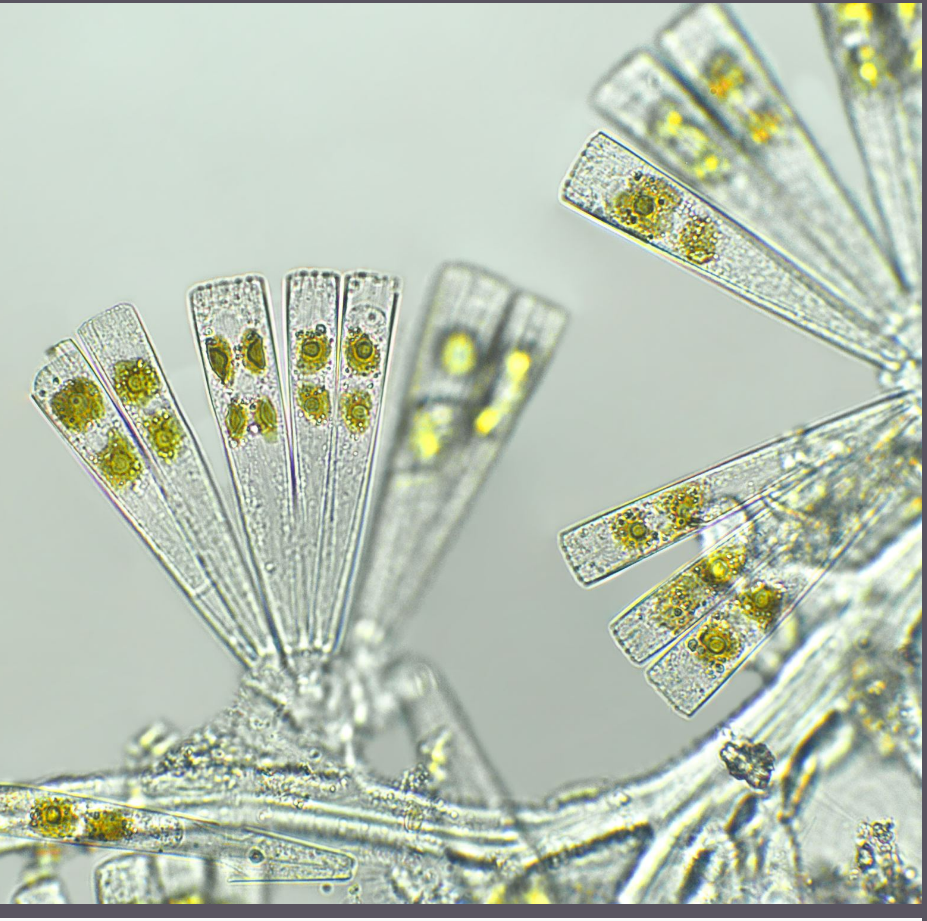
D.Sc. Paula Assemany

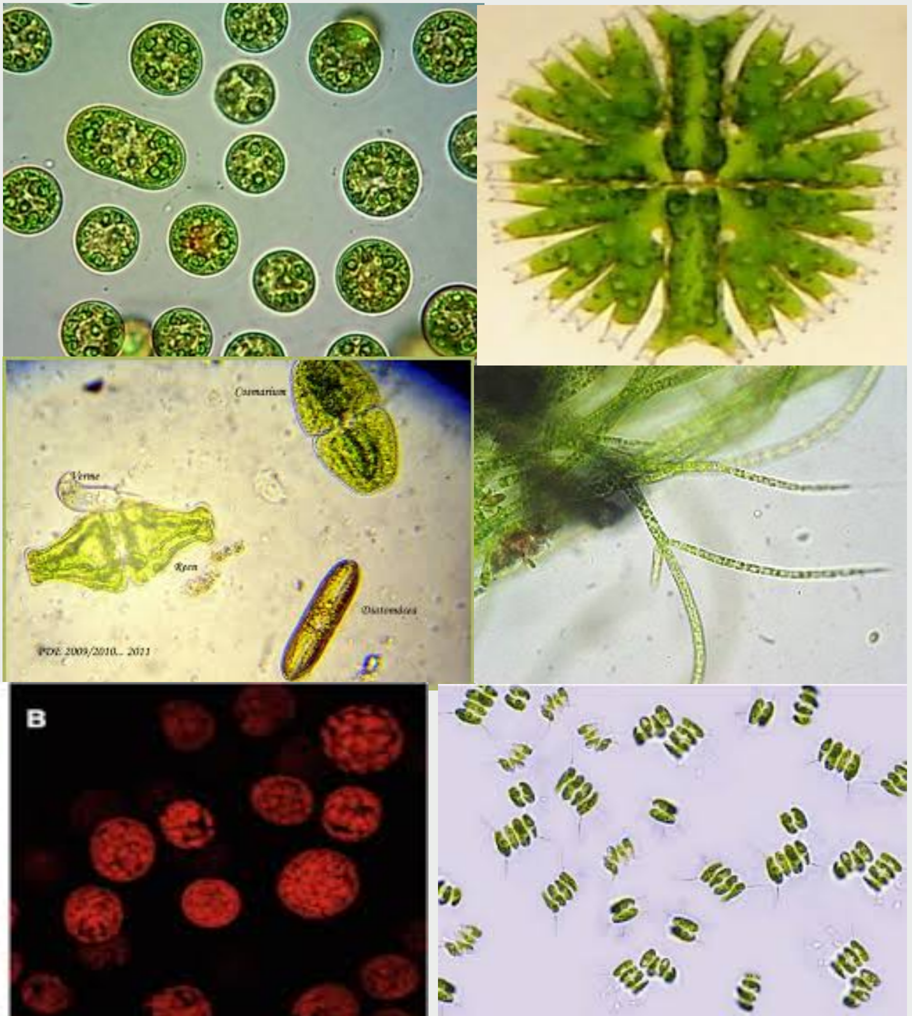
Federal University of Lavras, Brazil



MICROALGAE

In the wastewater treatment

Microalgae



"microorganisms that can grow photosynthetically"

(SHEEHAN, 1998)

SOLAR ENERGY

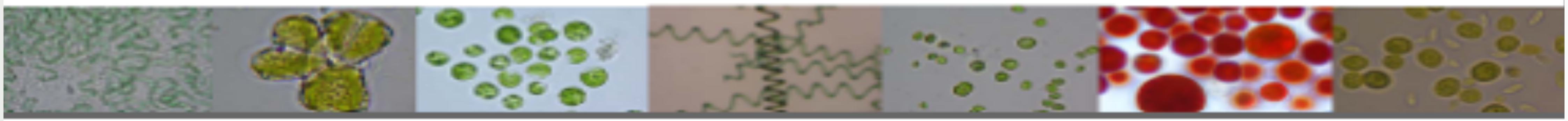
$$CO_2+NO_3^{-}+PO_4^{-3}+H_2O \longrightarrow [CH_nONP] + O_2$$

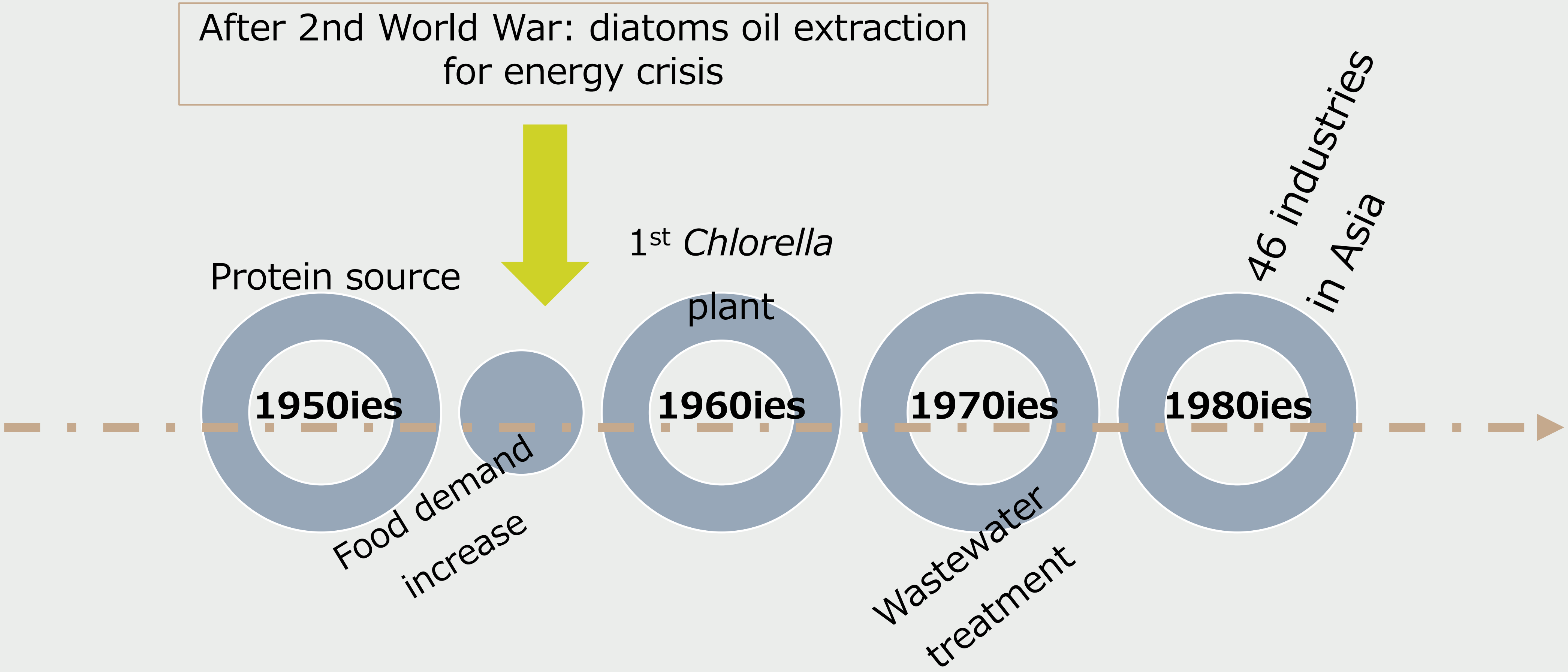
ALGAL BIOMASS

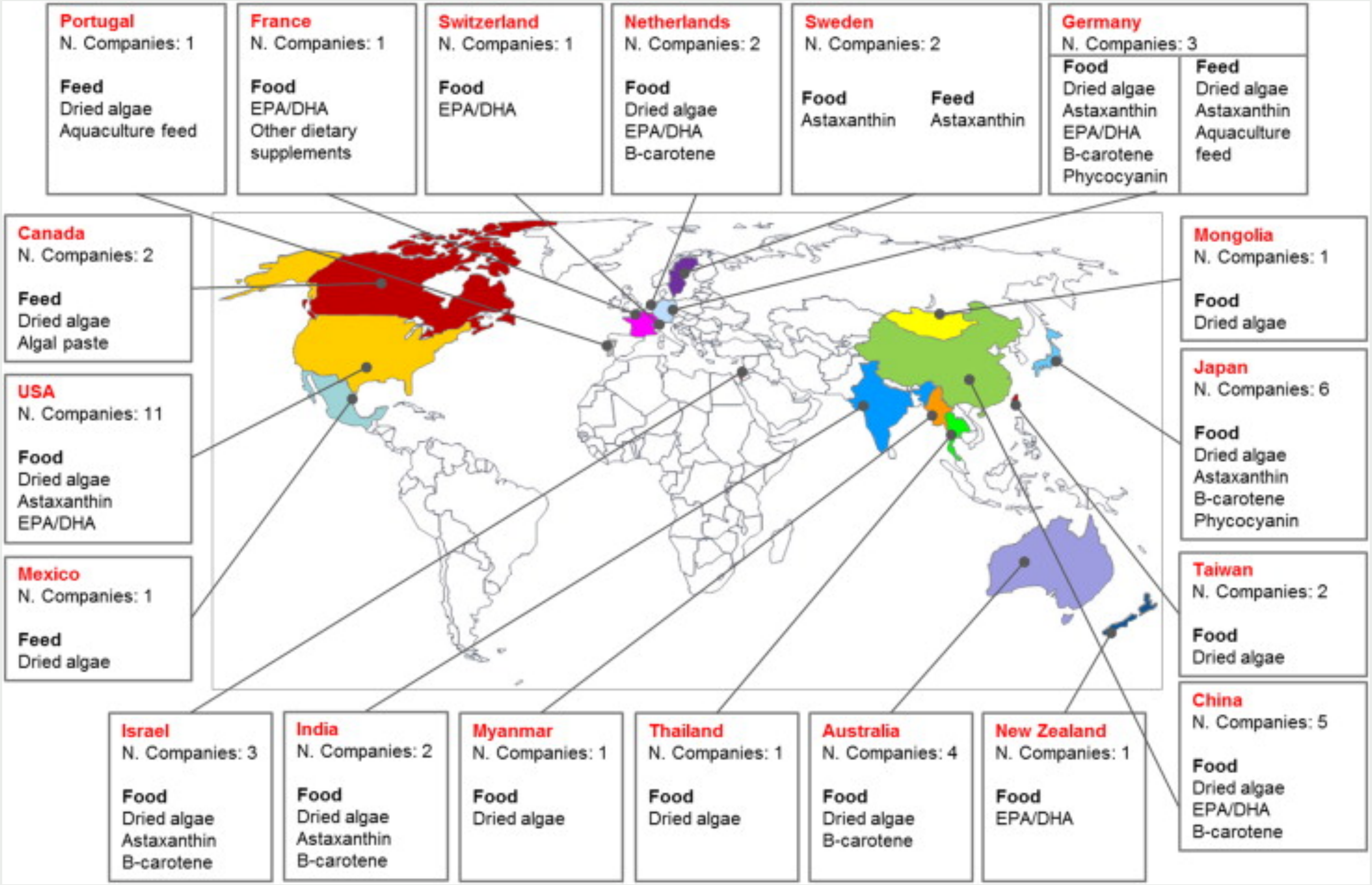
Microalgae

Great potential for biotechnology industry and **energy**:

- higher growth rate compared to other plant species
- possibility of cultivation throughout the year
- ability to grow in areas unsuitable for agriculture
- ability to develop in the most different climates




After 2nd World War: diatoms oil extraction for energy crisis
Protein source
1950ies
Food demand increase
1st Chlorella plant
1960ies
1970ies
Wastewater treatment
1980ies
46 industries in Asia



Global distribution of private companies producing commercial food and feed products derived from microalgae (Vigani et al., 2015)

Algae in Products Today

Country	Company	Technological level	Uses/applications
Brazil and United State of America (USA)	Solazyme	Commercial/ Flagship	Microalgae production and cosmetics products, bioplastics, oils, encapsulated lubricant and fuels
USA	Algenol	Demo	Personal care ingredients, foods, biofuels (from ethanol to crude oils), biofertilizers and biostimulants
	BioProcess Algae, LLC		Microalgae production and other products: feed (including fish), chemicals compost, nutraceuticals, ethanol and biodiesel
Denmark	Kalundborg Symbiosis	Demo	Wastewater treated and microalgae production
Portugal	A4F Algae for future	Industrial/Demo/Pilot	Bioengineering projects for the industrial microalgae production, biofuels, microalgae-based products and applications
	Algafarm (A4F Algae for future) Secil/Allmicroalgae	Commercial/ Demo	Microalgae (*Chlorella*) biomass production and other by-products (utilized for biofuels)
	Buggypower (Portugal), Lda	Demo	Algal biomass for biofuels production and other products (fatty acids, antioxidants, minerals, pigments, vitamins and others)
Spain	AlgaEnergy	Pilot	Microalgae production for agriculture, aquaculture, food and feed, natural extracts, cosmetics, gardening and biofuels
The Netherlands	(The Netherlands) TNO-Valorie		Biofuels (biodiesel) and by-products
	(The Netherlands) AlgaePARC		Develop technologies both on a lab and pilot scale for microalgae production and by-products

Mendonça et al. (in press)

Microalgae production

The world's oil demand in 2018 was 98.8 million barrels per day (IEA, 2018).

In a scenario of meeting 5% of this demand, cultivating microalgae with 40% lipids:

$$106CO_2 + 236H_2O + 16NH_4^+ + HPO_4^{-2} \rightarrow C_{106}H_{181}O_{45}N_{16}P + 118O_2 + 171H_2O + 14H^+$$

High demand of water and nutrients

61.4 million tons of N would be necessary to meet such production (~58.9% of what was consumed in agriculture in the entire world in 2010 - Heffer, 2013).

8.7 million tons of P would be required.

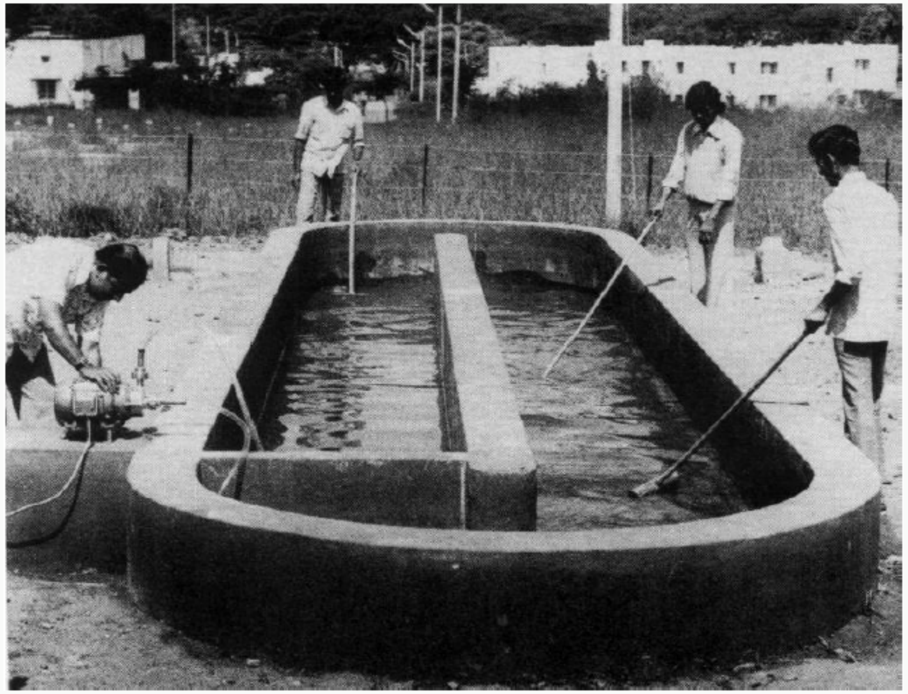
The water consumption would be 2.6 billion m³.

Couto et al. (2020)

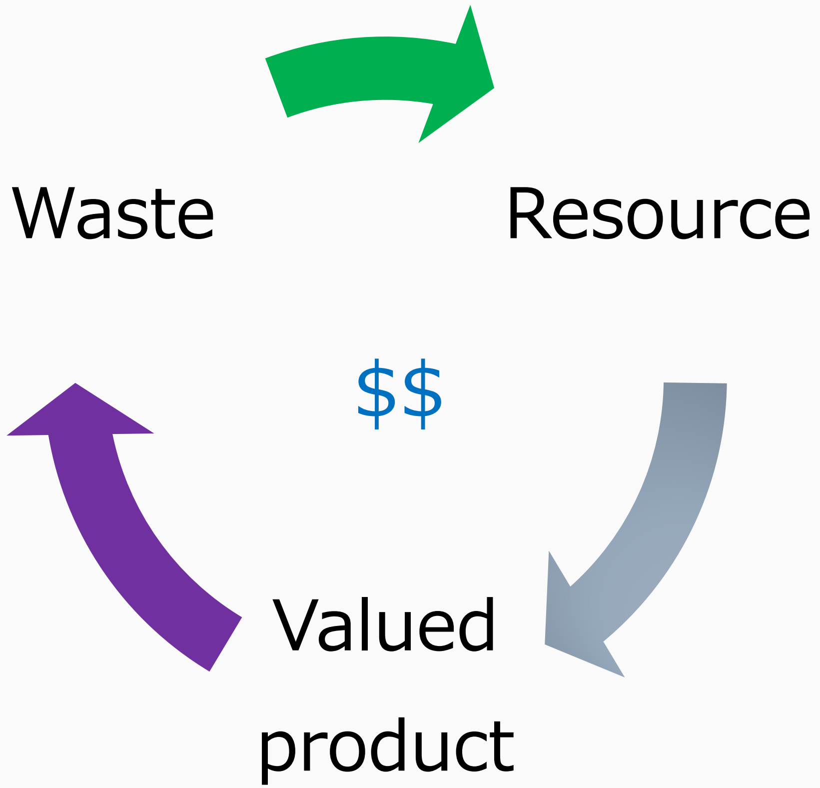
How to stimulate the growth of microalgae in a rational and sustainable way up to the commercial scale?

Wastewater as growth medium

- Inputs “at no cost”
- Reduced production costs
- Recycling of nutrients from the wastewater



Change of perspective

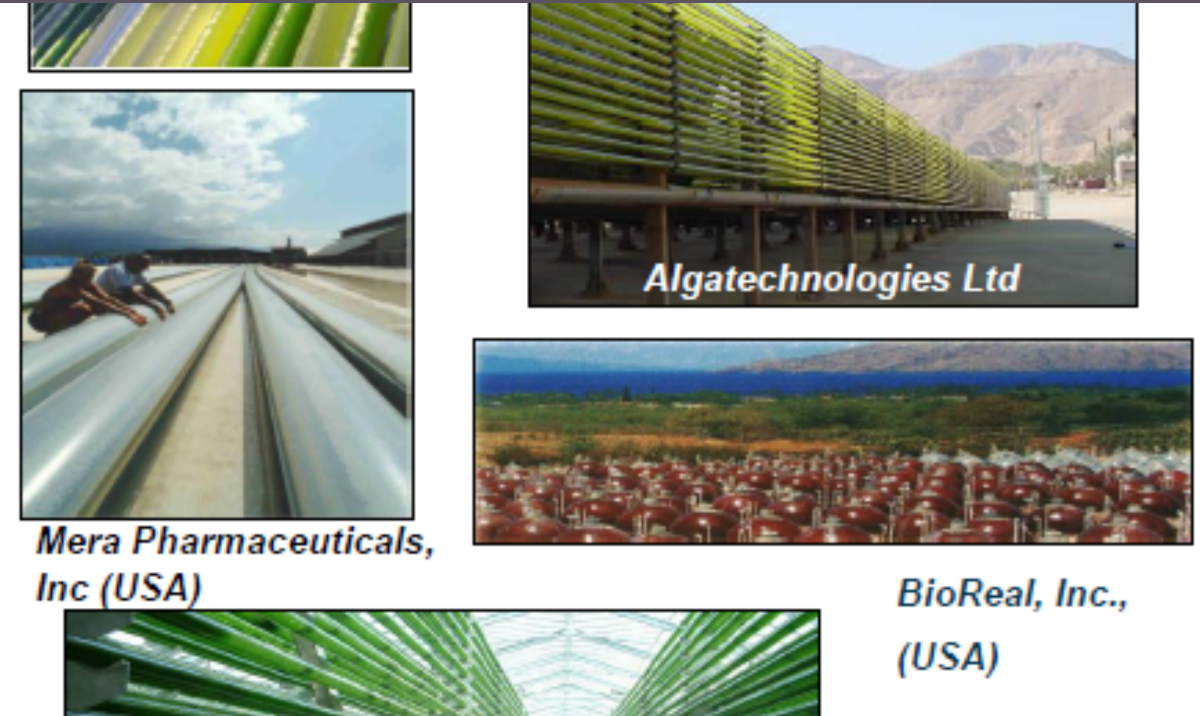


Integrated resource recovery

Nutrient removal

✓Recovery

Closed Photobioreactors



<u>Biomass productivity</u>:

1.5 kg/m².day (~158 ton/ha.year)

<u>Maximum biomass concentration</u>:

4 kg/m³

Open Photobioreactors

<u>Biomass productivity</u>:

0.025 kg/m^2.day (~82 ton/ha.year)

<u>Maximum biomass concentration</u>:

1 kg/m^3 (0.5 kg/m^3 - typical)

High rate algal ponds (HRAPs) or raceways

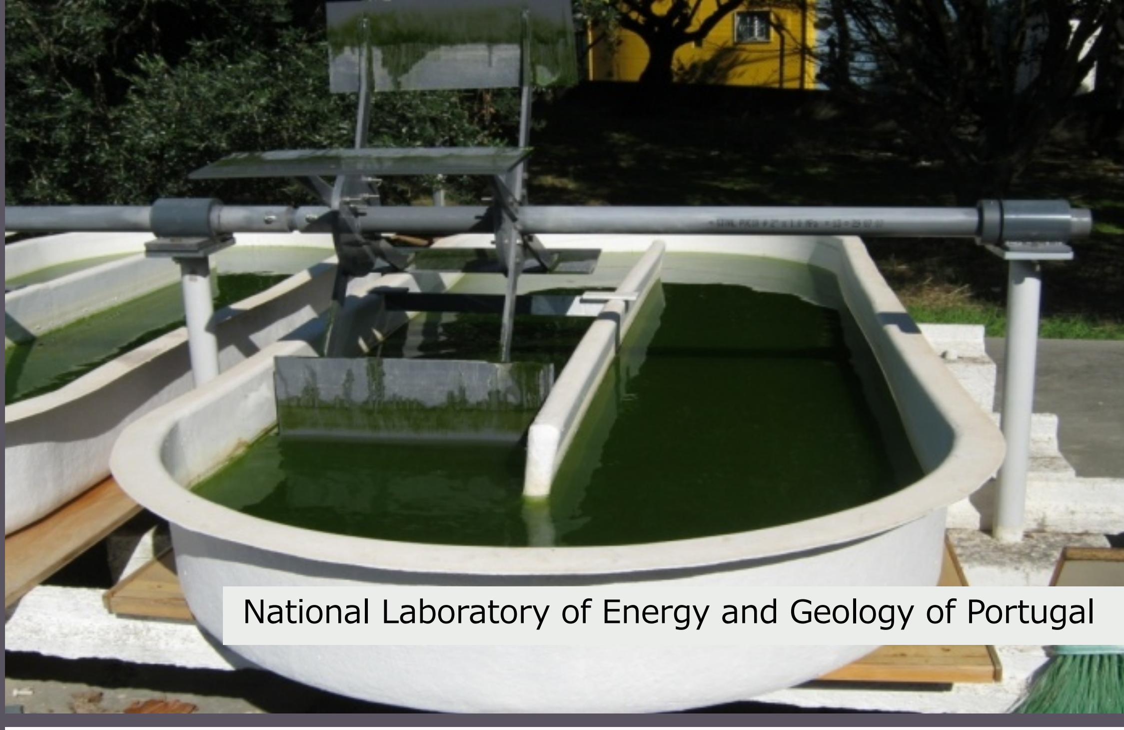
for wastewater treatment and biomass production

- **Sustainable wastewater treatment plants**
- **Polishing unit - nutrient recovery**
- **Easy operation and reduced construction and maintenance costs**

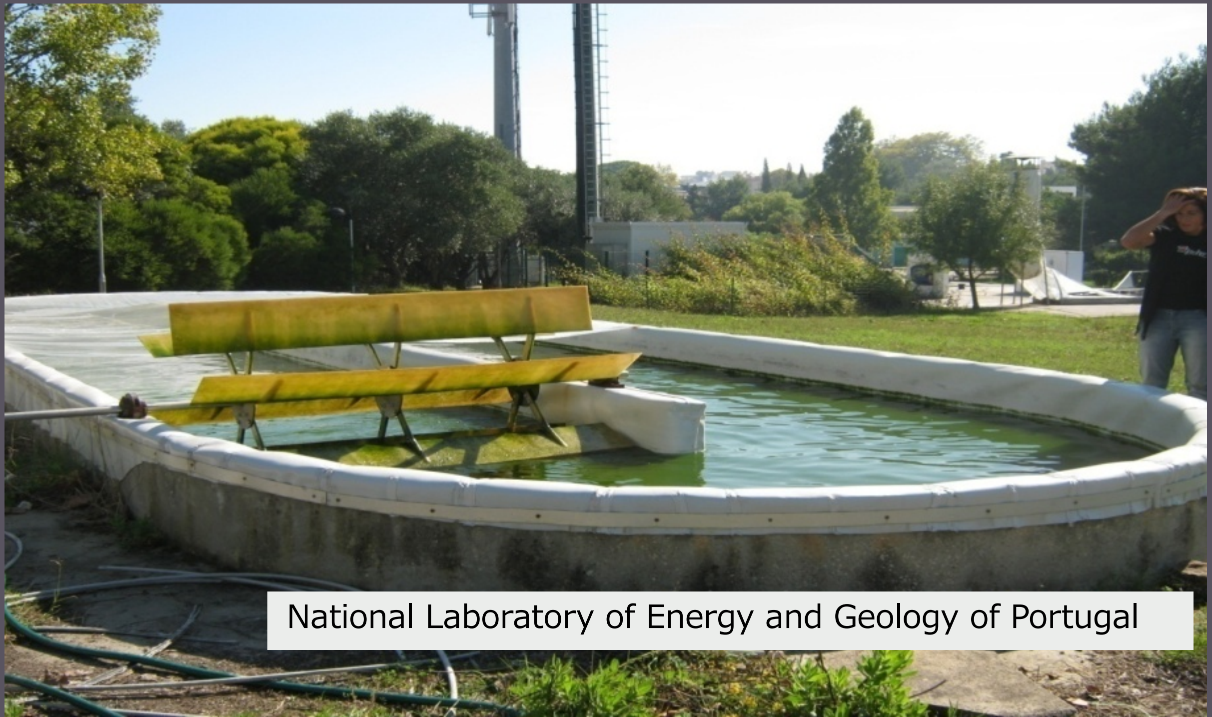
HRAPs in Christchurch, New Zealand (5 ha)

HRAPs in Cambridge, NZ (2 ha)

Microalgae in the wastewater treatment

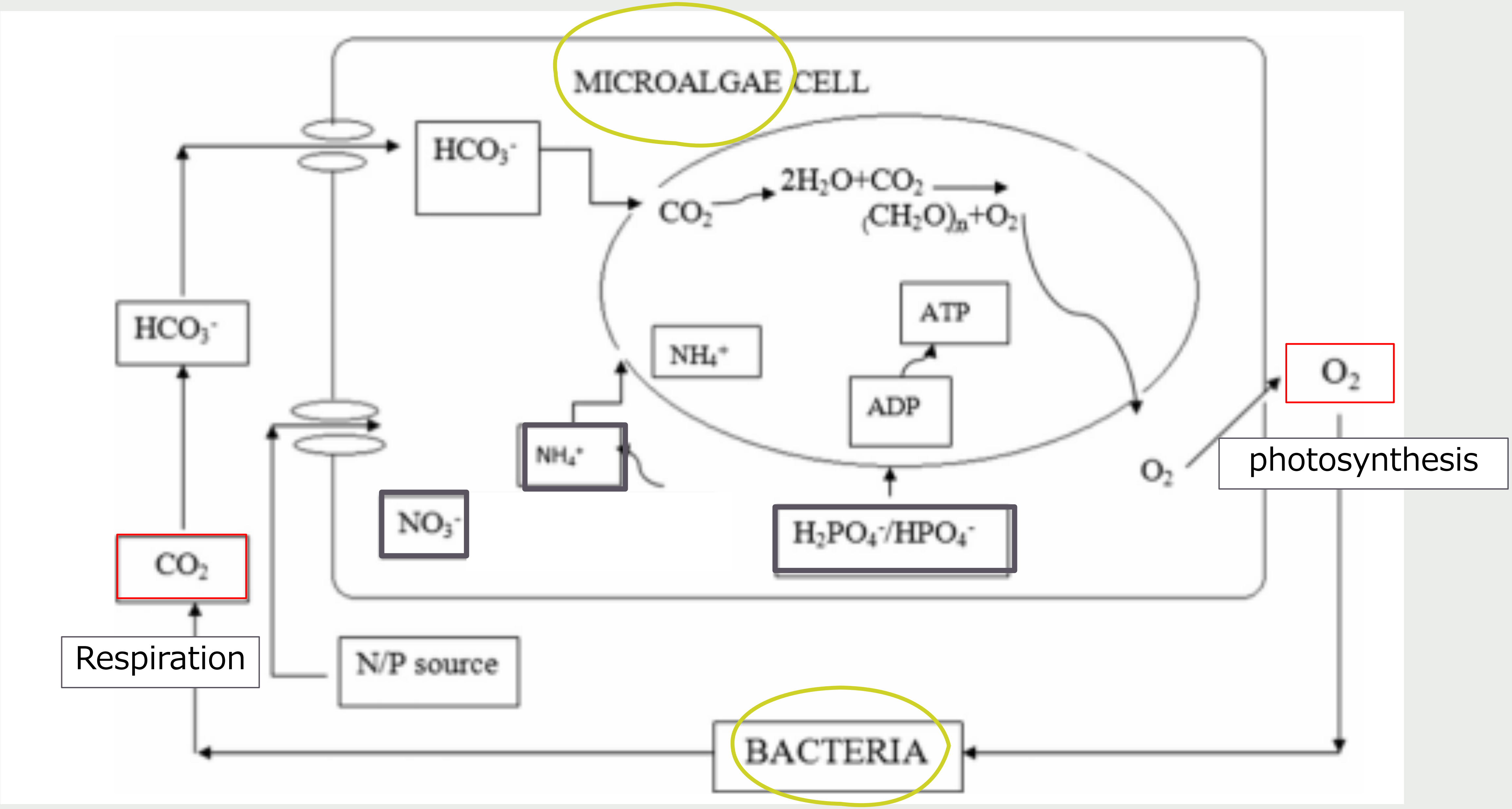


National Laboratory of Energy and Geology of Portugal



National Laboratory of Energy and Geology of Portugal

- Symbiotic relationship between algae and heterotrophic bacteria
- Mixotrophic metabolism
- Native species
- CO_2 assimilation



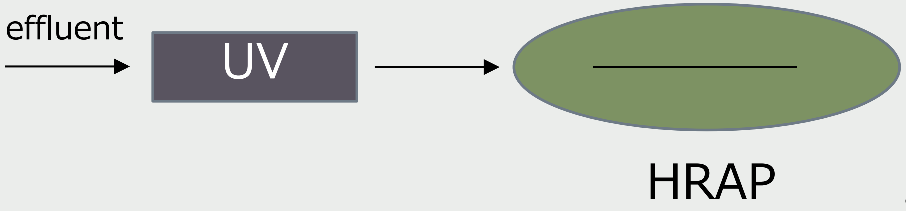
Abinandan and Shanthakumar (2015)

Effluent	Microalgae strain	Reactor	Efficiency removals (%)			Biomass productivity (g TSS m^{-2} d^{-1})	Reference
			N	P	Organic Matter		
Rural streams with nutrient pollution	Consortium: *Spirogyra sp., Cymbella sp and Navicula* sp.	HRAP (20 m^2) with filamentous algae matrix	18% of TN	65.8% of TP and 68.1% of PO_4^{3-}	-32.8% of total COD	-	Kim et al. (2018)
Primary settled domestic wastewater	Consortium: *Mucidosphaerium pulchellum* (85% of abundance)	HRAP 20 cm depth (2.23 m^2) with CO_2 addition	69.3 - 78.9	19.2 - 34.3	-	2.1 - 10.1	Sutherland et al. (2014)
Primary settled domestic wastewater	Consortium: *Micractinium* sp. and *Desmodesmus* sp.	HRAP (1.25 ha) with CO_2 addition	5.6 - 67.4	14.0 - 24.4	81.8 - 92.1% of dissolved BOD_5	4.4 - 11.5 g VSS m^{-2} d^{-1}	Craggs et al. (2012)
Landfill leachate	*Chlorella vulgaris, Spirulina* sp., *Scenedesmus quadricauda*	HRAP (0.27 m^2)	94.3 - 98.7	49.3 - 85.6% of PO_4	69.4 - 90.7% of COD	9.2 - 26.3 g VSS m^{-2} d^{-1}	Mustafa et al. (2012)
Pre-treated diluted swine manure	Consortium: *Chlamydomonas, Chlorella* and *Nitzschia*	HRAP (1.5 m^2)	62 - 88% of TKN	-	57 - 67 of COD	5.7 - 27.7 g m^{-2} d^{-1}	De Godos et al. (2009)

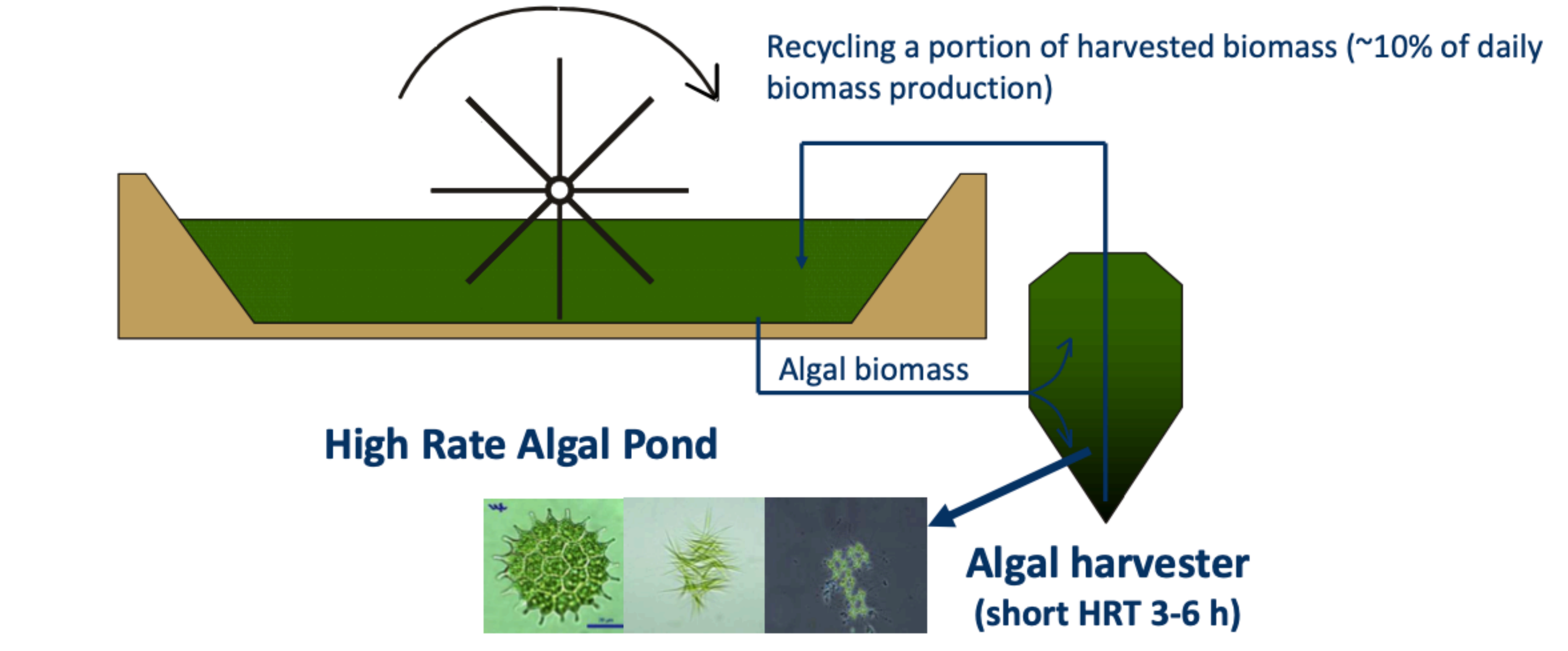
Mendonça et al. (in press)

Devices for biomass production increase:

- CO_2 addition
- Pre-UV disinfection
- Biomass recirculation



Santiago et al. (2013)



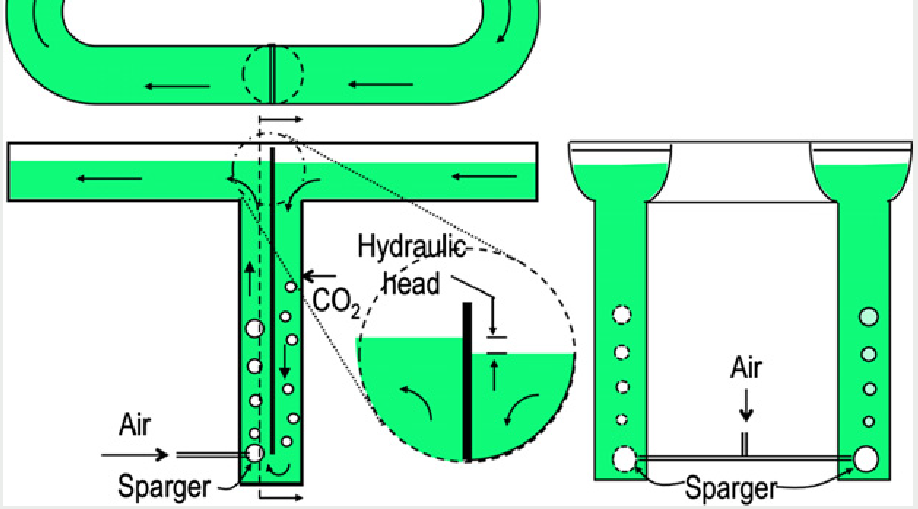
Park et al. (2016)

CO_2 addition

- Avoids pH increase and nutrients loss
- Depends on the WW C/N ratio

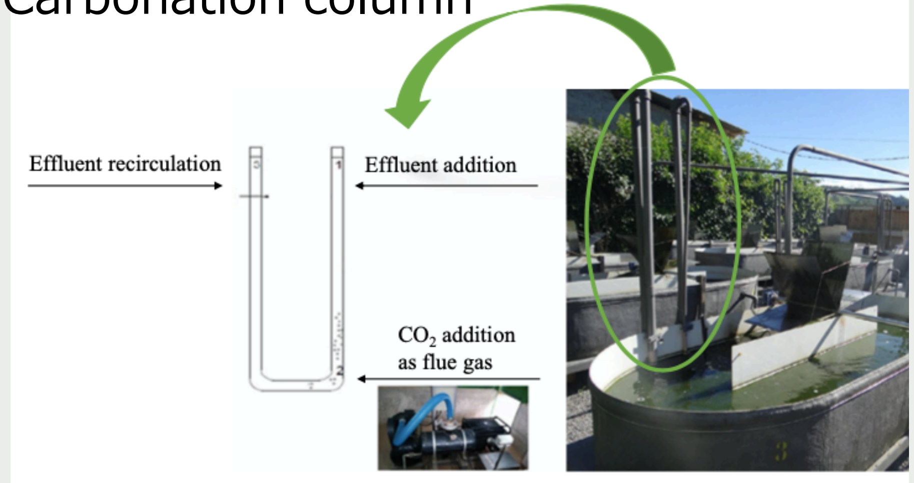
(i.e. domestic sewage)

➤Sump



Ketheesan and Nirmalakhandan (2012)

➤Carbonation column



Couto et al. (2020)

Atmospheric emissions as CO_2 source

Microalgae strain	Growth medium	Reactor	CO_2 source	CO_2 concentration (%)	Biomass productivity ($g.L^{-1}.d^{-1}$)	Reference
Consortium (predominance of *C.vulgaris*)	Domestic sewage after septic tank	HRAP	Exhaust gas of gasoline combustion	5.9	6.12 $g.m^{-2}.d^{-1}$	Assis et al. (2019)
Nannochloropsis oculata	Synthetic medium	HRAP	Coal-fired power plant	11 - 14	26.4 $g.m^{-2}.d^{-1}$	Cheng et al. (2015)
Tetraselmis sp.		10 L Glass Flasks	Cement flue gas	12 - 15	0.057	Olofsson et al. (2015)
Spirulina sp.		Tubular Photobioreactor	Thermoelectric industry	12	0.08	Radmann et al. (2011)
Scenedesmus obliquus					0.05	
Synechococcus nidulans					0.04	
Chlorella vulgaris					0.09	
Nannochloropsis gaditana		Flat-Panel reactor	Coal-fired powerplant	10 - 15	0.078	Rodríguez-López et al. (2020)
Chlorella sp.		Bubble column Photobiorreator	Coke oven Stell	23	0.13	Chiu et al. (2011)
Desmodesmus abundans		3L Photobioreactor	Cement kiln dust	25	0.227	Lara-Gil et al. (2016)

Mendonça et al. (in press)

Biomass harvesting

- Settlers
- Sedimentation ponds
- Coagulation and floculation process
- Biofilm reactors (attached growth)

Concentration step will depend on biomass valorization route

Assis et al. (2020)

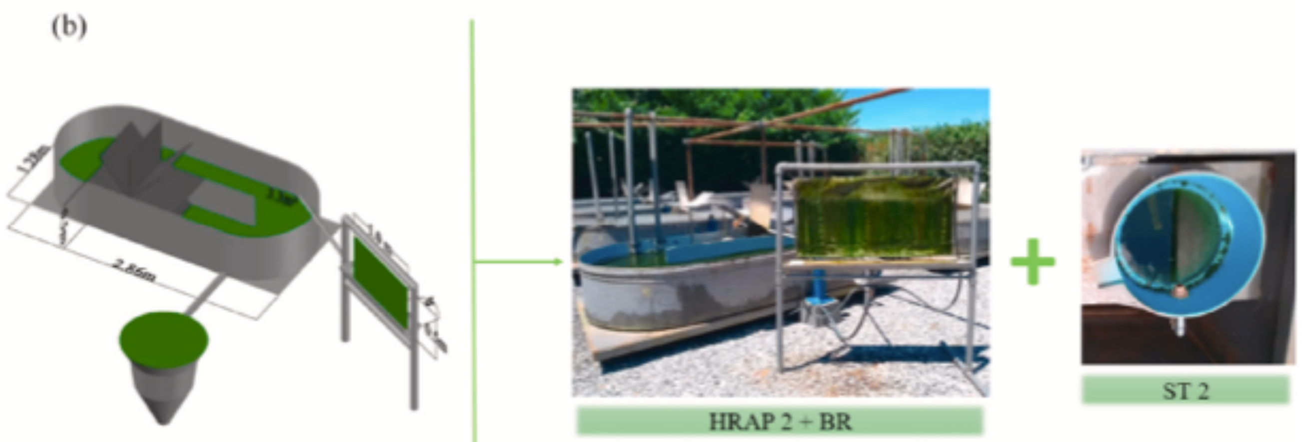
Hybrid reactor

HRAP + biofilm reactor

HRAP for WW treatment

Biofilm for biomass separation and harvesting

- ✓ **Presence of BR in a HRAP was able to supply the demand for CO_2 (Assis et al., 2017)**
- ✓ **Easiness of biomass harvesting**



Characteristics of separation and harvesting of the concentrated biomass in the settling tanks and in the BR (standard deviations are shown in parentheses).

		SVI (ml/g)	Humidity* (%)	Harvesting (g/day)
System 1	ST 1	21.12^{a} (7.71)	$\boxed{91.84^{a}}$ (1.79)	2.64^{b} (1.04)
System 2	ST 2	29.65^{a} (15.25)	91.67^{a} (2.01)	$\boxed{2.23^{b}}$ (1.36)
	BR	–	$\boxed{93.89^{a}}$ (4.99)	11.45^{a} (7.98)
	Total (ST 2 + BR)	–	–	$\boxed{13.68}$

Biomass production in HRAPs and BR (standard deviations are shown in parentheses).

		Production of chlorophyll-a		Total biomass production (volatile solids)	
		Production (g/m^2)	Productivity (g/m^2.day)	Production (g/m^2)	Productivity (g/m^2.day)
System 1	HRAP 1	0.55^{b} (0.38)	0.05^{a} (0.04)	36.75^{b} (18.05)	$\boxed{3.68^{a}}$ (1.81)
System 2	HRAP 2	0.48^{b} (0.29)	0.05^{a} (0.03)	28.79^{b} (11.28)	2.88^{a} (1.13)
	BR	1.64^{a} (0.93)	0.08^{a} (0.04)	64.28^{a} (29.83)	3.25^{a} (1.10)
	Total (HRAP 2 + BR)	2.12	0.13	93.07	$\boxed{6.13}$

Assis et al. (2020)

- Low lipid content
- Less noble uses
- Native species

Directly influenced by WW characteristics

Nutritional aspects from wastewater grown biomass

Composition (%)	Beer biomass	Sewage biomass
Neutral lipids	14.9 (0.1)	11.7 (1.6)
Membrane lipids	3.0 (0.8)	9.9 (1.7)
Total lipids	17.9 (0.6)	21.6 (2.6)
Carbohydrates	30.2 (0.5)	3.6 (0.8)
Proteins	31.4 (0.0)	26.3 (4.7)
Ash	15.5 (0.0)	40.0 (8.1)

Mean values, with standard deviation in parentheses

Assemany et al. (2020)