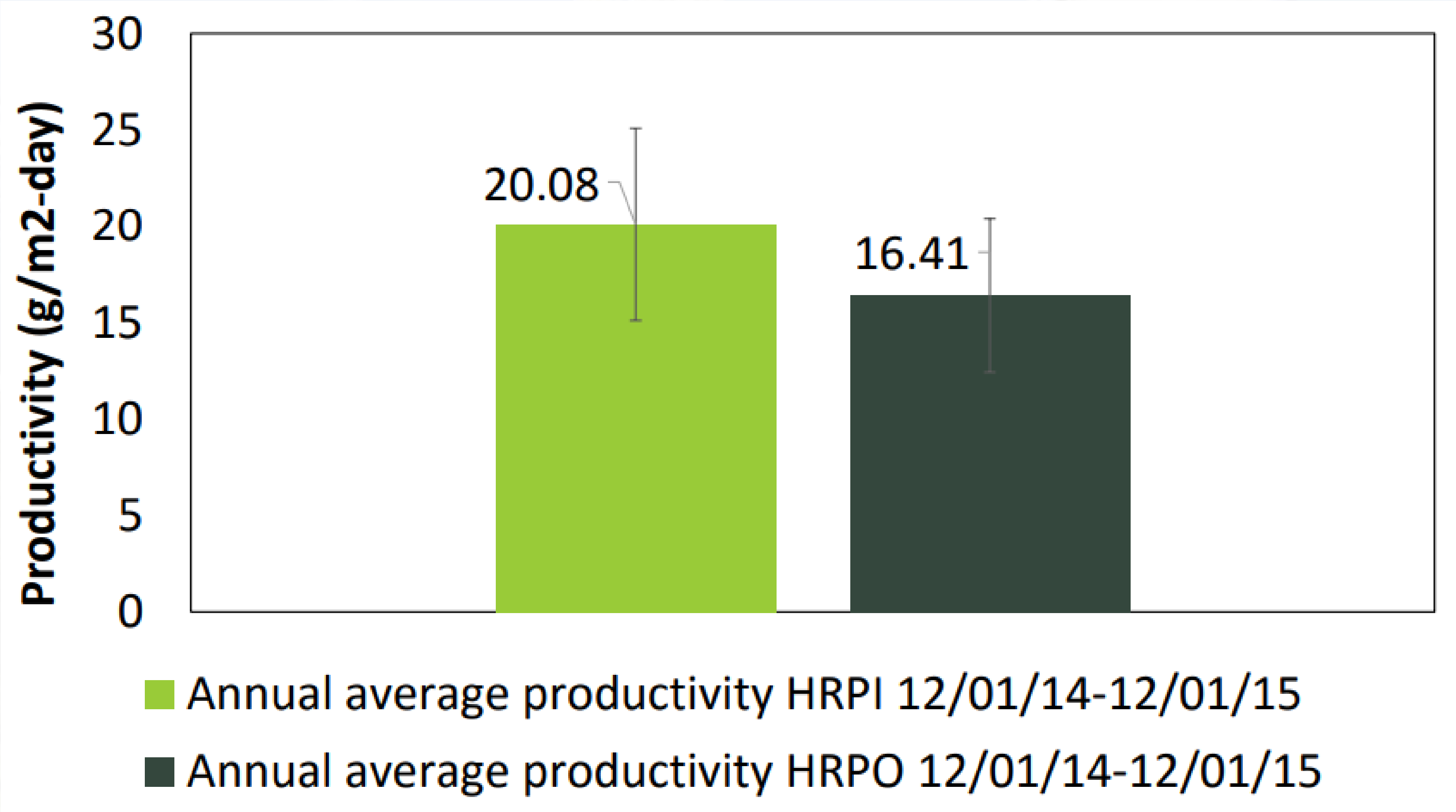
Process Scheme – Real example scale up

100 k gallons of 3% solids algae in decanted settling basin

Solar dried algae

ML 2.0 Annual average productivity

20 g/m2 day needed for 2500 gal/ac/yr.

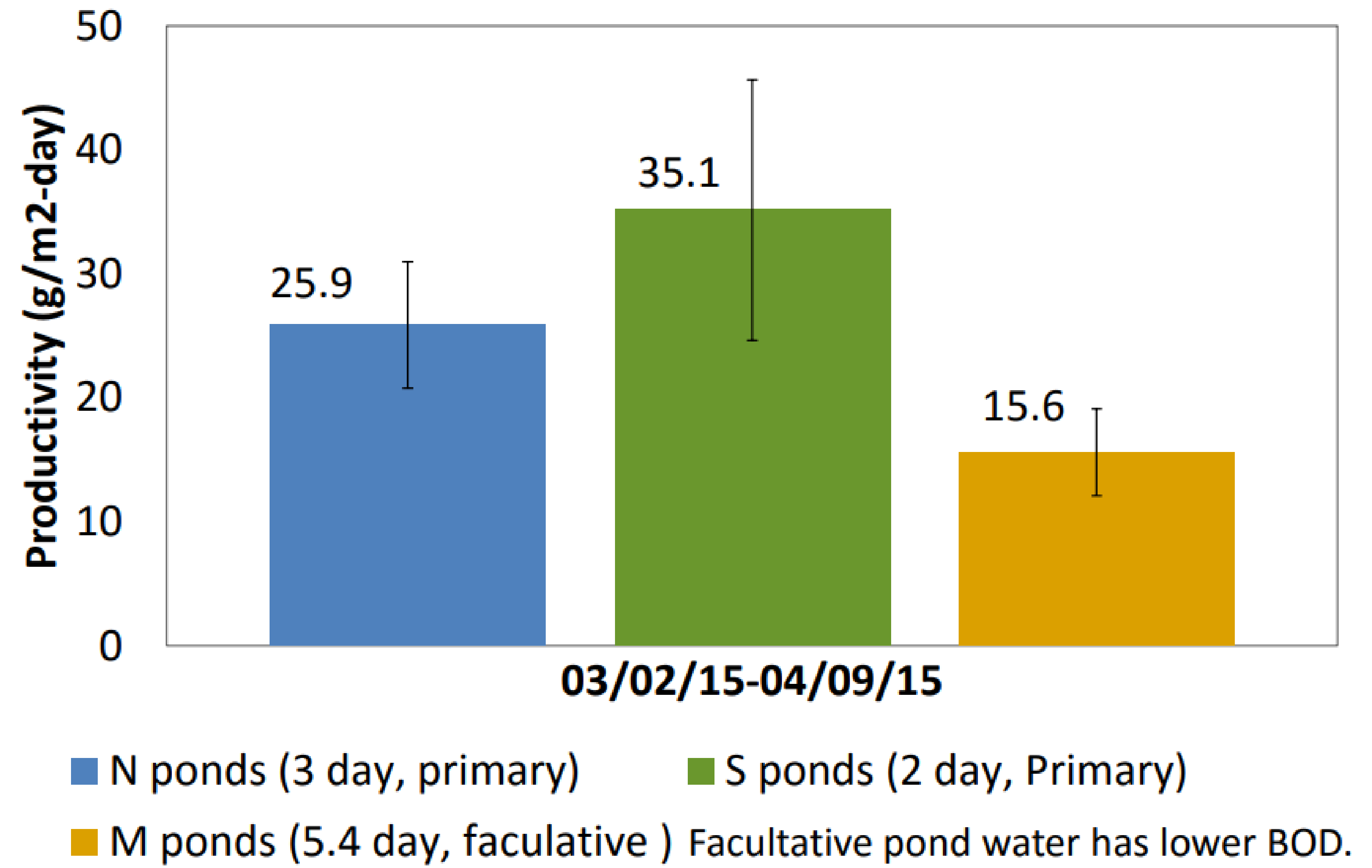


Gross productivity shown. Respiration etc. losses occurred from the full-scale inner to the outer raceways (high rate ponds, HRPI and HRPO) in series.

Harvesting suggested for between ponds and shorter residence time.

ML 2.4 Dilution and productivity

Conclusions: Shorter residence times and higher BOD (organic matter) loads are generally more productive



Facultative pond water has lower BOD.

Process Scheme – TEA/LCA Result Summary

MFSP 2014

$4.29-9.62 /GGE

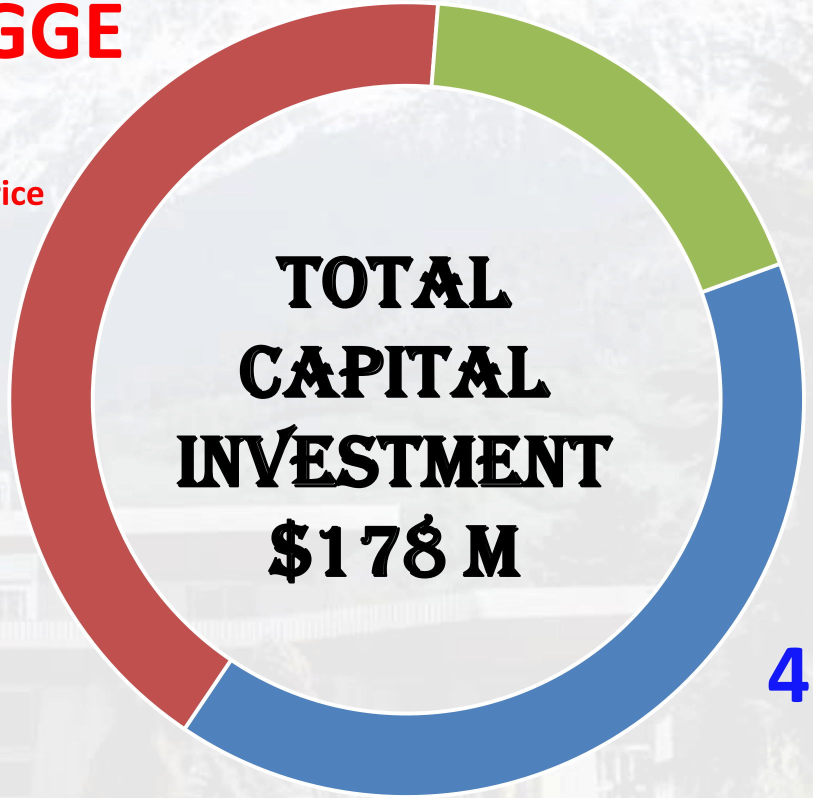
(2014 USD)

Minimum Fuel Selling Price

$3.0 /GGE

(13.3g CO_2e/ MJ)

87% reduction in Green Gas Emisions



MFSP 2011

4.08-9.14$ /GGE

Net Energy Ratio (Consumed/Produced):

0.39 → if >1 → it self-sustaining

Summary

1. Overview-Optimize productivity in out-door wastewater treatment algae raceways

2. Approach

- Characterize the full-scale system
- Optimize the pilot scale system

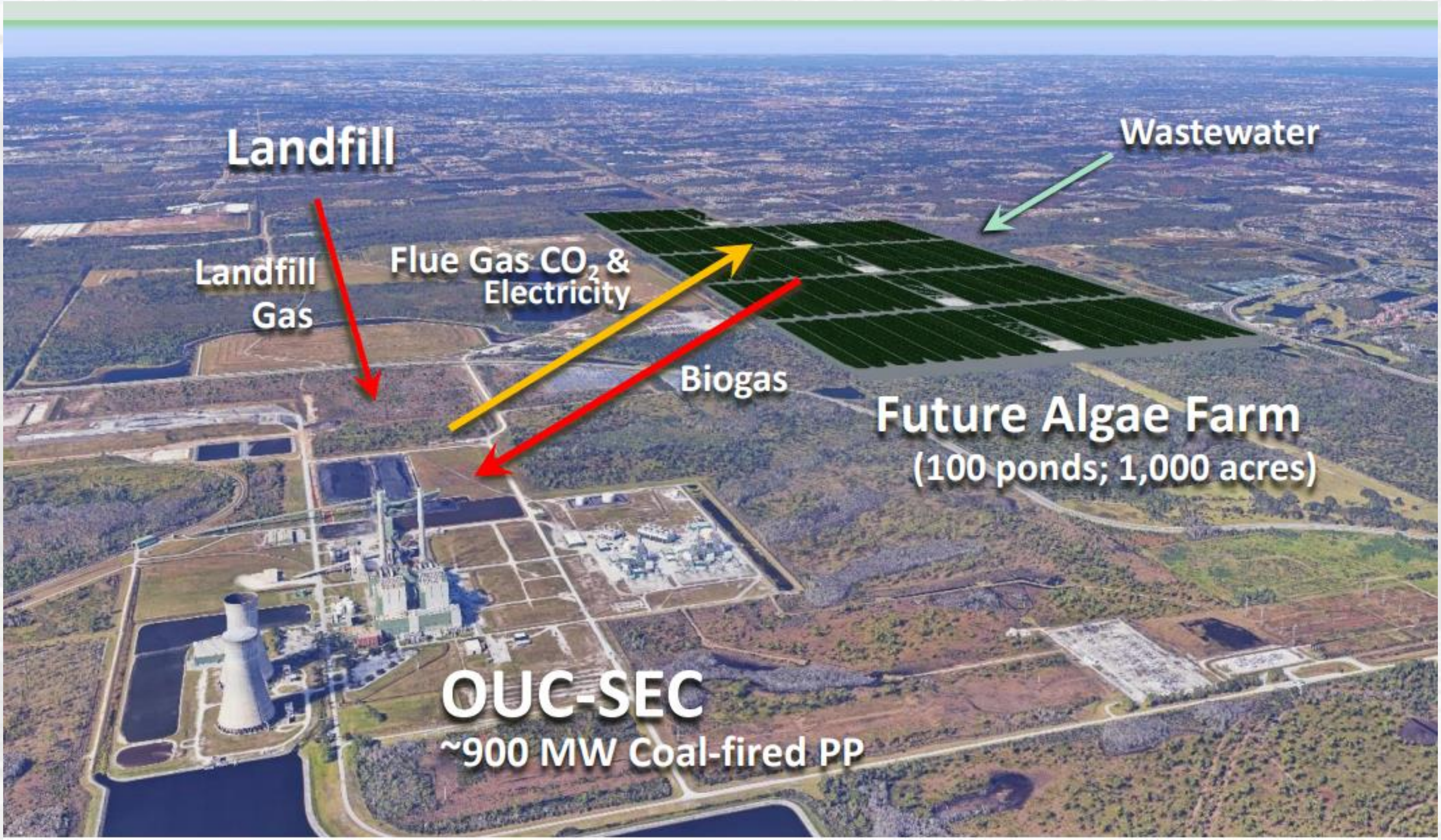
3. Technical Accomplishments/Progress/Results

- 33 g/m2day
- 0.35 g oil/ g algae
- 55% of carbon contained in fuel
- 4,100 gal/ac-yr

4. Relevance

- Increased biomass yield to 33 g/ m2 -day annual average,
- exceeding MYPP goals of 2,500 gal/ac-yr by 2018, and 3,700gal/ac-yr by 2020.

Future algae farm



Q & A

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