Economic Wastewater Treatment and Biofuel Prospects

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Where do we start ?

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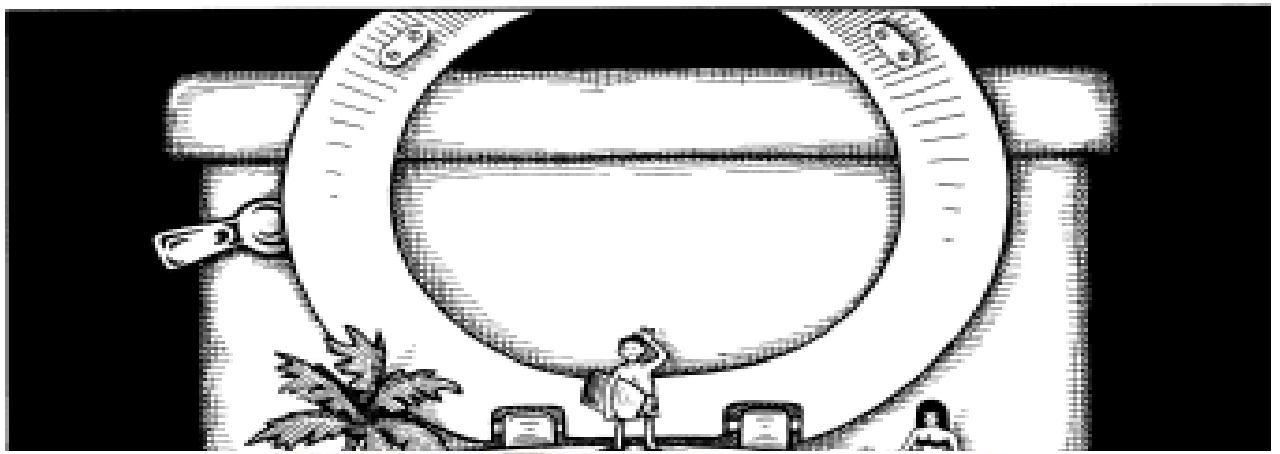
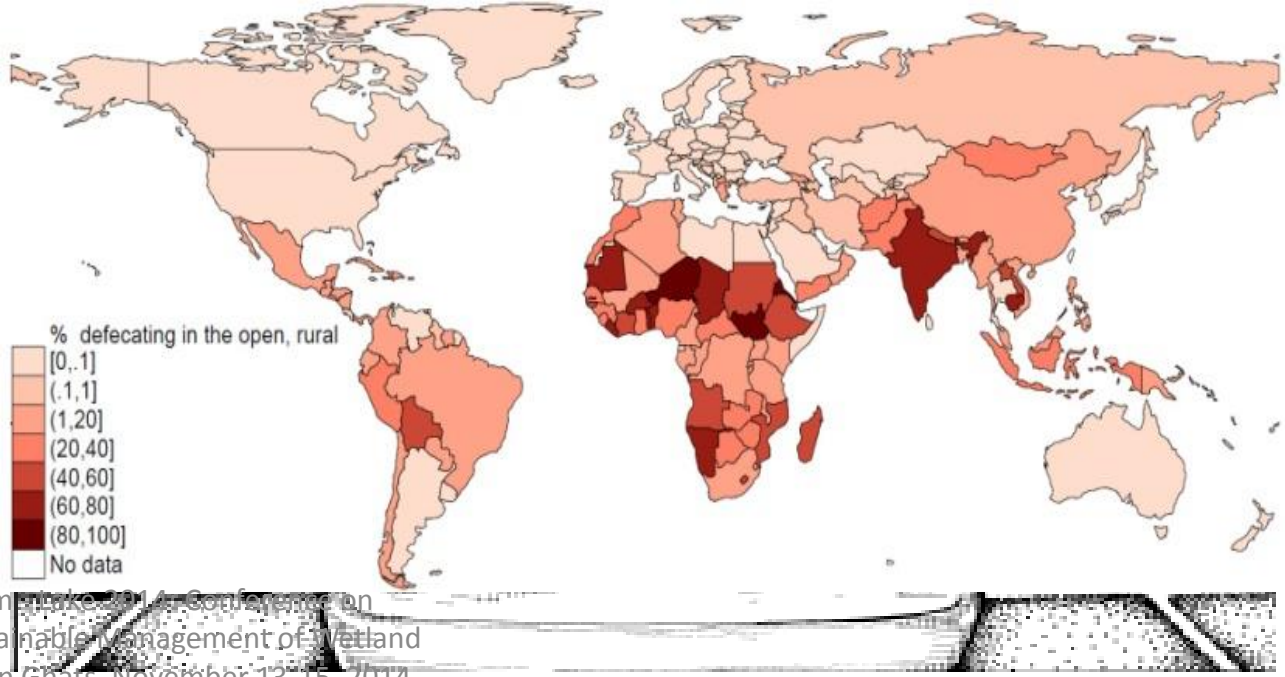
Where Are we Running Away From?
How Far Can we Run?





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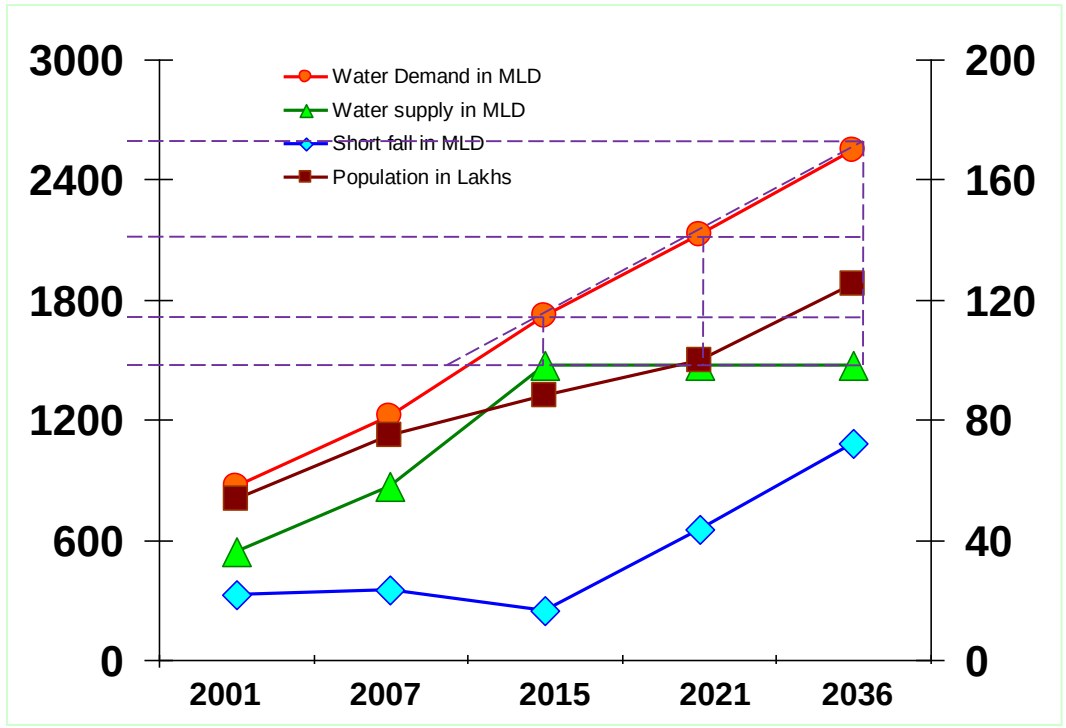
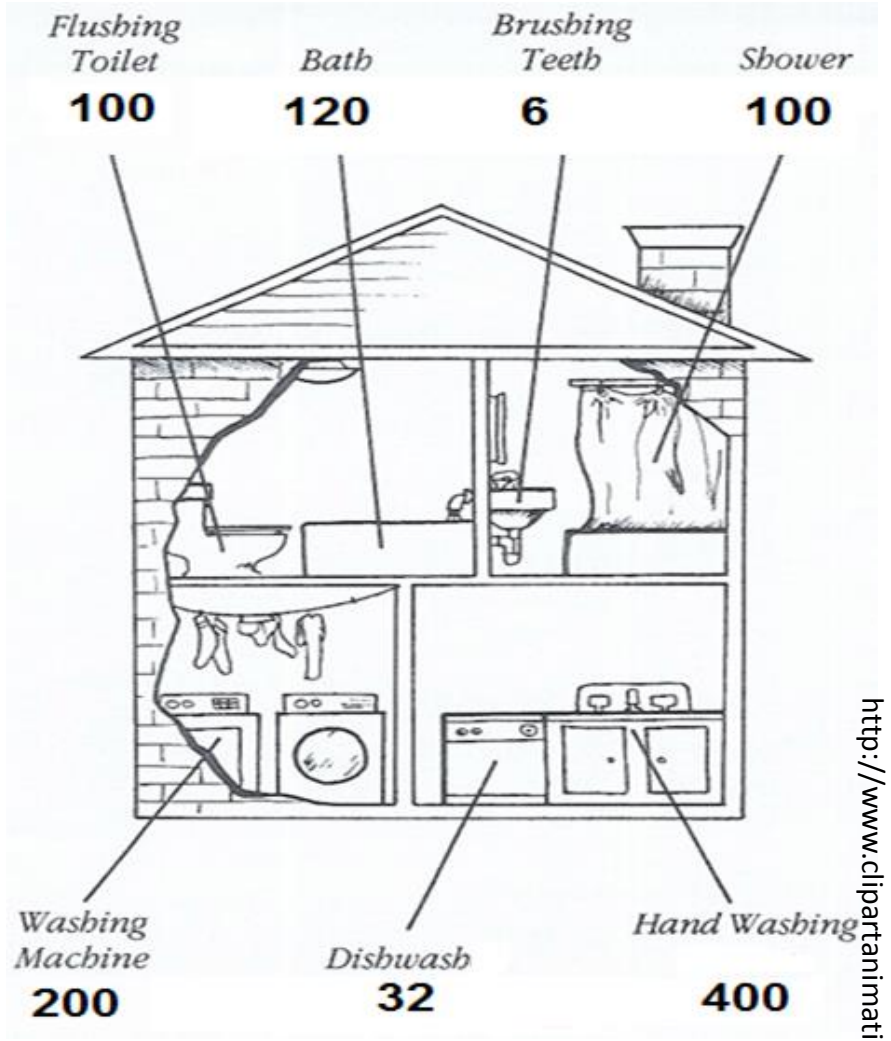
Water utility & supply; Wastewater generation per capita
How do we calculate?





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What are the visible effects/impacts of nutrient enrichment ?

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How Do I estimate Treatment parameters?

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Approach followed

- Physico-chemical Analysis and analysis of biota
- Nutrient remediation and nutrient budgeting
- Isolation, selection of algal consortia for examining nutrient removal and biomass production
- Growth and lipid production studies – batch and Continuous culture
- Assessment of the potential of algal groups for complete nutrient remediation and biofuel production in Bangalore

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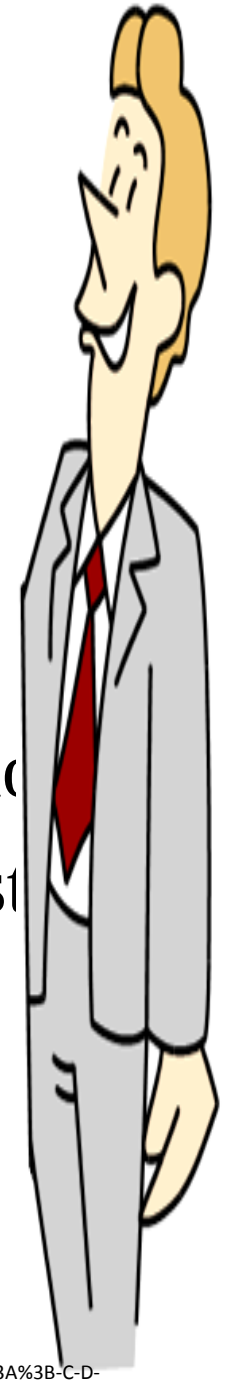
Major Findings

- Treatment abilities of urban wastewater fed ponds/water bodies
- Macrophytes interference in Pond functionalities & Zonation
- Nutrient budgeting – Scope for N and P recovery from urban ponds
- Algal functionalities in treatment ponds: *Euglena* sp.
- Lipid content and nutrient removal in Batch mode
- Continuous Algal bioprocess for WW treatment and biofuel productio
- Assessment of feasibility for integration of algal bioprocess into exist treatment network in Bangalore



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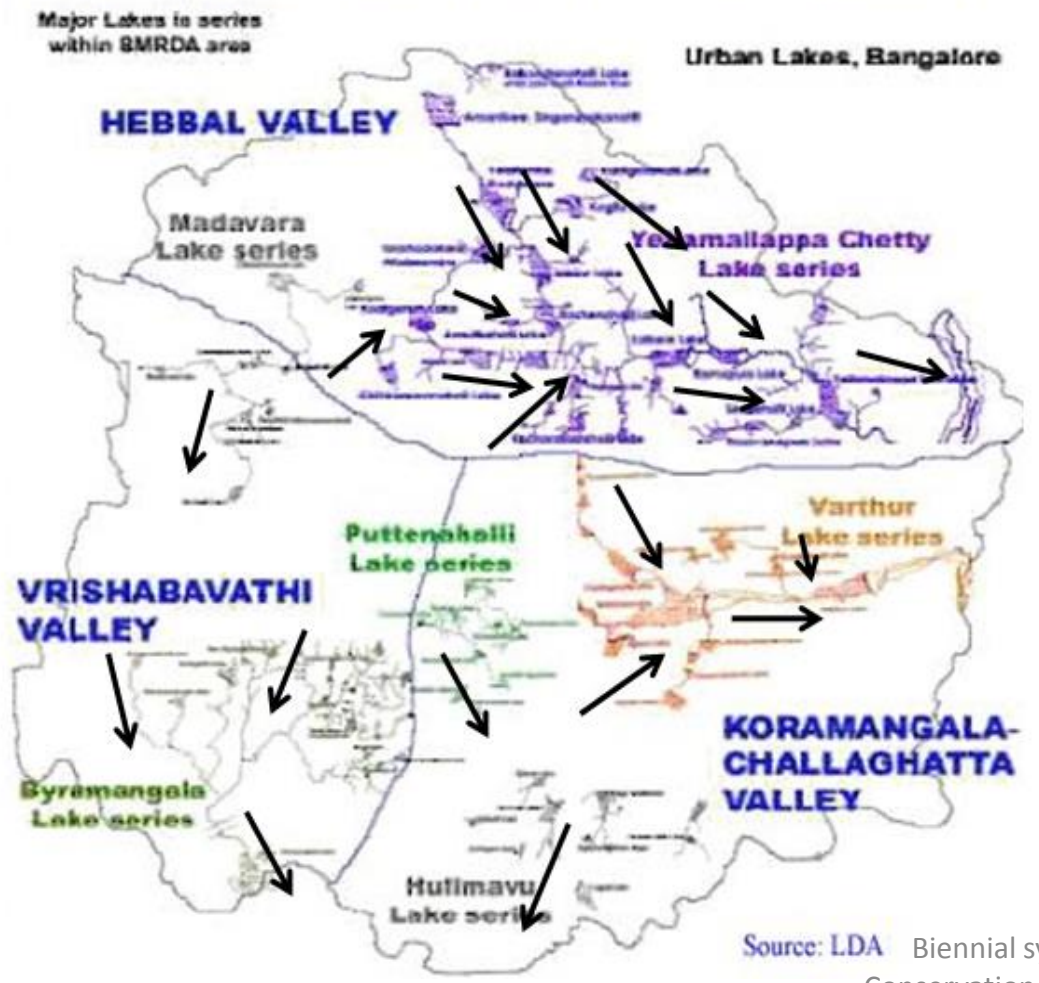
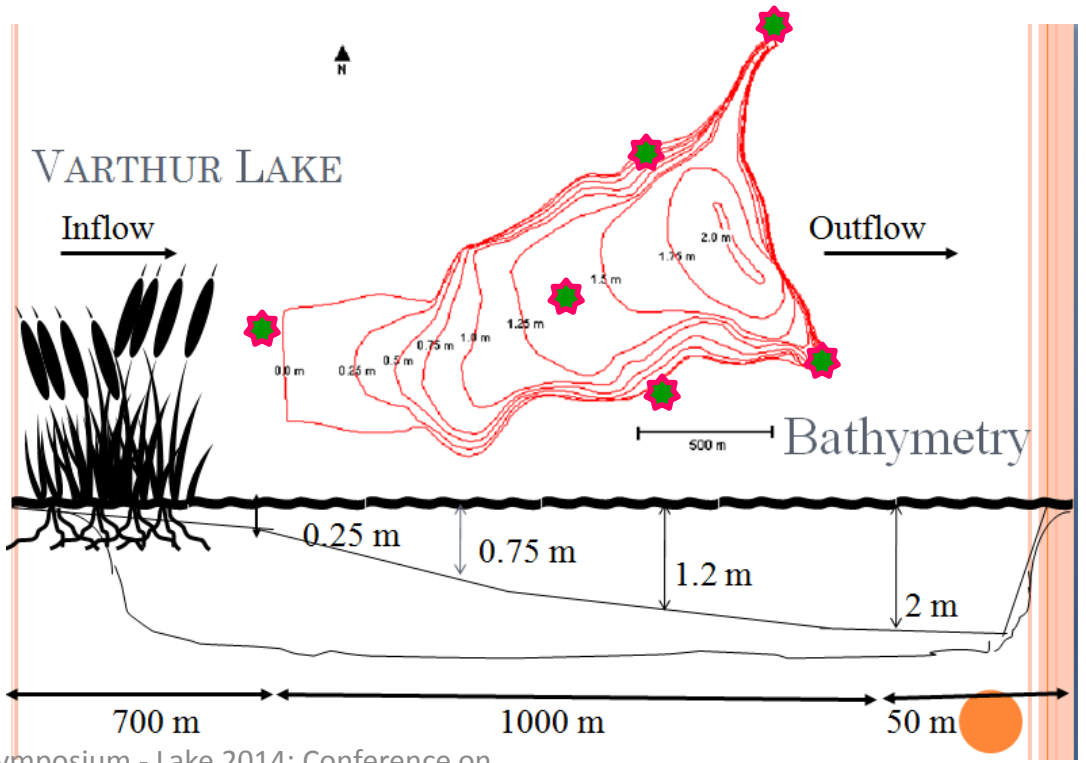
Major Findings

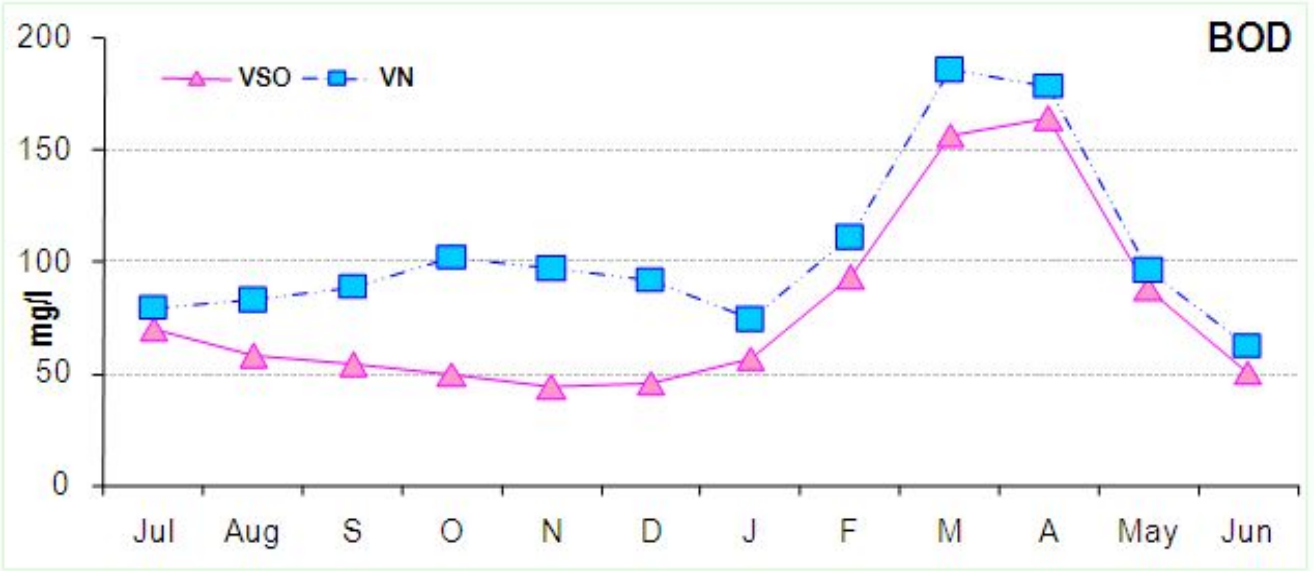
- Treatment abilities of urban wastewater fed lakes/water bodies





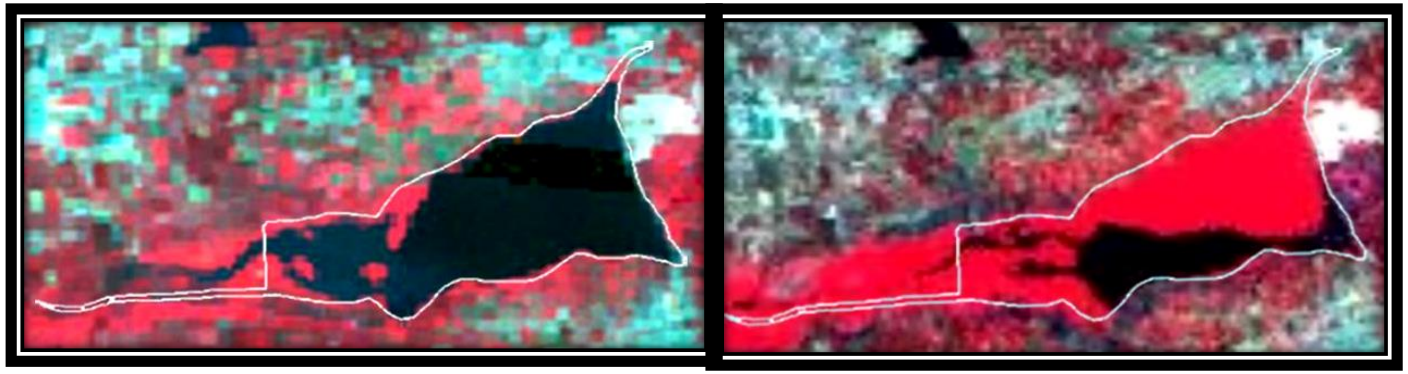
1. Treatment abilities

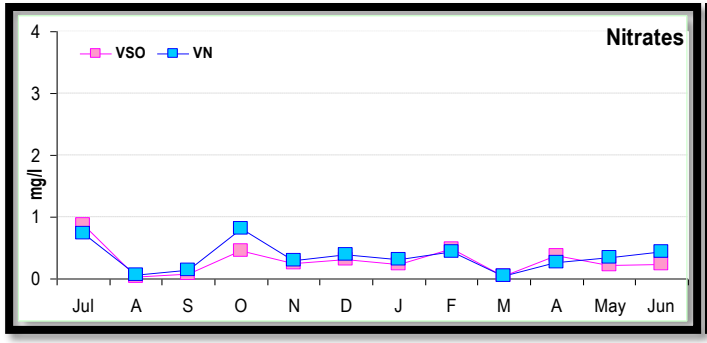
- Significant BOD reduction 55% (Total) <30 ppm (filtrable) ➔ During wet season
- COD reduction of about 62.3 %.
- Removal of TN = 51.2%.
- Ammonia removal = 57 %.

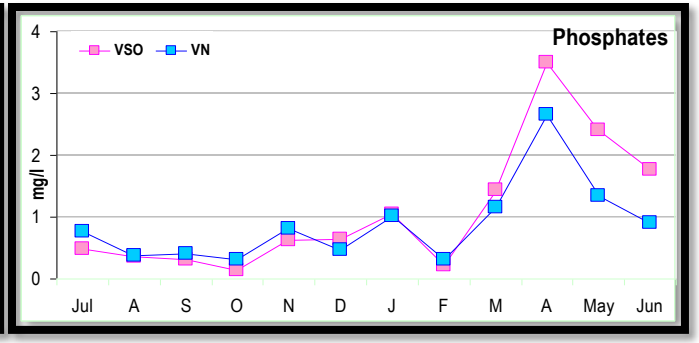


Nutrients:

- No significant change in the nitrates levels (<1 mg/l)
- Orthophosphates increased towards the outlets during the warm period.
- Algae played a major role in the uptake of nutrients during the monsoon period.







Major Findings

- Treatment abilities of wastewater fed lakes/water bodies
- Macrophytes interference in Pond functionalities & Zonation

Plant species	Common Name
Typha augustifolia	cat tail
Colocasia essculanta	taro
Cyperus haspans	dwarf papyrus sedge
Alternanthera phyloxiriodes	alligator weed
Eichhornia crasssipes	water hyacinth
Lemna major	duckweed
Lemna minor	lesser duckweed
Pistia stratiotes	water lettuce
Cyanodon dactylon	burmuda grass

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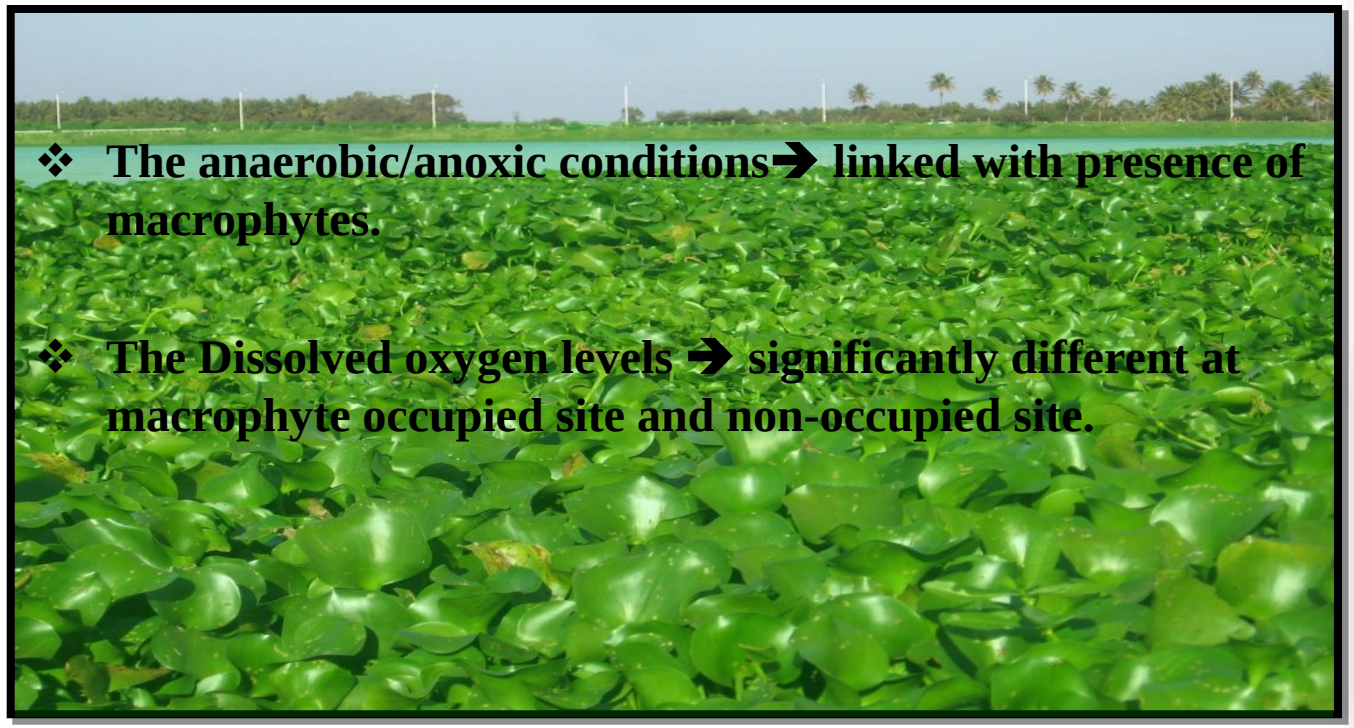
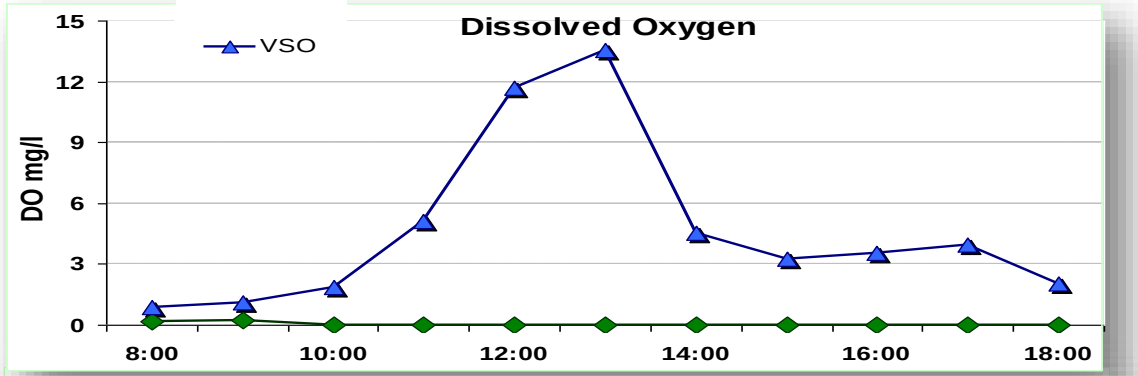
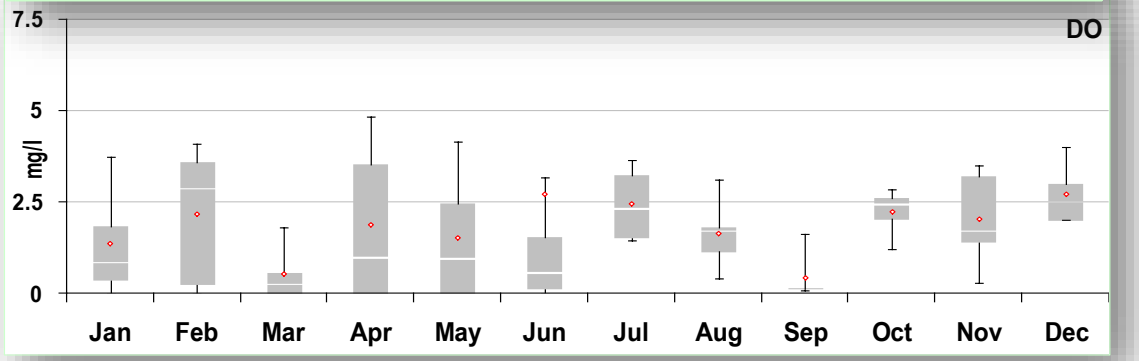
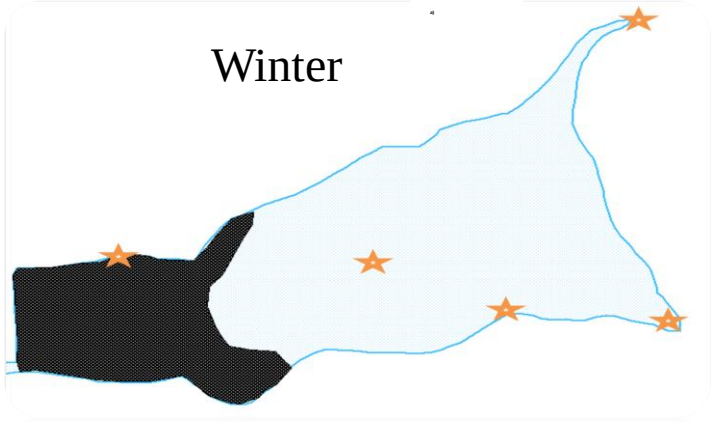
2. Role of Macrophytes

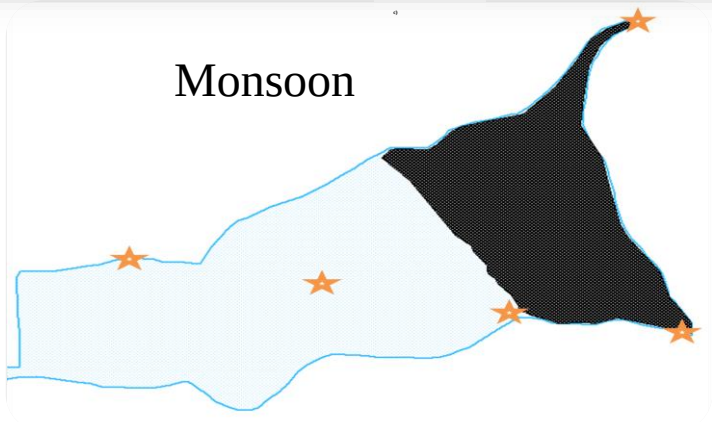


- The anaerobic/anoxic conditions➔ linked with presence of macrophytes.
- The Dissolved oxygen levels ➔ significantly different at macrophyte occupied site and non-occupied site.









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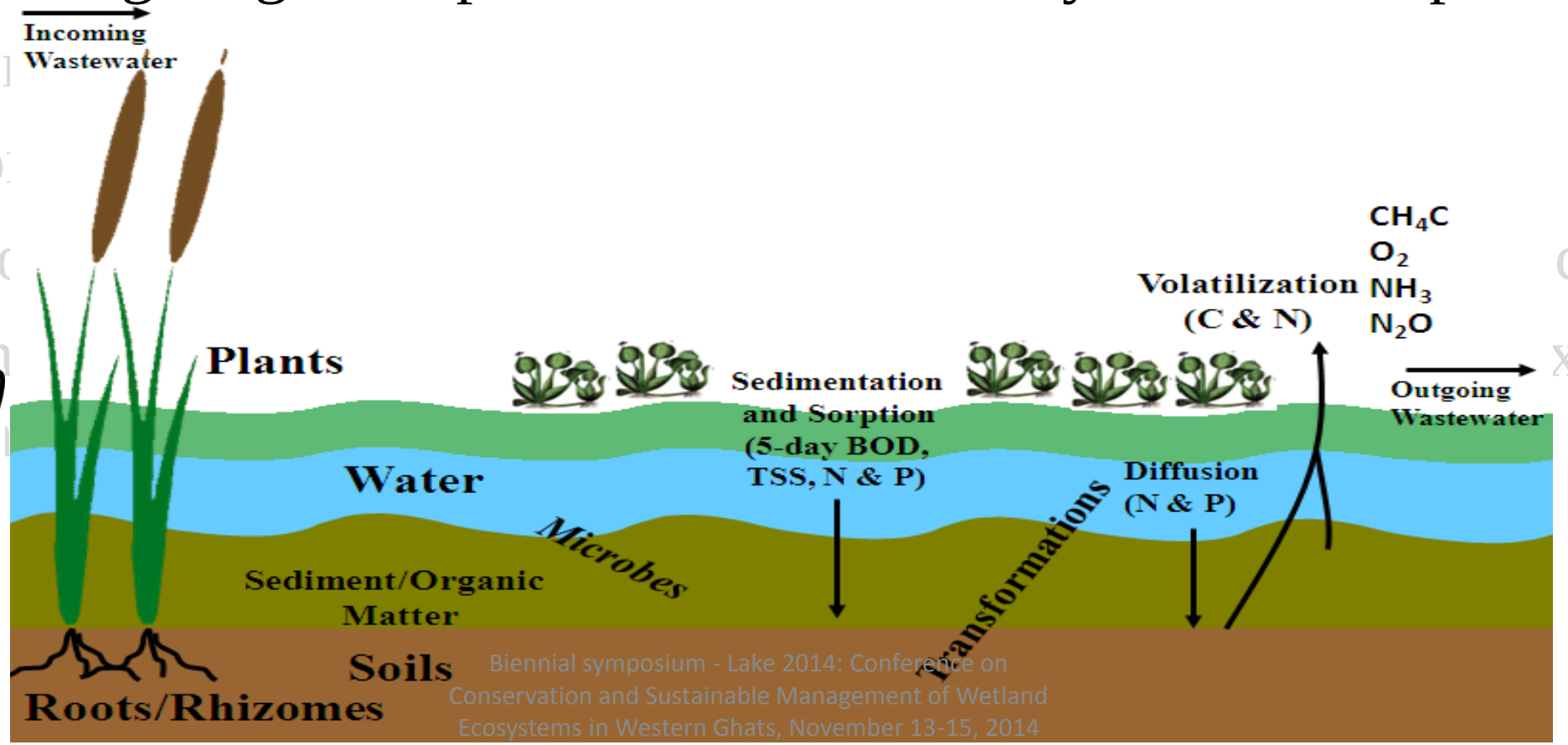
- Algal fu
- Lipid co
- Continuc
- Assessm



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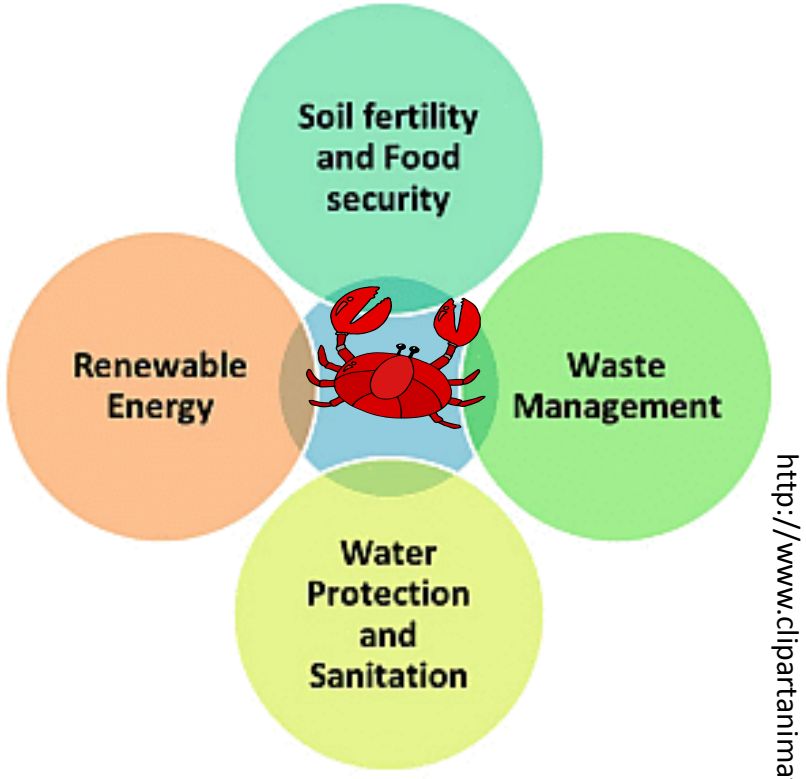
What are we looking at ??

Potential Nutrient recovery in terms of Algal biomass

1. C- ~40 % (24.2 tonnes/d) of total input C (~60 tonnes/d)
2. N- ~45 % (14.7 tonnes/d) of N (~32.7 tonnes/d)
3. P- ~60 % (8.4 tonnes/d) of P (~14.2 tonnes/d)



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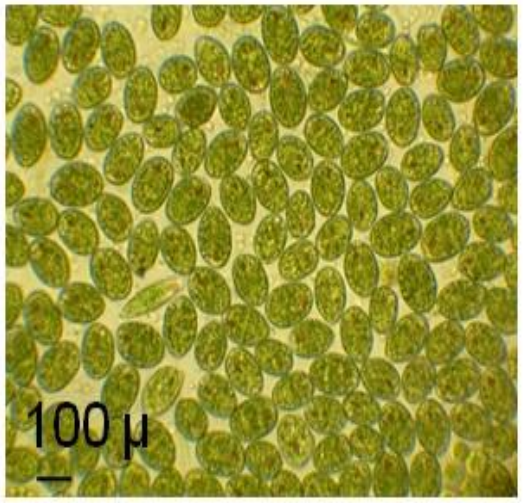
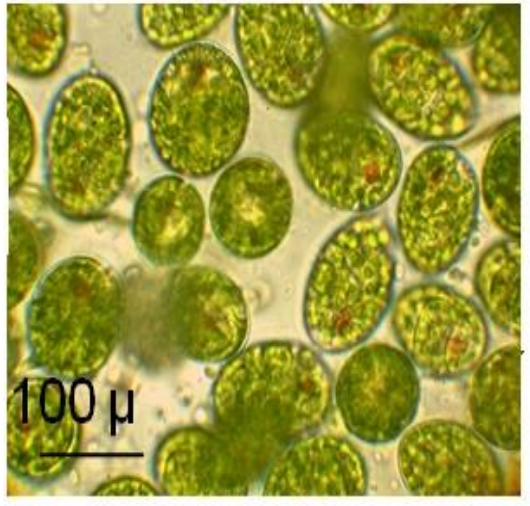
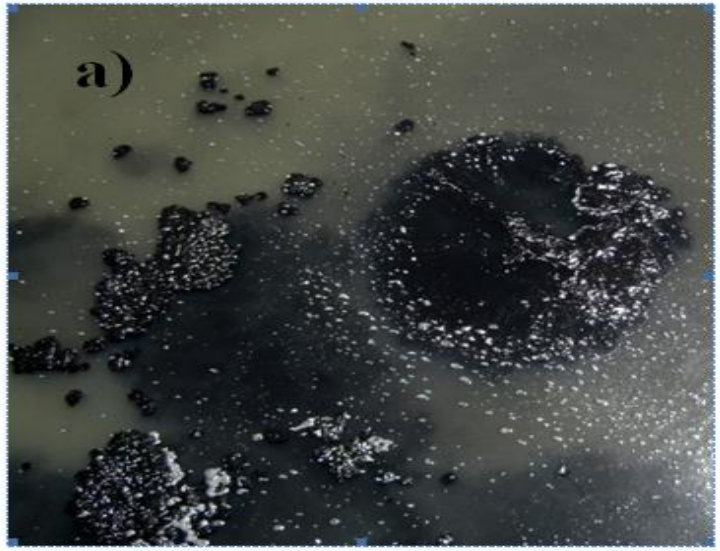
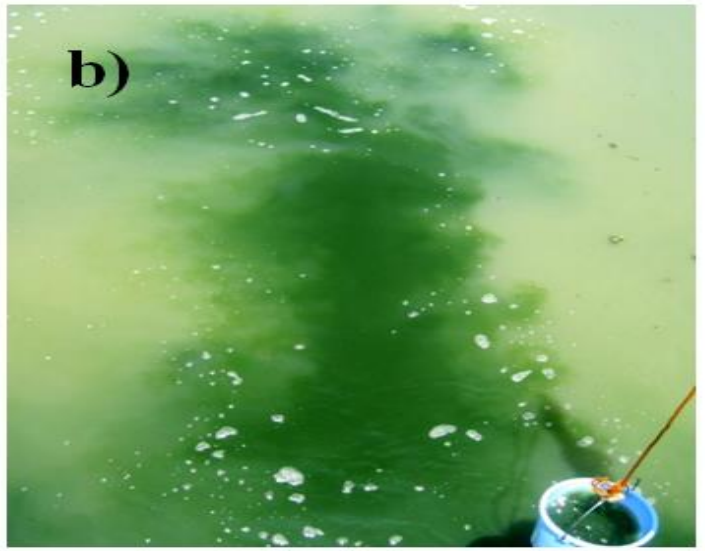


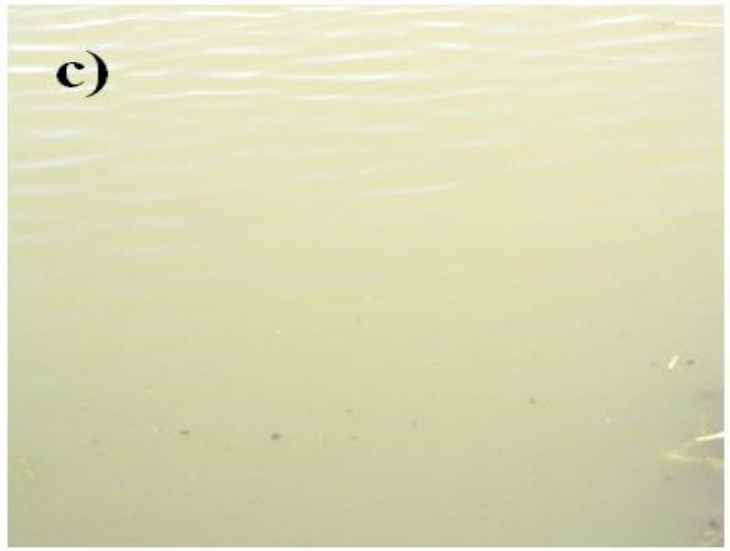


4. Algal functionalities in treatment ponds: *Euglena* sp.

ANAEROBIC, FACULTATAIVE AND AEROBIC ZONES

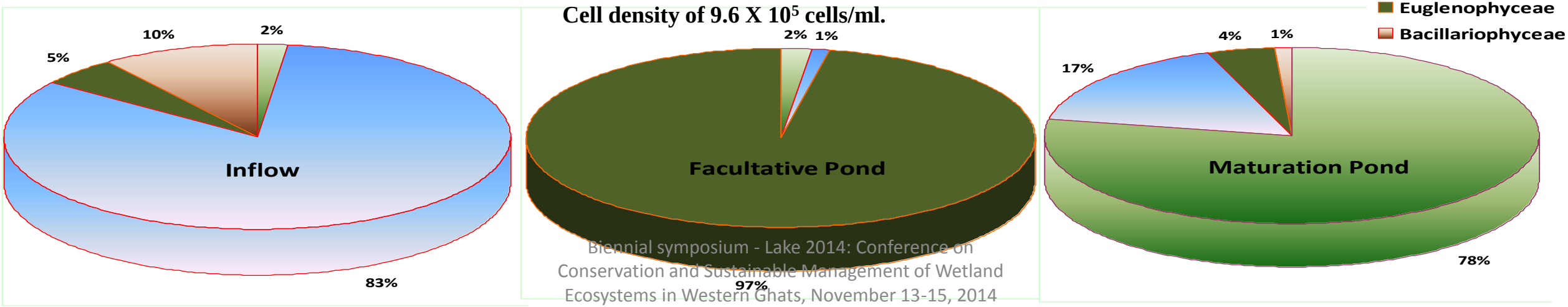




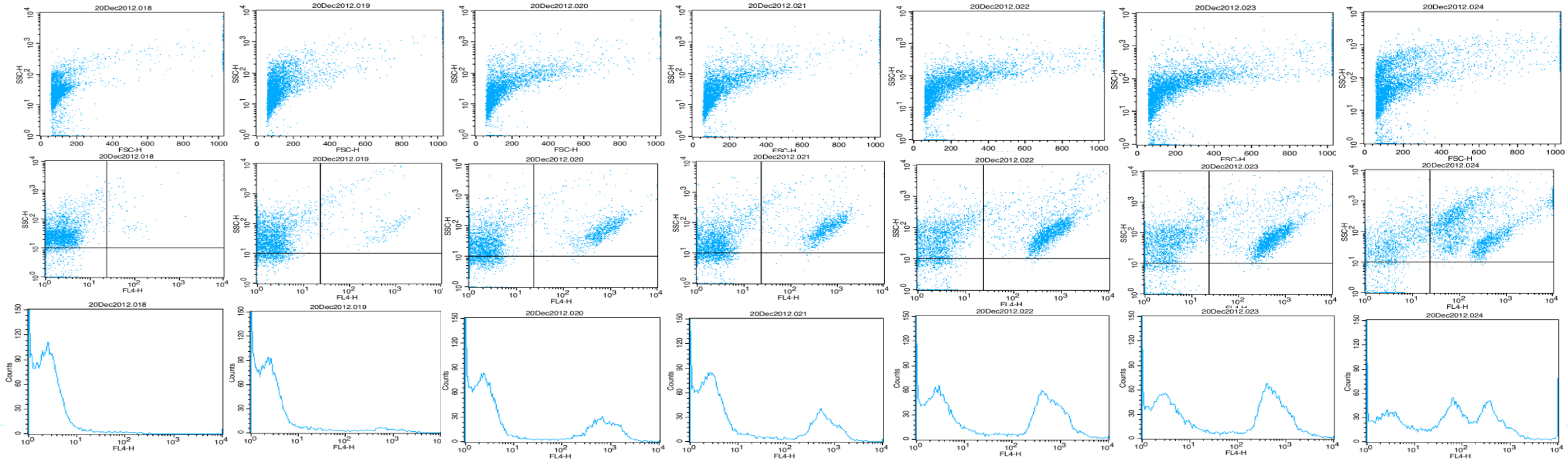


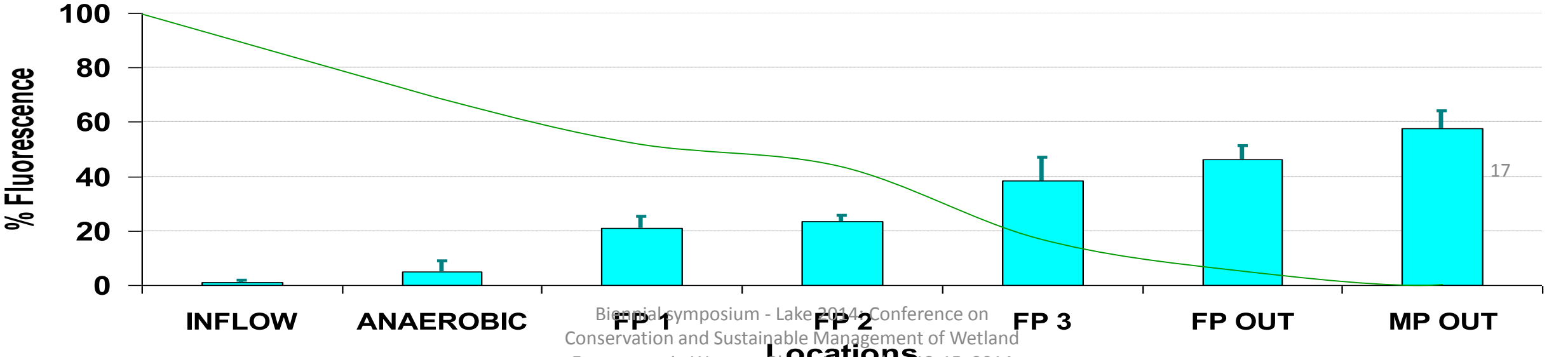
a) Anaerobic zone – Sludge upwelling
b) Facultative zone - (High algal growth – euglenophyceae) and
c) Aerobic Zone - water is clear with slightly muddy colour

Cell density of 9.6 X 10^5 cells/ml.



Bacterial Removal/Algal growth





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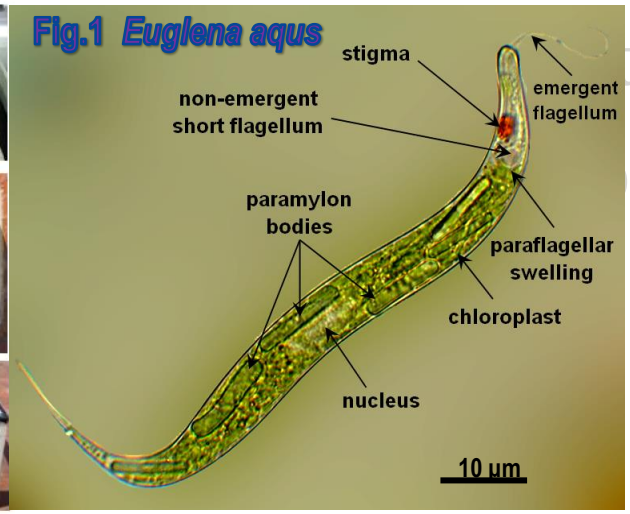
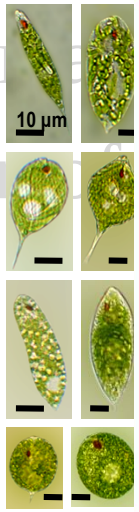
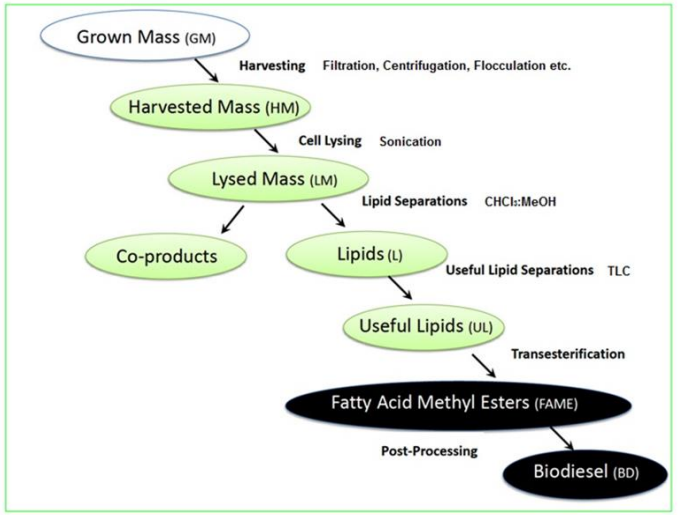
EXPERIMENTAL SETUP







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Is there a solution ?

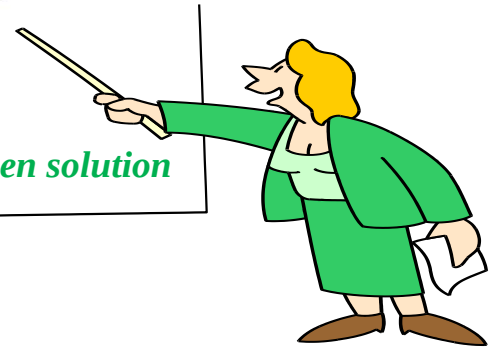
Greenery everywhere

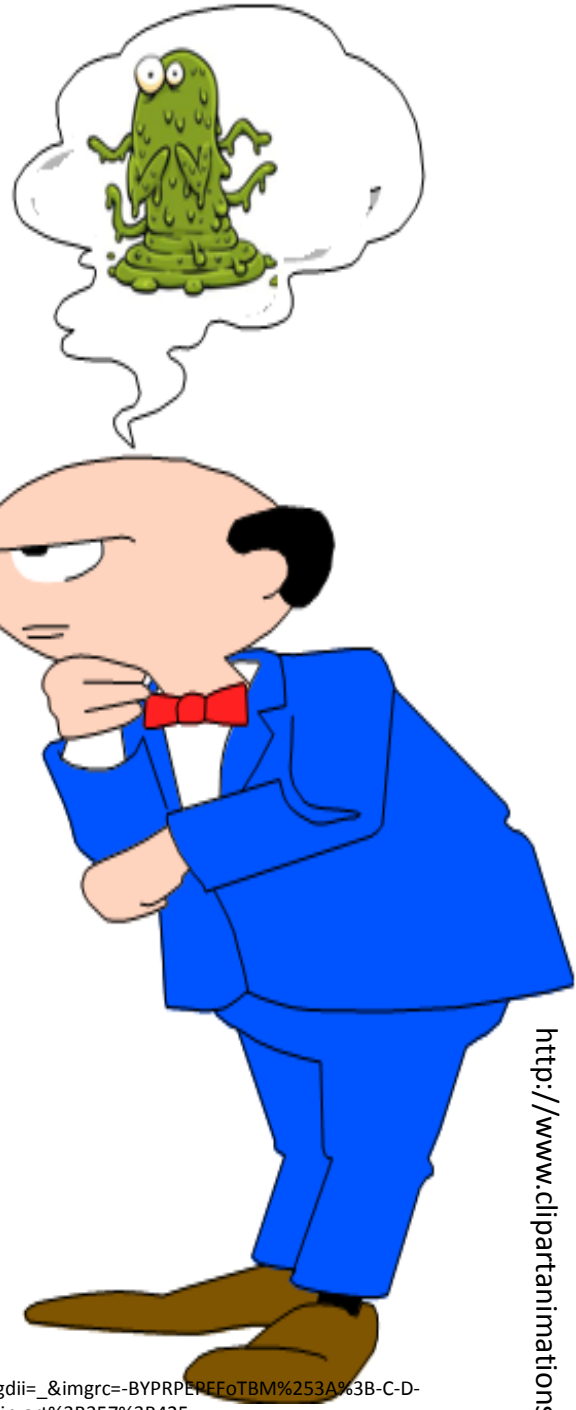
In Lakes and ponds

In storm-water drains

Algae

The Green solution





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5. Lipid content and Nutrient Removal- Batch Mode

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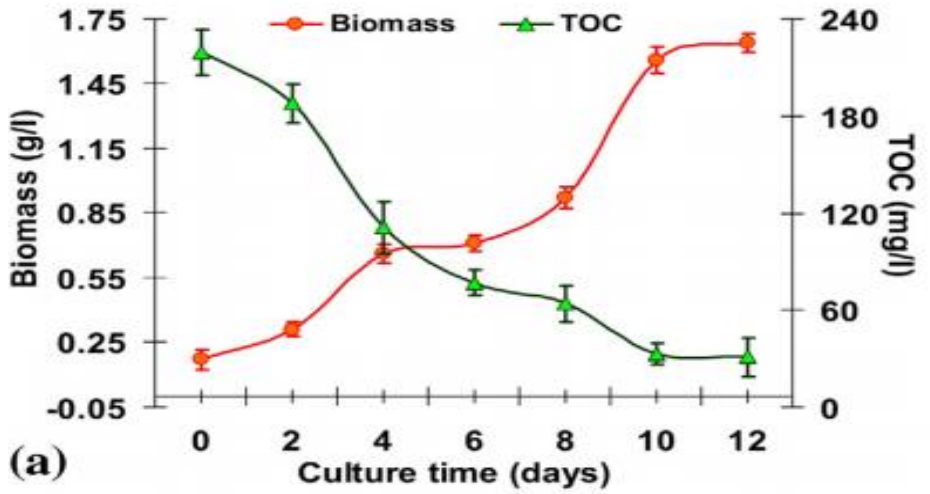

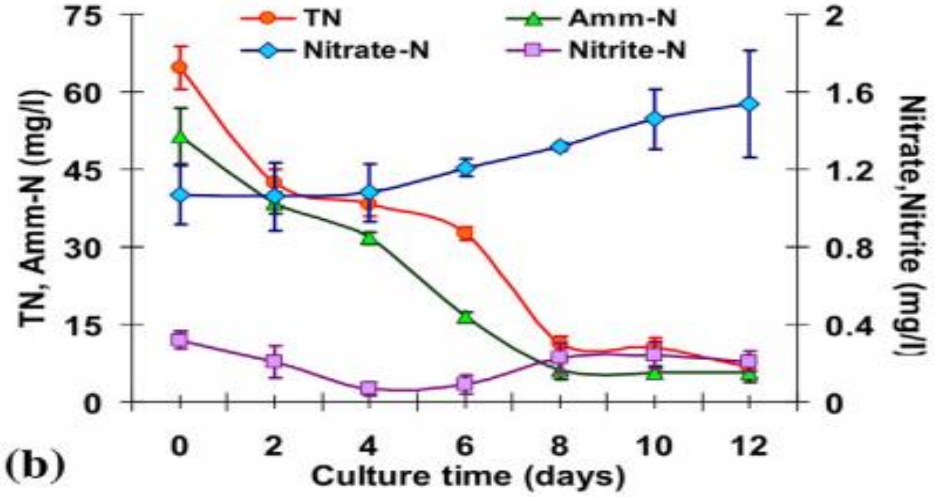

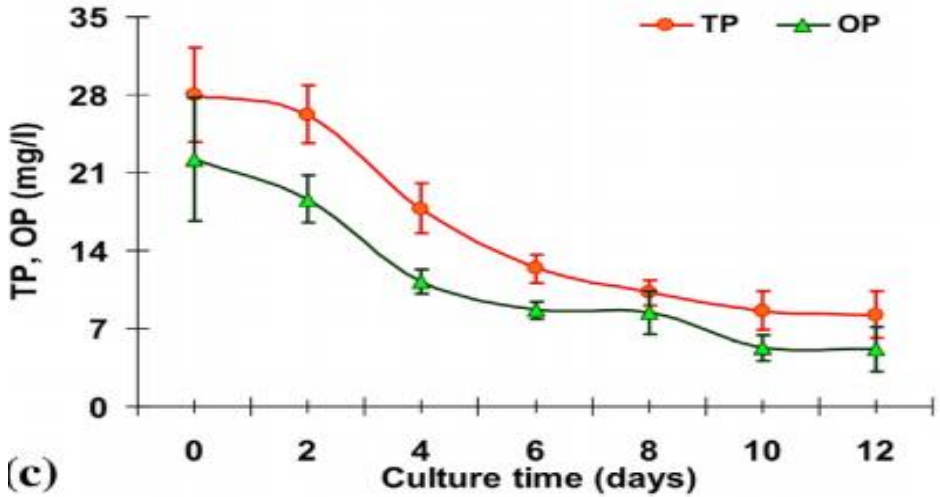

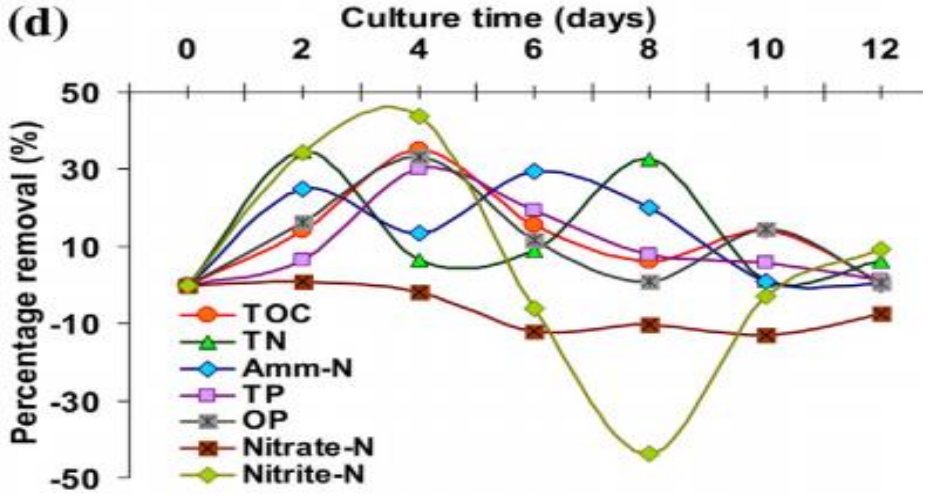

- Biomass productivity ~116 mg/l/d from the open tubs with an areal productivity of 23.2 g/m^2/d .

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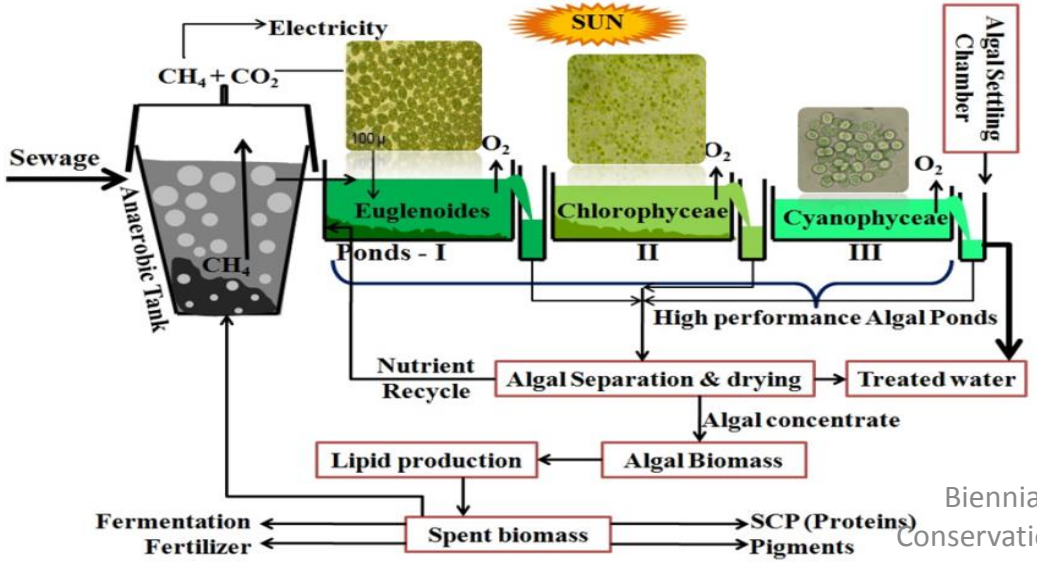
Major Findings

- Treatment abilities of urban wastewater fed lakes/water bodies
- Macrophytes interference in Pond functionalities & Zonation
- Nutrient budgeting – Scope for N and P recovery from urban ponds
- Algal functionalities in treatment ponds: *Euglena* sp.
- Lipid content and nutrient removal in Batch mode
- Continuous Algal bioprocess for WW treatment and biofuel production



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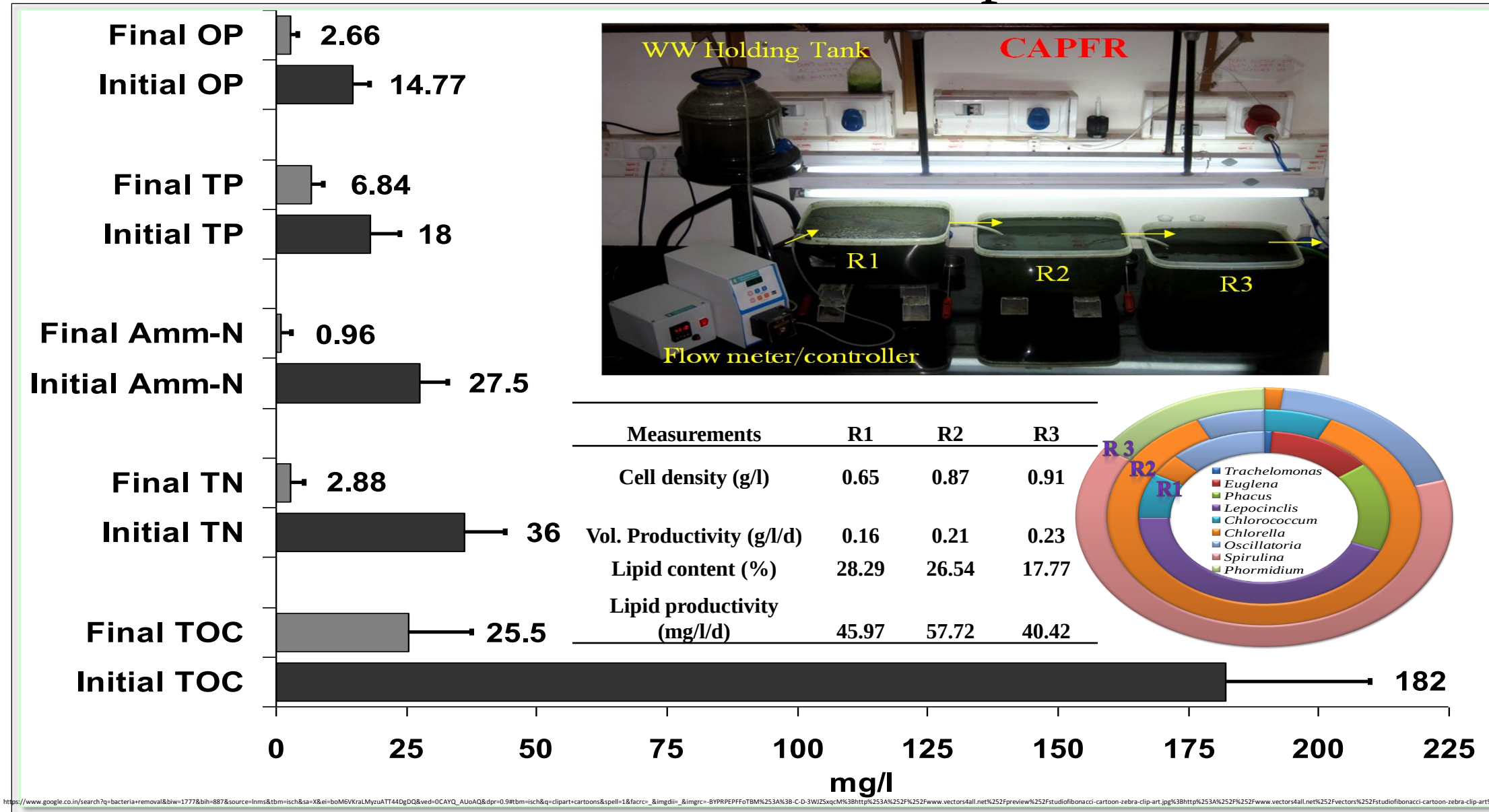
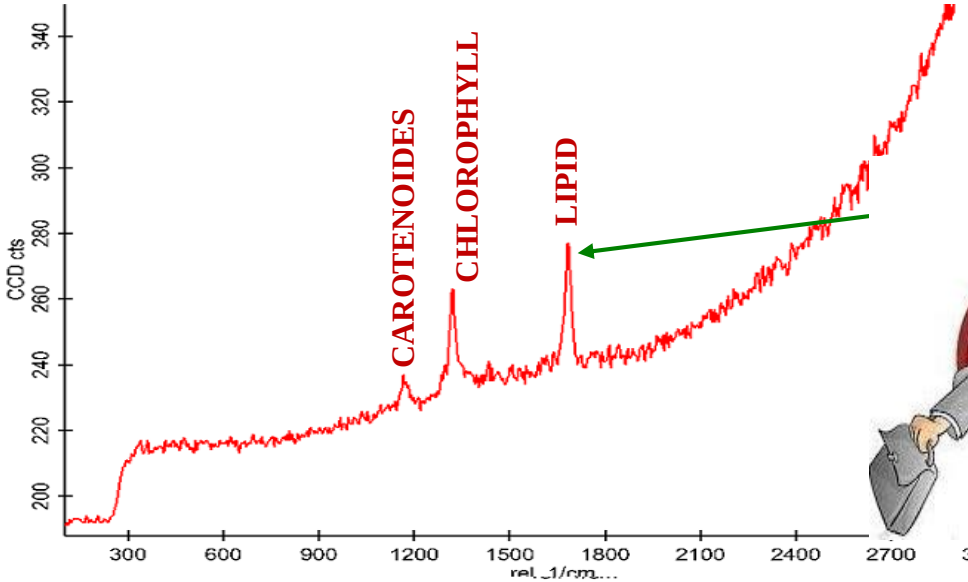
6. Continuous Algal bioprocess for Wastewater treatment and biofuel production

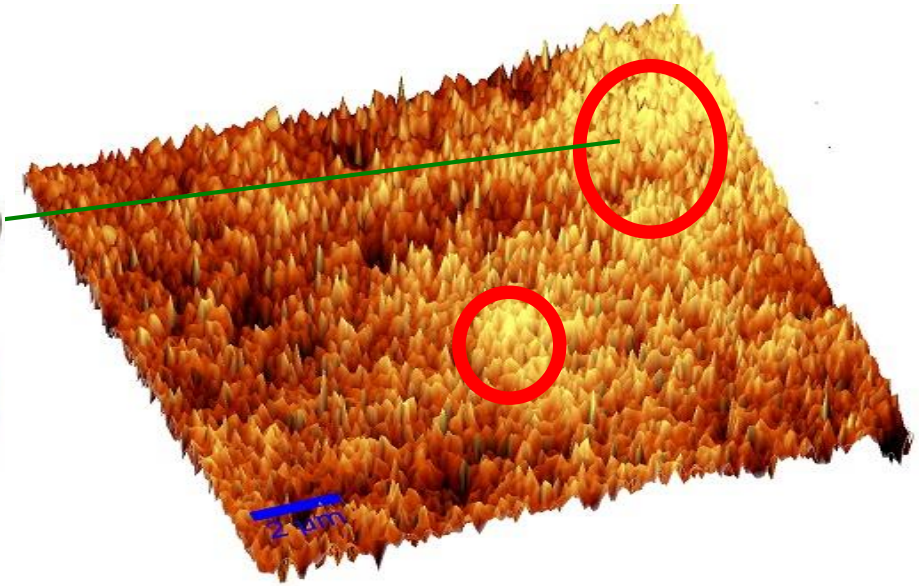


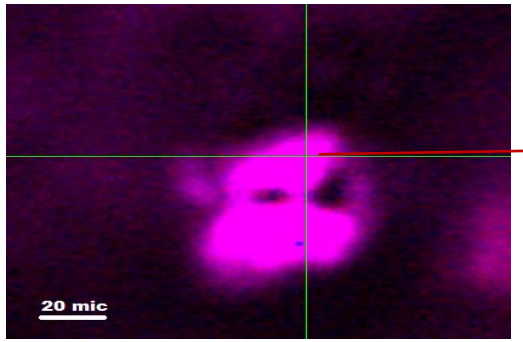
Measurements	R1	R2	R3
Cell density (g/l)	0.65	0.87	0.91
Vol. Productivity (g/l/d)	0.16	0.21	0.23
Lipid content (%)	28.29	26.54	17.77
Lipid productivity (mg/l/d)	45.97	57.72	40.42

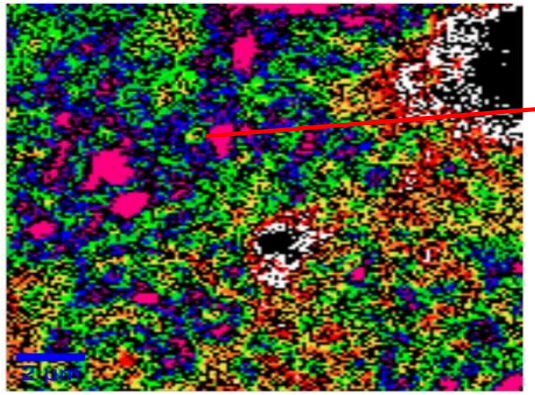
Micro Raman Spectroscopy

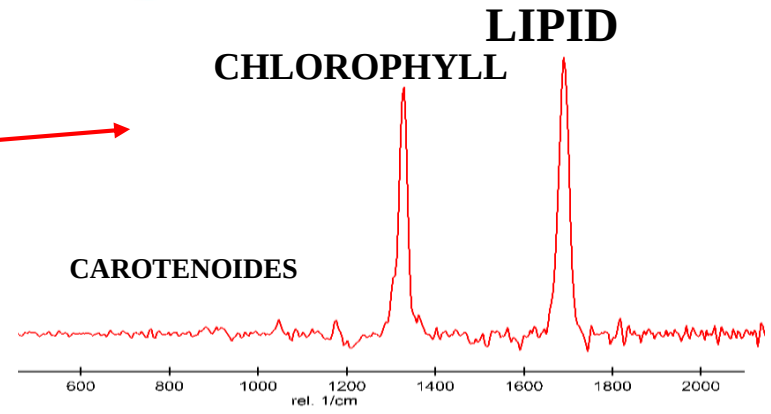
Lipid accumulation in vivo











http://www.clipartanimations.com/

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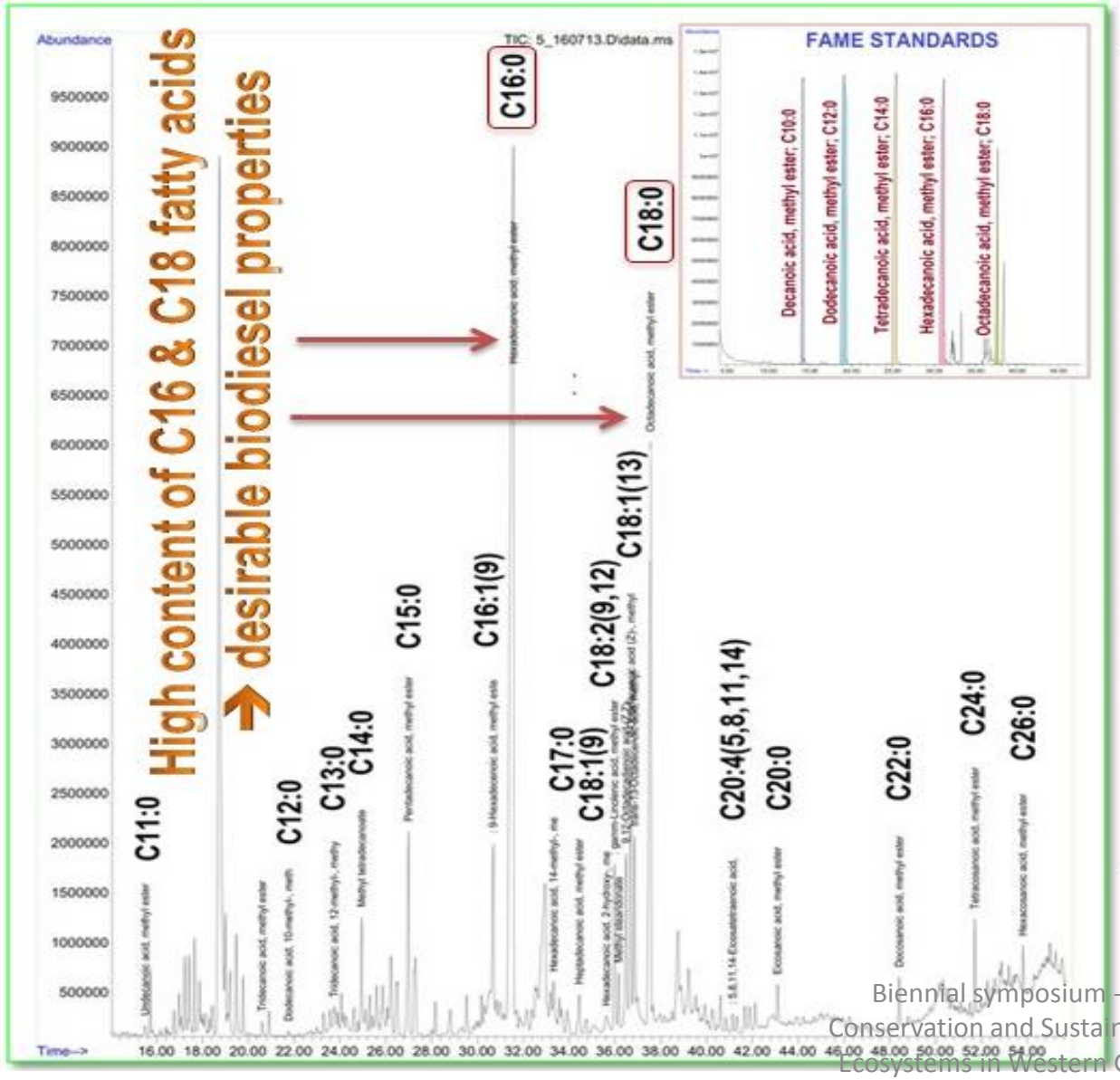
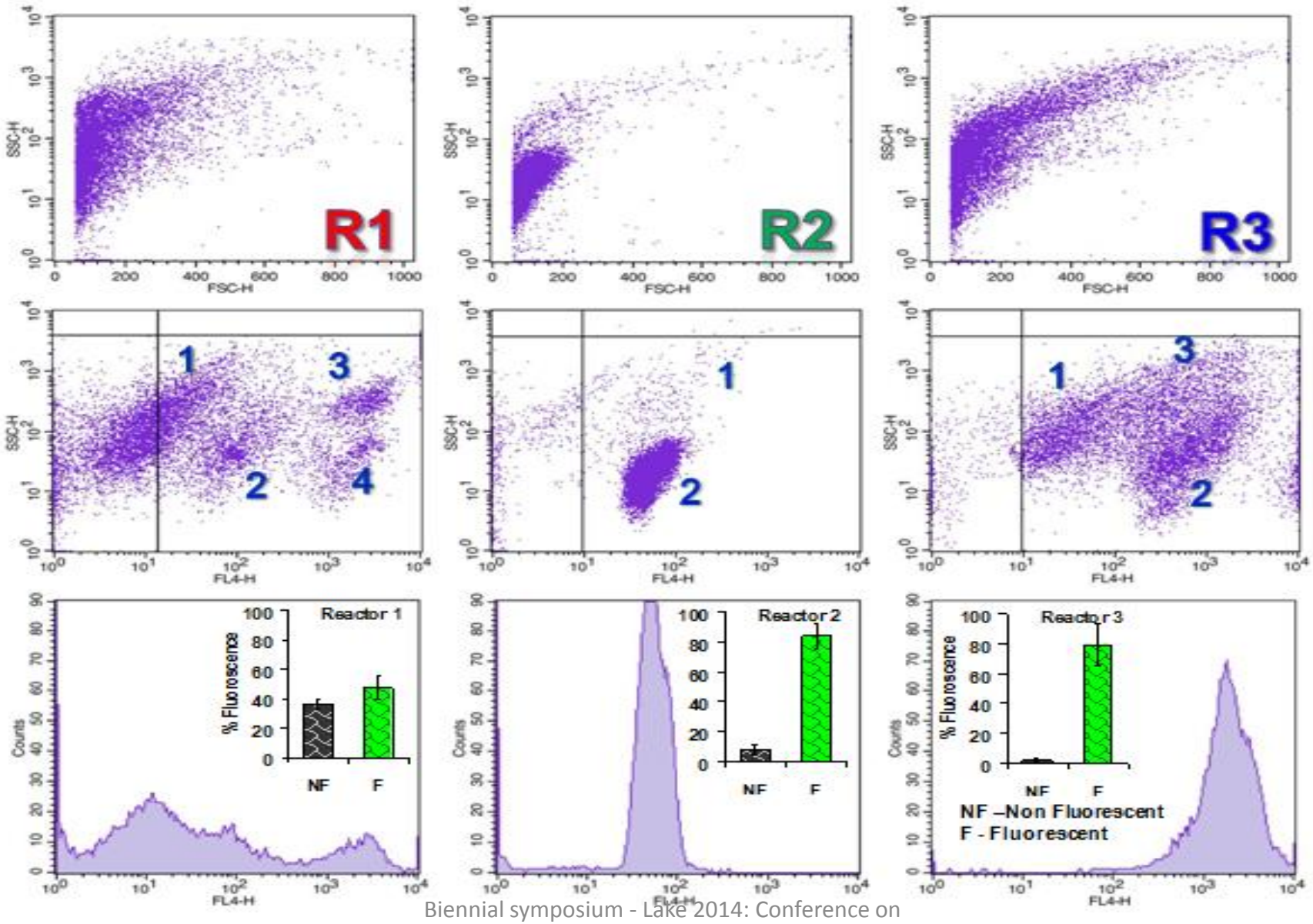
Bioreactor FAME composition

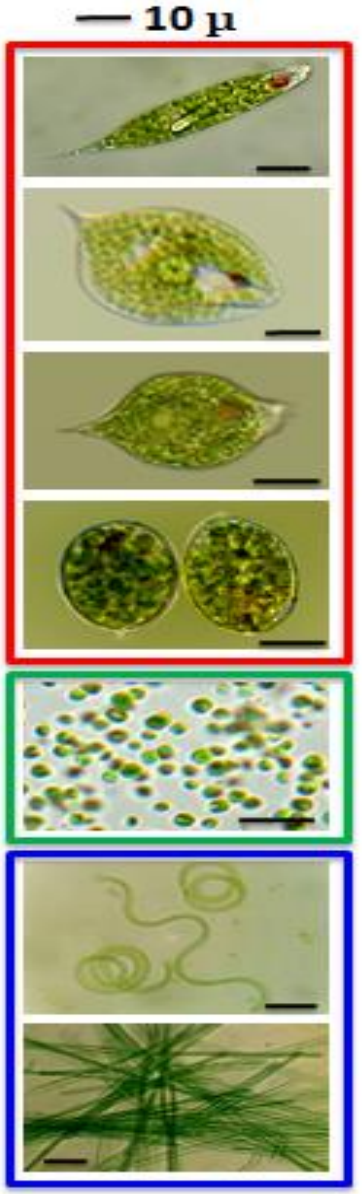


Peak	FAME	Formula	R.T.	R-01	R-02	R-03
1	Butanedioic acid, dimethyl ester	$C_6H_{10}O_4$	7.527	--	1.541	--
2	Undecanoic acid, methyl ester	$C_{12}H_{24}O_2$	15.494	--	--	0.231
3	Tridecanoic acid, methyl ester	$C_{14}H_{28}O_2$	20.603	--	--	0.237
4	Dodecanoic acid, 10-methyl-, methyl ester	$C_{14}H_{28}O_2$	21.757	--	--	0.085
5	Tridecanoic acid, 12-methyl-, methy ester	$C_{15}H_{30}O_2$	23.757	--	--	0.665
6	Methyl tetradecanoate	$C_{15}H_{30}O_2$	24.946	1.028	1.767	2.259
7	Tetradecanoic acid, 12-methyl-, methyl ester	$C_{16}H_{32}O_2$	26.953	1.957	--	--
8	Pentadecanoic acid, methyl ester	$C_{16}H_{32}O_2$	26.992	0.42	5.862	5.764
9	7,10-Hexadecadienoic acid, methyl ester	$C_{17}H_{30}O_2$	30.284	1.366	--	--
10	7,10,13-Hexadecatrienoic acid,	$C_{17}H_{28}O_2$	30.467	0.866	--	--
11	9-Hexadecenoic acid, methyl ester, (Z)-	$C_{17}H_{32}O_2$	30.684	--	3.362	3.357
12	**Hexadecanoic acid, methyl ester**	**$C_{17}H_{34}O_2$**	**31.575**	**50.32**	**49.107**	**45.66**
13	Hexadecanoic acid, 14-methyl-, methyl ester	$C_{18}H_{36}O_2$	33.313	--	0.681	0.635
14	Heptadecanoic acid, methyl ester	$C_{18}H_{36}O_2$	34.444	1.252	1.07	1.12
15	Hexadecanoic acid, 2-hydroxy-, methyl ester	$C_{17}H_{34}O_3$	35.621	--	--	1.161
16	γ-Linolenic acid, methyl ester	$C_{19}H_{32}O_2$	35.976	--	2.683	3.544
17	cis-6,9,12,15-Octadecatetraenoic acid methyl ester	$C_{19}H_{30}O_2$	36.159	--	0.754	1.081
18	9,12-Octadecadienoic acid (Z,Z)-, methyl ester	$C_{19}H_{34}O_2$	36.479	2.991	3.218	3.855
19	9,12,15-Octadecatrienoic acid, (Z,Z,Z)-	$C_{19}H_{32}O_2$	36.65	8.844	--	--
20	9-Octadecenoic acid (Z)-, methyl ester	$C_{19}H_{36}O_2$	36.696	1.273	4.353	5.499
21	11-Octadecenoic acid, methyl ester	$C_{19}H_{36}O_2$	36.81	--	2.925	--
22	trans-13-Octadecenoic acid, methyl ester	$C_{19}H_{36}O_2$	36.844	--	--	3.318
23	**Octadecanoic acid, methyl ester**	**$C_{19}H_{34}O_2$**	**37.553**	**29.19**	**19.98**	**17.35**
24	5,8,11,14-Eicosatetraenoic acid, methyl ester, (Z)-	$C_{21}H_{34}O_2$	41.131	0.201	0.304	0.429
25	Eicosanoic acid, methyl ester	$C_{21}H_{42}O_2$	43.096	0.295	0.659	0.823
26	Docosanoic acid, methyl ester	$C_{23}H_{46}O_2$	48.4	--	0.871	1.031
27	Tetracosanoic acid, methyl ester	$C_{25}H_{50}O_2$	51.703	--	0.865	1.263
28	Hexacosanoic acid, methyl ester	$C_{27}H_{54}O_2$	53.806	--	--	0.631
	Saturated Fatty acids			**84.46**	**82.403**	**78.92**
	Unsaturated Fatty acids			15.54	17.599	20.65
	Monoenoic Fatty acids			1.273	10.64	12.17
	Polyenoic Fatty acids			14.27	12.821	8.909
	C16-C18 Fatty acids			**96.1**	**88.133**	**86.58**
	FAME Content (µg)			231.13	363.15	631.05

Bacterial Removal and Algal growth

Flow Cytometry
High Fluorescence in Reactors 2 & 3
shows higher biomass production





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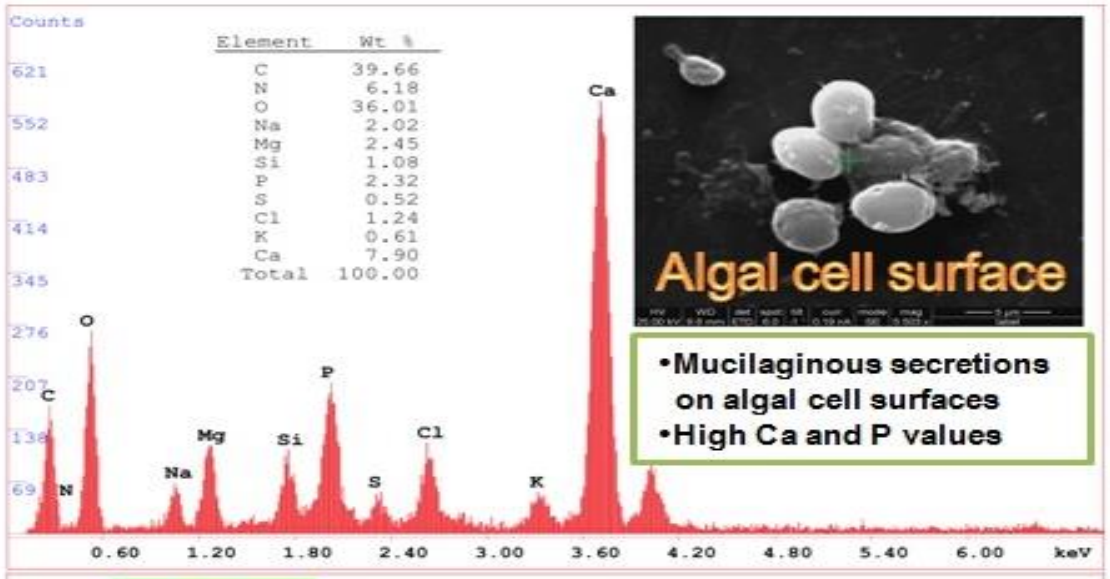
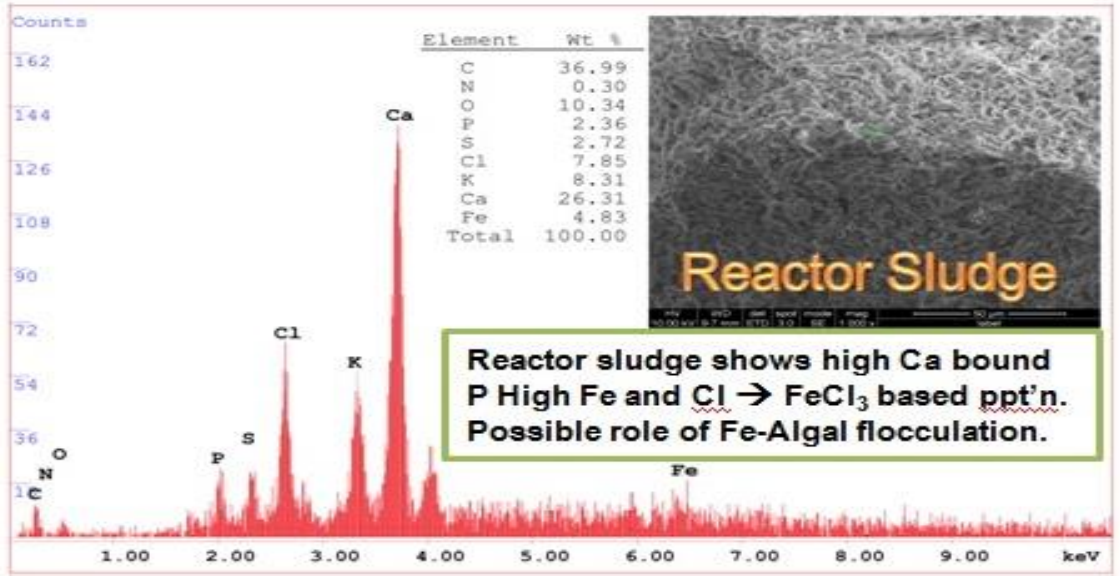
Elemental composition and flocculation analysis

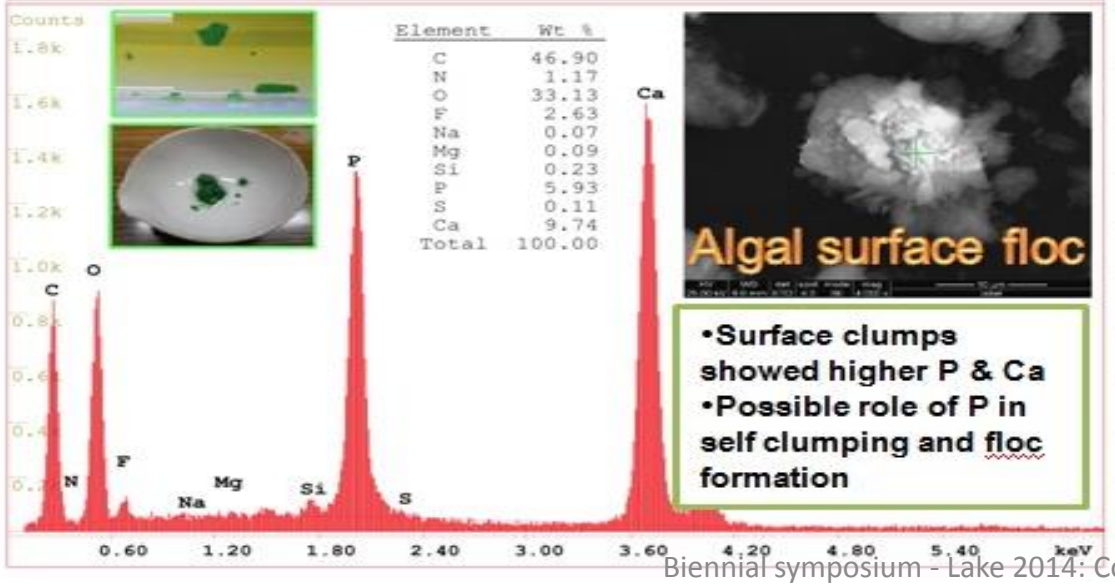
Cell Surfaces shows high Ca content.
High poly-P content in algal cells ~2-3 %



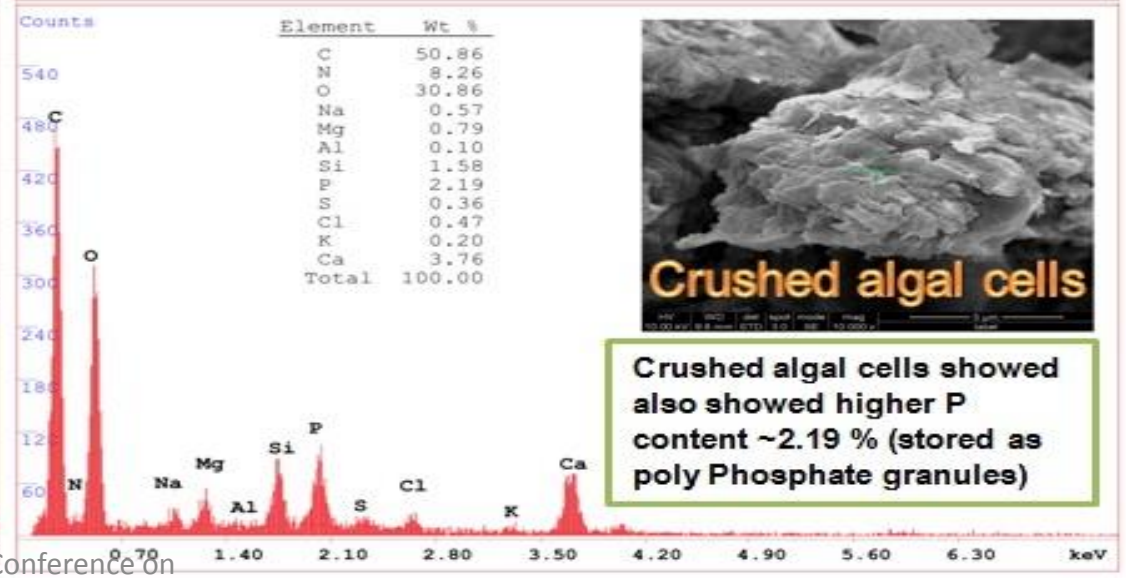
- Mucilaginous secretions on algal cell surfaces
- High Ca and P values



Reactor sludge shows high Ca bound P High Fe and Cl → $FeCl_3$ based ppt'n. Possible role of Fe-Algal flocculation.



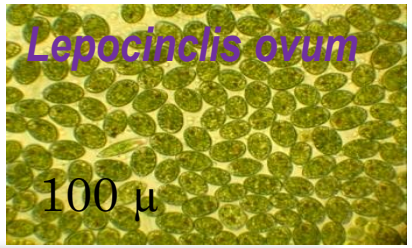
- Surface clumps showed higher P & Ca
- Possible role of P in self clumping and floc formation

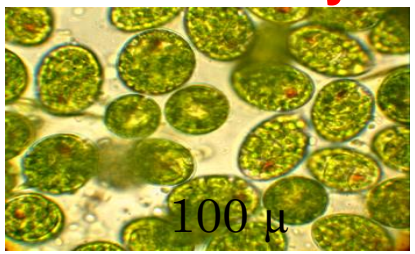


Crushed algal cells showed also showed higher P content ~2.19 % (stored as poly Phosphate granules)

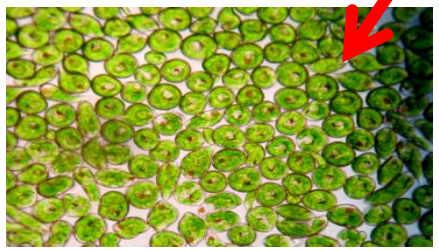
Harvestibility in Wastewater algae CAPFR

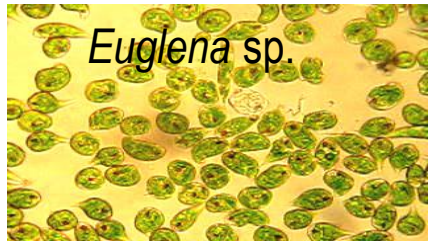
1. Euglenophyceae ➔ Settleability

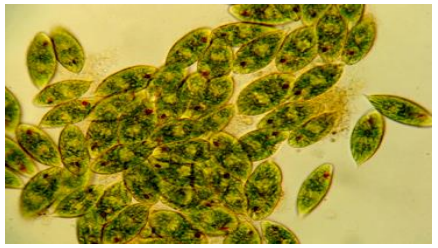


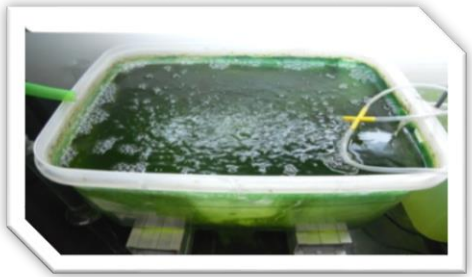


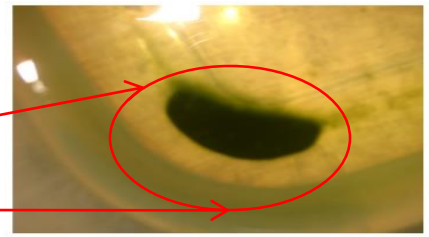
Palmella form



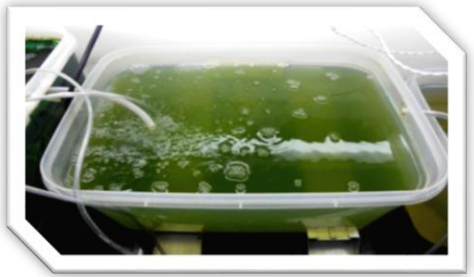


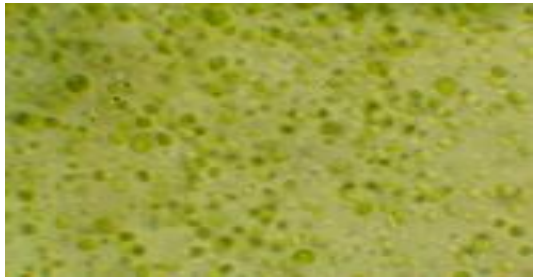




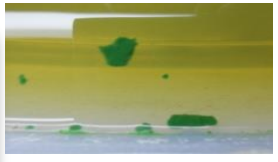


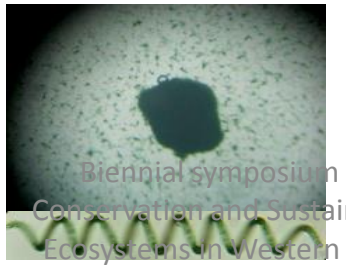
2. *Chlorococcum* sp.➔ Auto-Flocculation

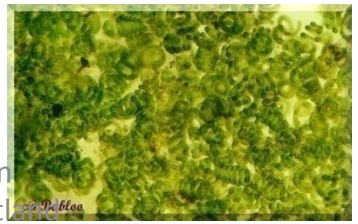




3. *Spirulina* sp. ➔ Clusters or Aggregates







Major Findings

- [illegible]nt abilities of urban wastewater fed lakes/water bodies
- Macrophytes interference in Pond functionalities & Zonation
- Nutrient budgeting – Scope for N and P recovery from urban pond systems
- Algal functionalities in treatment ponds: *Euglena* sp.
- Lipid content and nutrient removal in Batch mode
- Continuous Algal bioprocess for WW treatment and biofuel production & harvestability
- Assessment of feasibility for integration of algal bioprocess into existing treatment network in Bangalore

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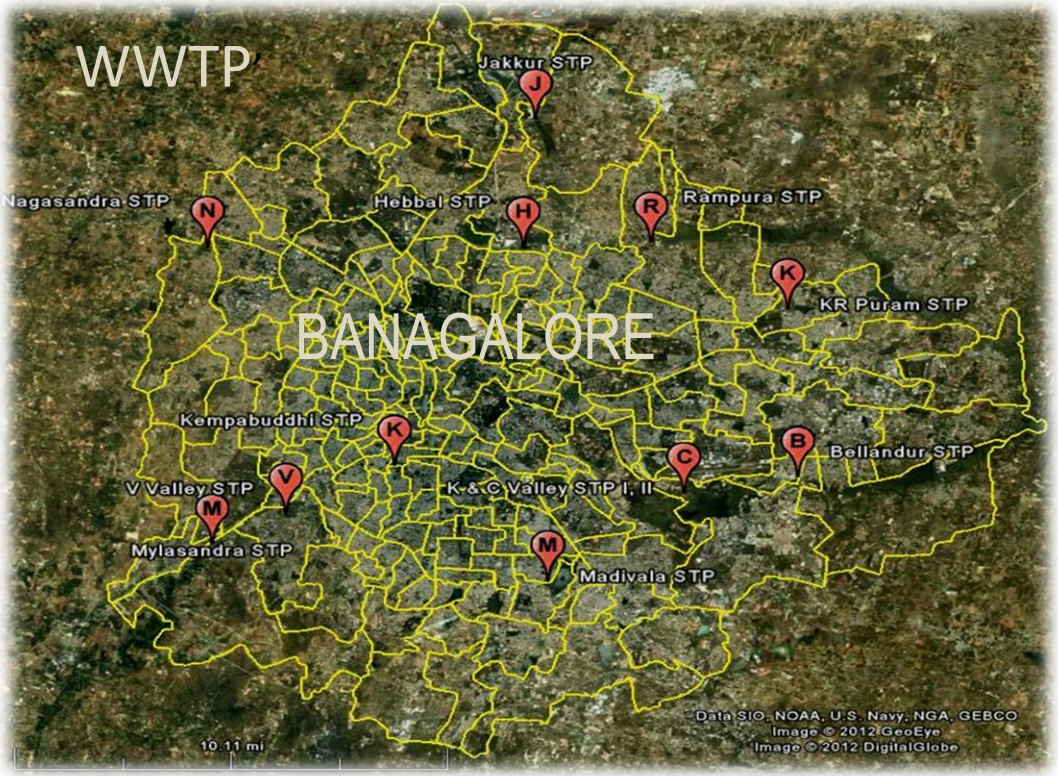
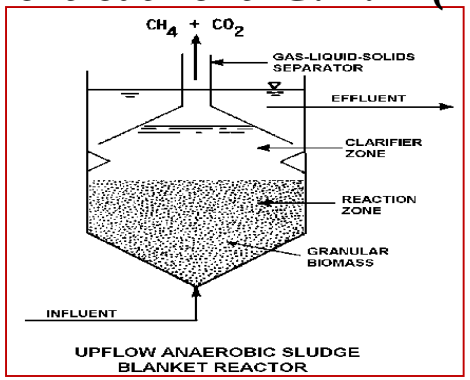


Location	Installed Cap. (MLD)	Treatment Facility
V Valley	**180**	**Secondary : Trickling filters**
K & C Valley I	**163**	**Secondary: Activated sludge process**
Hebbal Valley	**60**	**Secondary: Activated sludge process**
Madivala	4	Secondary: UASB + Oxi. Ponds + Const. Wetlands
Kempambudhi	1	Secondary: Extended Aeration
Yelahanka	10	Activated Sludge process + Fil.+ Chlorination (Tert.)
Mylasandra	75	Secondary: Extended Aeration
Nagasandra	20	Secondary: Extended Aeration
Jakkur	10	Secondary: UASB + Extended Aeration
K.R. Puram	20	Secondary: UASB + Extended Aeration
Kadabeesananahalli	50	Secondary: Extended Aeration
K & C Valley II	30	Secondary: Extended Aeration
K & C Valley III	55	Secondary: CMAS
Raja-canal	40	Secondary: Extended Aeration
Total	**718**	

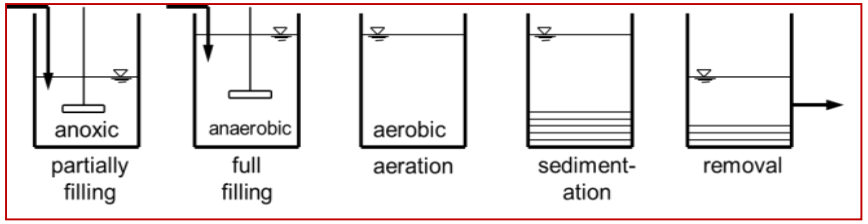
Anaerobic treatment- C:N:P (250:5:1)

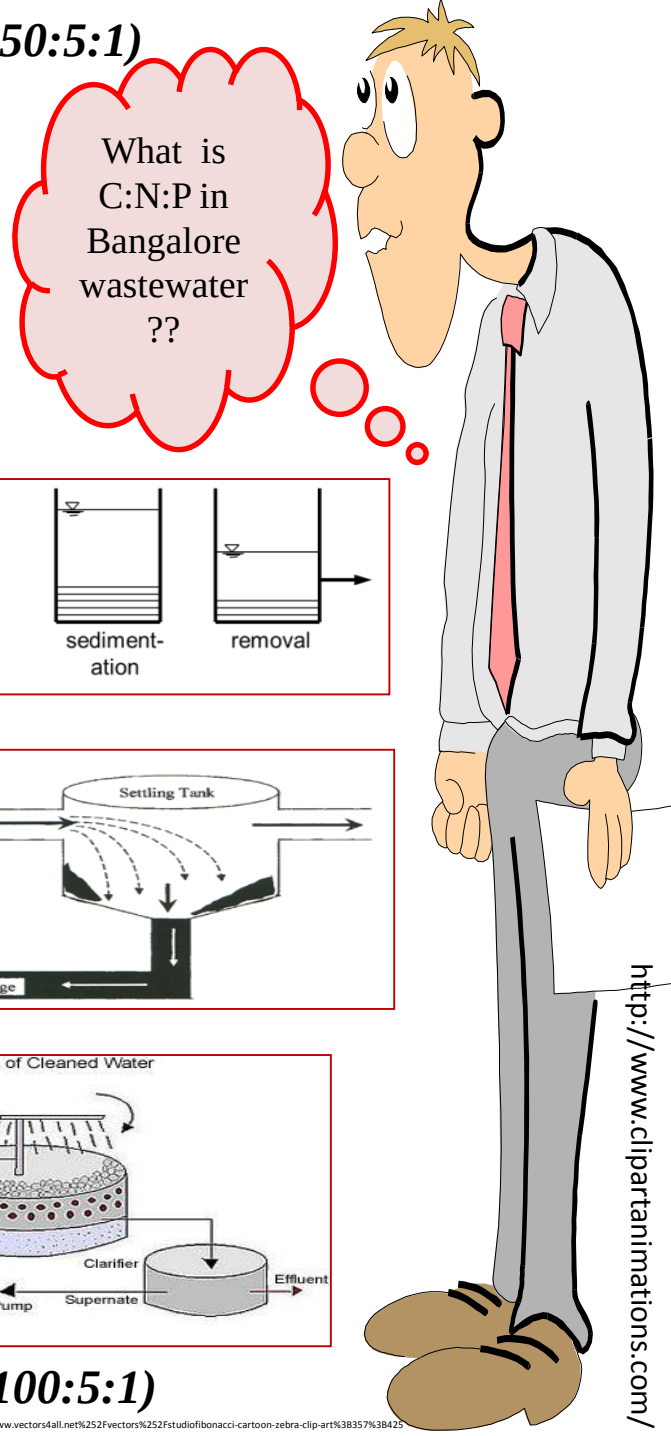
ANAEROBIC

1.UASB



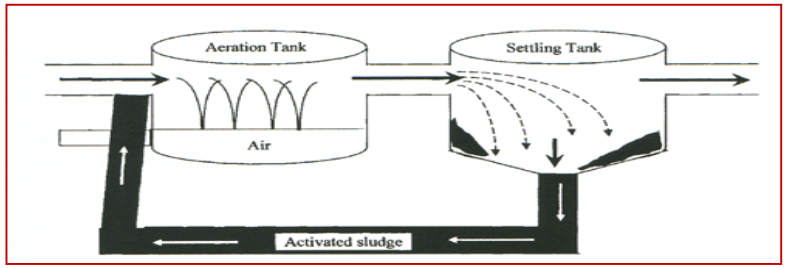
2. SBR





AEROBIC

3. ASP



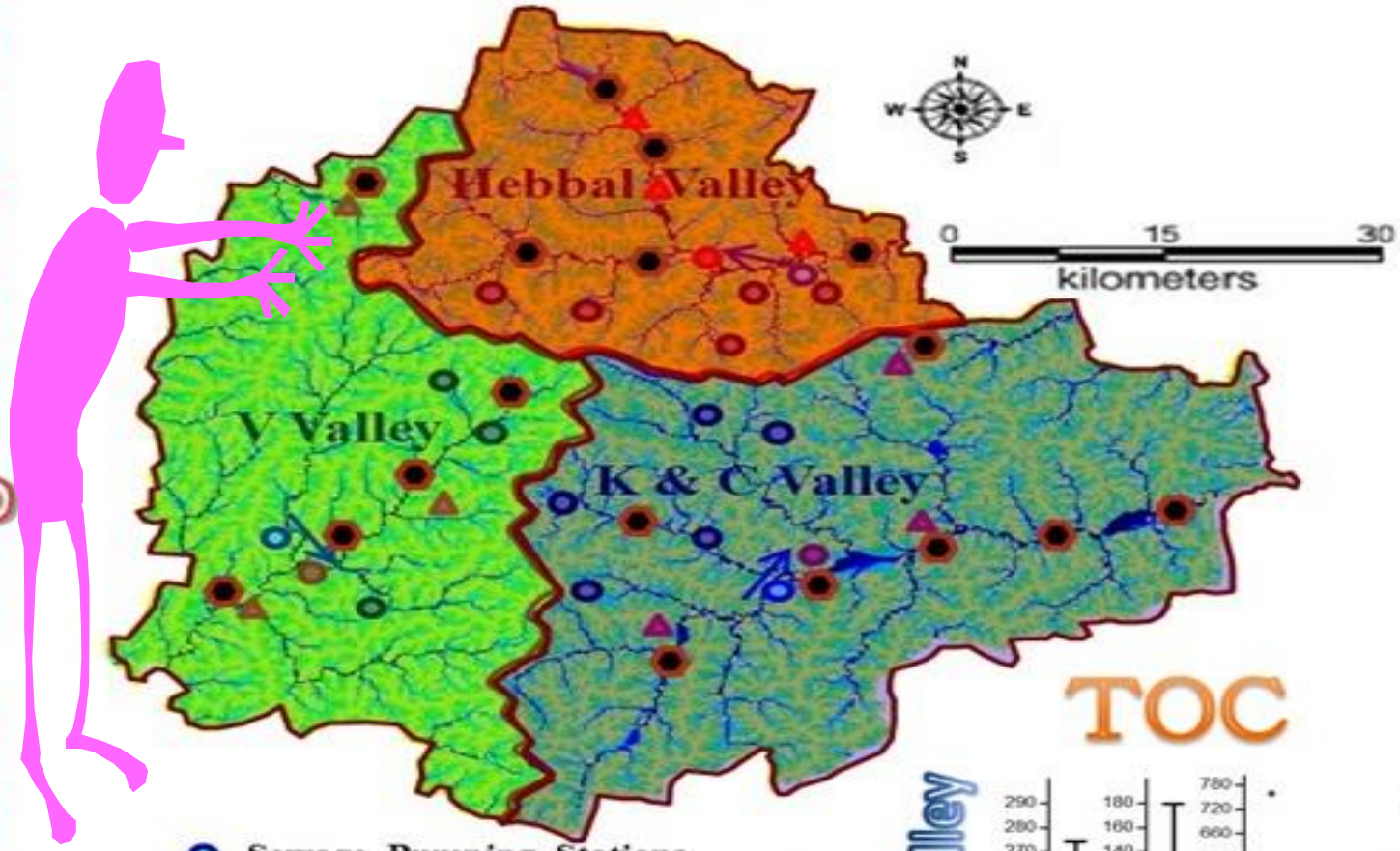
4.TF

Aerobic treatment- C:N:P (100:5:1)

C limitation in city waters:

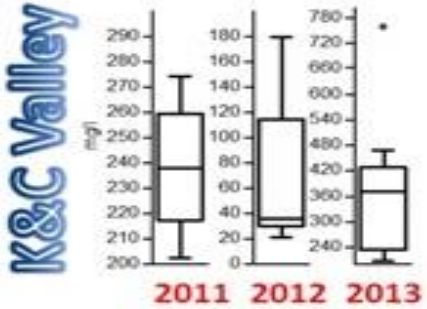
Suitable - Algal treatment

GREATER BANGALORE

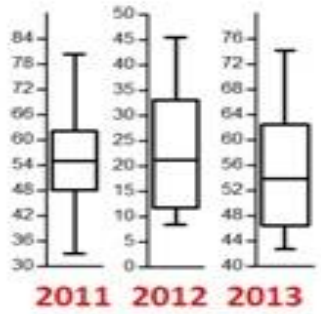


Nutrients	μ (mg/l)	St. dev
Carbon		
COD	560	89.08
Sol. COD	277.33	97.76
TOC	243.48	38.73
SOC	120.58	16.5
Nitrogen		
Tot. Nitrogen	58.76	18.26
Amm.-N	40.94	13.88
Nitrate-N	3.24	1.42
Nitrite-N	0.018	0.009
Phosphorus		
Inorganic-P	16.17	5.39
Sol. Org. P	5.73	1.23
Part. Org . P	24.89	8.54
Total P	47.64	14.06

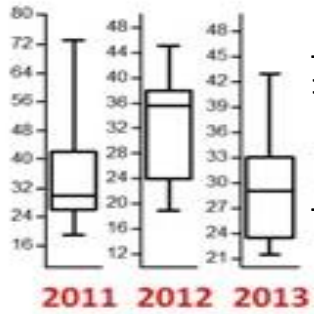
TOC



TN

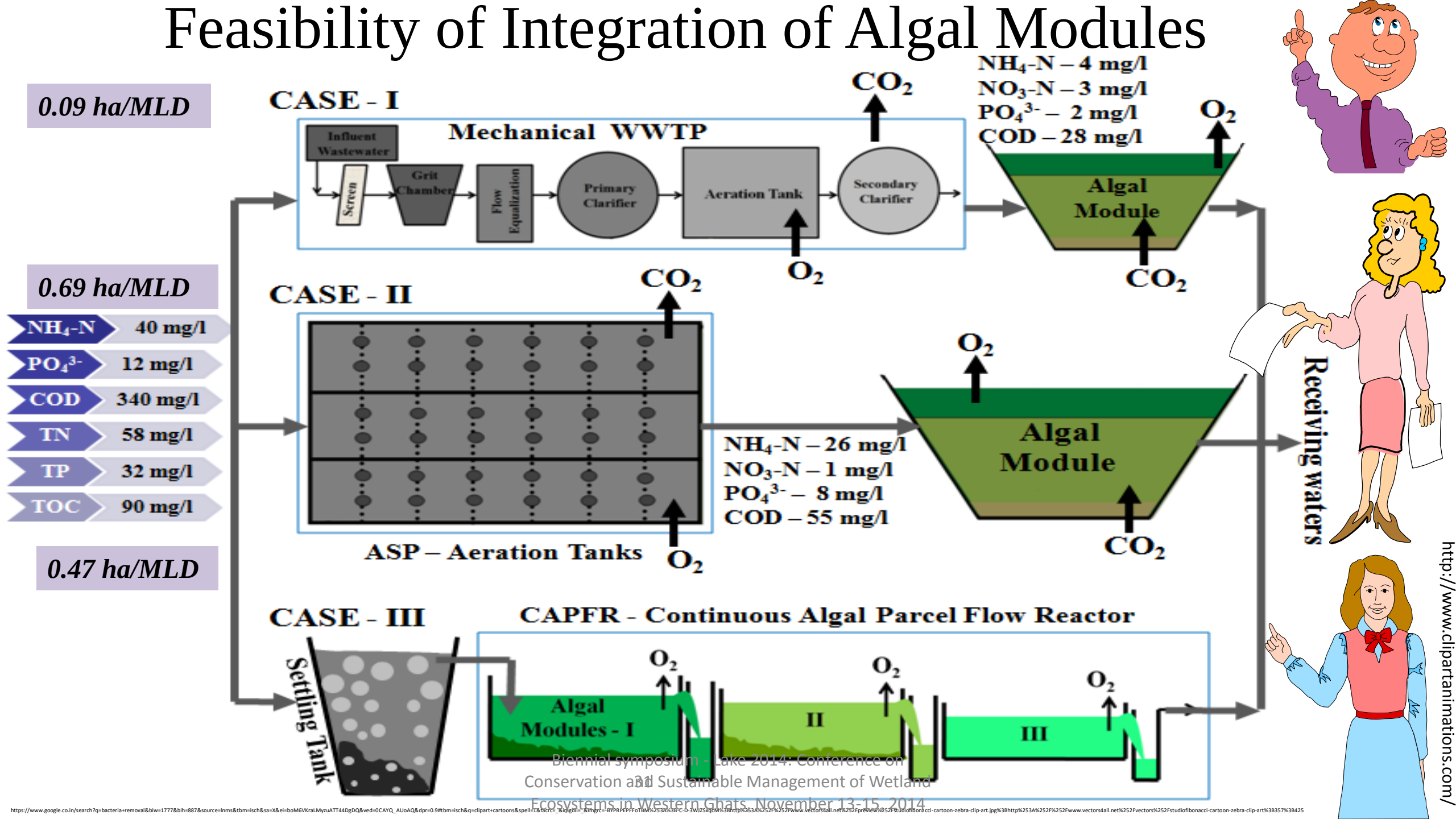


TP

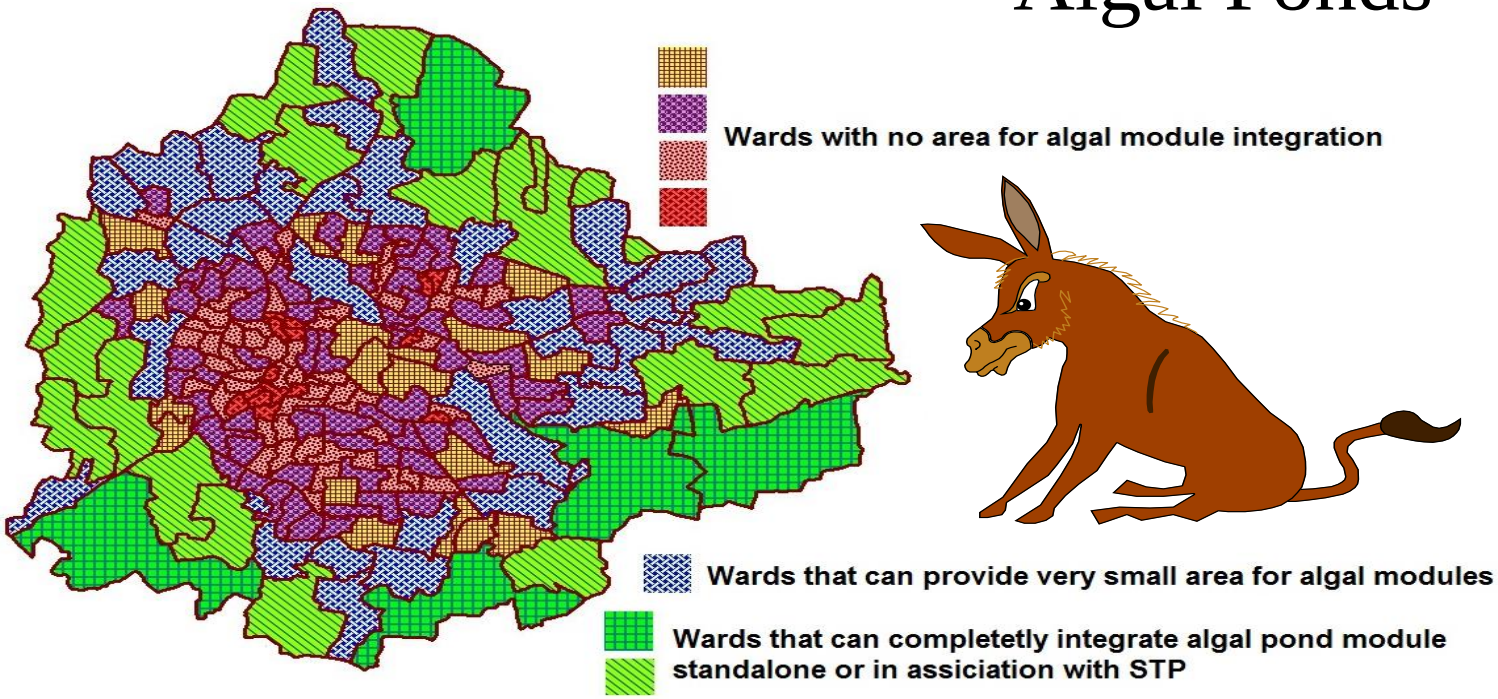


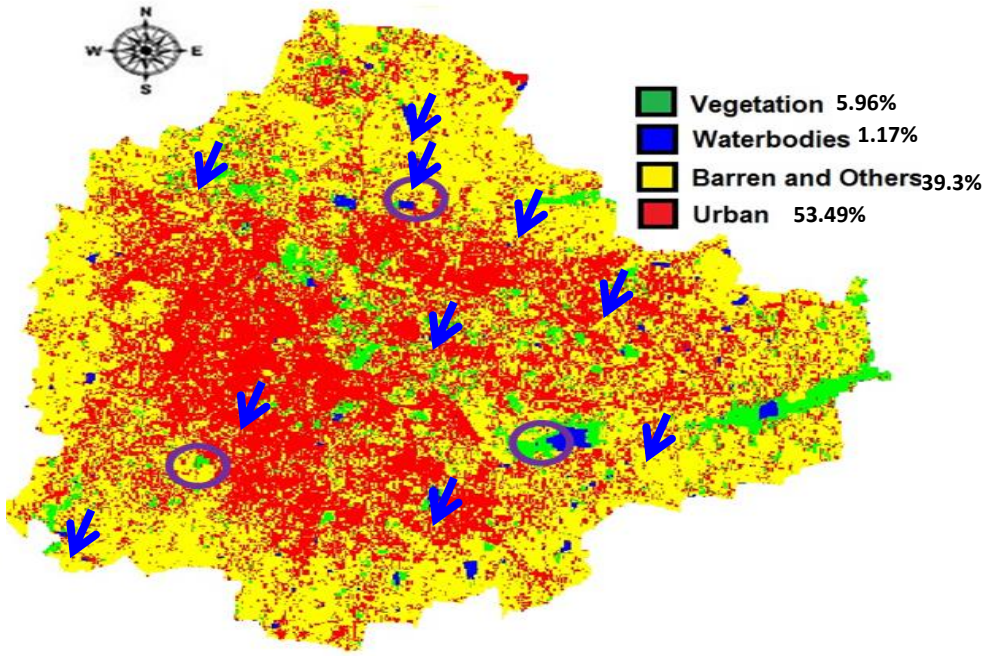
Bangalore Wastewater C:N:P = 5.11:1.23:1

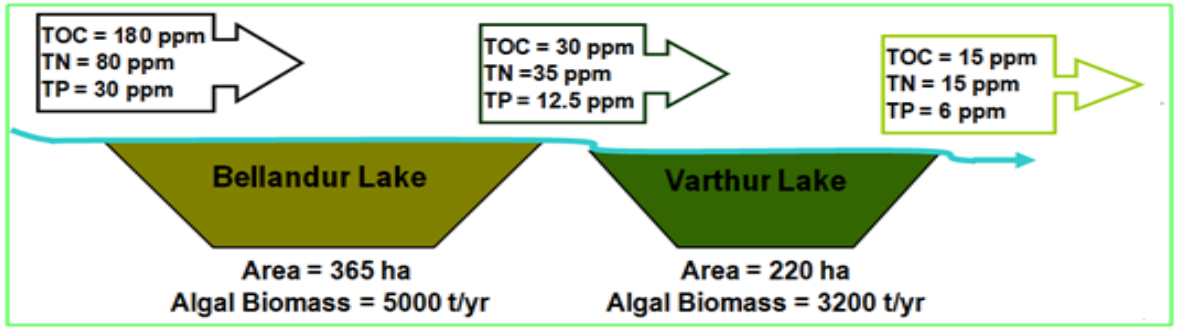
Feasibility of Integration of Algal Modules



Potential Lipid Generation and Establishment of Feasible Area For Algal Ponds







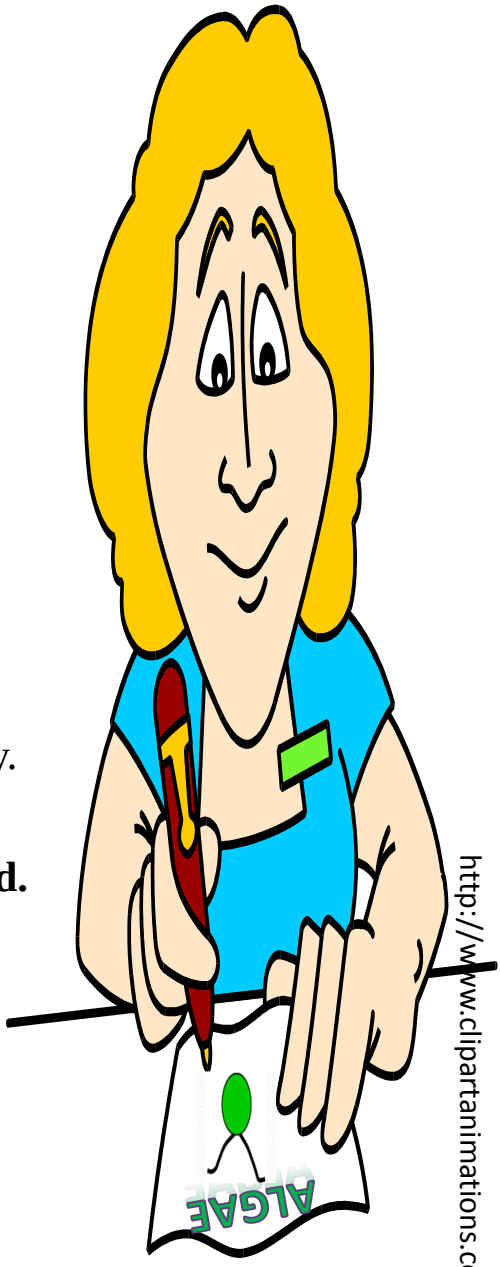
	Treatment Plant Location	Inst. Cap. (MLD)	Treatment Facility	Area (Hac)	Algal bioreactor area required (Hac)*
1	V Valley	180	Secondary : Trickling filters	37	73.12
2	K & C Valley I	163	Secondary: ASP	22	33.11
3	Hebbal Valley	60	Secondary: ASP	19	12.19
4	Madivala	4	Secondary: UASB + OP +CW	4	0.81
5	Kempambudhi	1	Secondary: Ext. Aeration	2	0.20
6	Yelahanka	10	ASP + filtration + chlorination	4	2.03
7	Mylasandra	75	Secondary: Ext. Aeration	7	15.23
8	Nagasandra	20	Secondary: Ext. Aeration	4	4.06
9	Jakkur	10	Secondary: UASB + Ext.	3.5	2.03
10	K.R. Puram	20	Secondary: UASB + Ext.	4	4.06
11	Kadabesanahalli	50	Secondary: Ext. Aeration	22	10.16
12	K & C Valley II	30	Secondary: Ext. Aeration	8	6.09
13	K & C Valley III	55	Secondary: CMAS	6	11.17
14	Rajacanal	40	Secondary: Ext. Aeration	15	8.12
	Total	**718**		**157.5**	**182.38**

Biennial symposium - Lake 2014: Conference on Conservation and Sustainable Management of Wetland Ecosystems in Western Ghats, November 13-15, 2014

Scope for Nutrient Recovery & Biofuel

- The algal rich water bodies help in **70-80 % nutrient** and **~90 % C** removal from influent wastewaters.
- CAPFR productivity **~0.1 g/l/d** of algal biomass.
- For **1 MLD ➔ 100 kg/day** of algal biomass can be generated every day.
- If only 50% of the biomass is harvested, with an average lipid content is taken as ~25 %.
- Daily **12.5 kg** of lipid crude could be produced → **4.56 tonnes** of crude lipid per annum.
- Left over biomass → carbohydrates and proteins – energy generation via fermentation yielding bio-ethanol (Heat value ~30 MJ/kg), or pyrolysis producing liquid crude (heat value >30 MJ/kg).
- Sludge → direct combustion (10-14 MJ/kg dry biomass) or for biogas generation (heat value ~21 MJ/m^3) and the slurry left behind after bio-methanetion can be used as potential manure.
- High nutrient recovery potential **of ~44 t C/yr; ~20t N/yr** and **~8t P/yr** can be achieved from wastewaters in a city.
- Integration of present wastewater methods with algal bioprocess would ensure multiple benefits of

i) water purification ii) nutrients capture iii) GHG mitigation & iv) biofuel to meet the growing energy demand.



http://www.clipartanimations.com/

https://www.google.co.in/search?q=bacteria+removal&biw=1777&bih=887&source=lnms&tbm=isch&sa=X&ei=boM6VKraLMyzuATT44DgDQ&ved=0CAYQ_AUoAQ&dpr=0.9#tbm=isch&q=clipart+cartoons&spell=1&facrc=_&imgdii=_&imgrc=-BYPRPEPFFoTBM%253A%3B-C-D-3WJZSxqcM%3Bhttp%253A%252F%252Fwww.vectors4all.net%252Fpreview%252Fstudiofibonacci-cartoon-zebra-clip-art.jpg%3Bhttp%253A%252F%252Fwww.vectors4all.net%252Fvectors%252Fstudiofibonacci-cartoon-zebra-clip-art%3B357%3B425

CONTINUOUS ALGAL BIOREACTOR (CAB), IISc, Bangalore

ALGAL BIOREACTOR - Wastewater Treatment with Biofuel Production

WATER PURIFICATION


Algal Bioreactor


Manual Harvest


Flow controller


Algal growth Week I


Thick algal growth: surface scum


Oil spill in reactor Lipids from Algae

Progressive Treatment of Domestic Wastewater with Autoflocculation-CAPFR

Oil droplets/lipid bodies inside algal cells


Harvesting Surface Flocs, Concentrating, Dewatering/Drying & Powdering

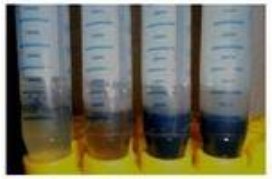
Algae: Wet *Dried* *Powdered*

THANK YOU

Cell disruption: Bead beating

Ultra-Sonication


Lipid extraction Chloroform:Methanol

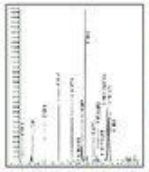

Solvent Ectraction CH_3Cl:MeOH 2:1


Total Lipids

TAG ext. -Thin Layer Chromatography


Transesterification to FAME through acid catalysis with BF_3 Methanol & final prurification through Hexane


GC-MS Analysis FAME Composition


Chromatogram FAME profile

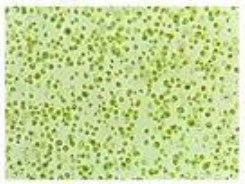

Extracted Biodiesel


Flame test Combustion


Suspended Algal Culture and Collection


Settleability Test

Demonstration of natural Auto flocculation of algal biomass.


Chlorella sp.


Ankistrodesmus sp.

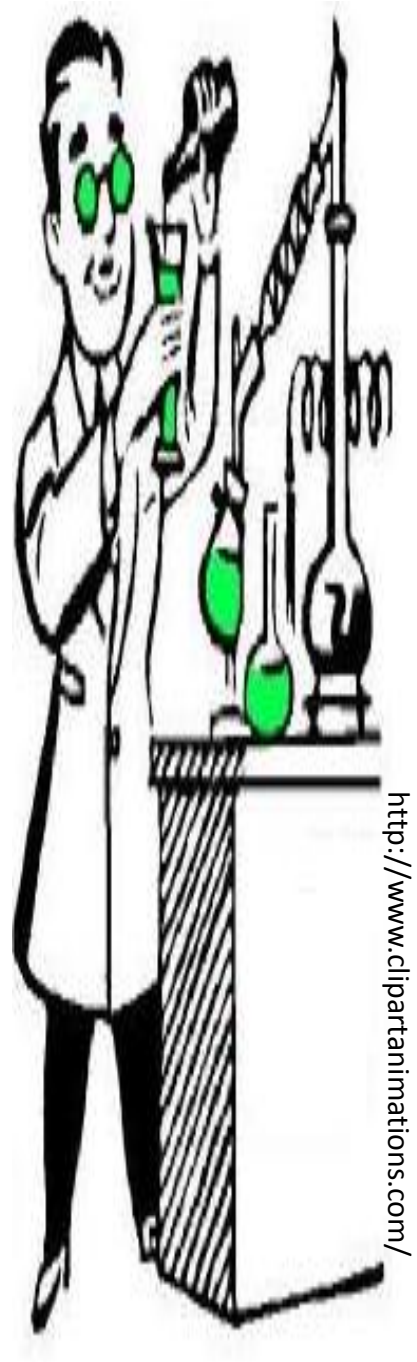

Spirulina sp.


Euglenoides

NUTRIENT RECYLE

CONTINUOUS BIOREACTOR DESIGN AND OPERATION

Support: Department of Biotechnolgy (DBT), The Ministry of Science and Technology (DST) and Indian Institute of Science (IISc), Bangalore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