

From Algae Biomass to Biofuels: Cultivation Systems, Processing Technologies, and Conversion Pathways



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Introduction

Can you imagine life without fuel?



MICROALGAE: THE
GREEN GOLD OF
FUTURE



Algal culture in PBR & Raceway



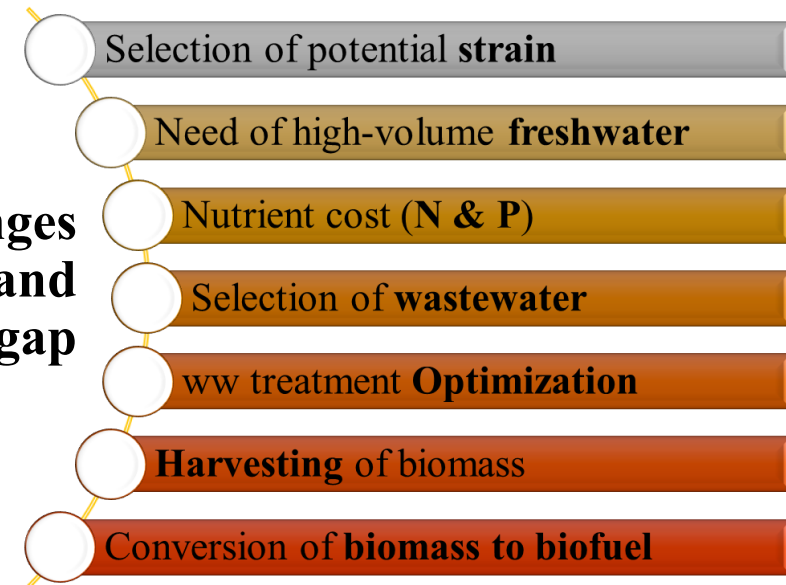
Biomass slurry



Microalgal cultivation and bioenergy production:
Clean, Green and Sustainable

- ✓ Superior oil yields.
- ✓ Not directly affecting the human food chain.
- ✓ Grown in places that are not suitable for agriculture.
- ✓ Utilizes CO₂ as the source for photosynthesis.
- ✓ Low-cost biofuel with limited waste discharge.

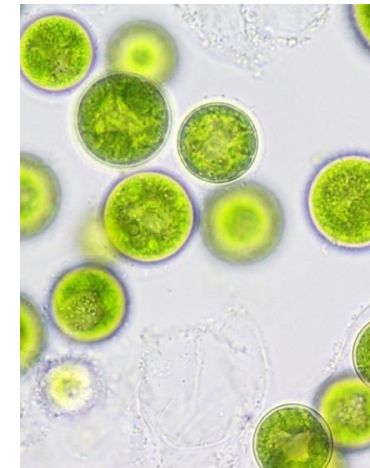
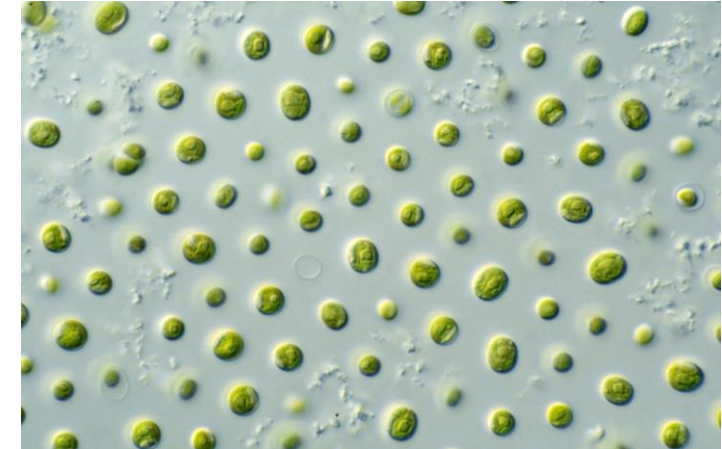
**Challenges
and
Research gap**



Basics of Microalgae

Algae types

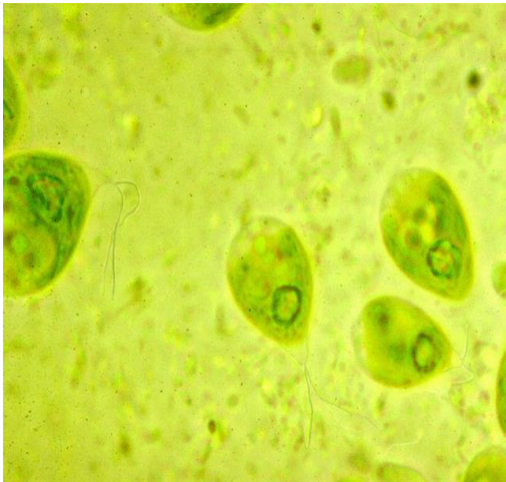
- **Algae** (singular **alga**) are the main microorganisms involved in the photosynthesis process and lack roots, stems, and leaves. **Chlorophyll-a** as their primary photosynthetic pigment.
- Algae range in size from microscopic organisms (**microalgae**) to macroscopic forms which are visible to the naked eye and appear plant-like (**Macroalgae** (Green algae, Brown algae, Red algae)).
- Algae most commonly occur in water. However, they have been also found in almost every other environment on earth.



Types based on Morphology

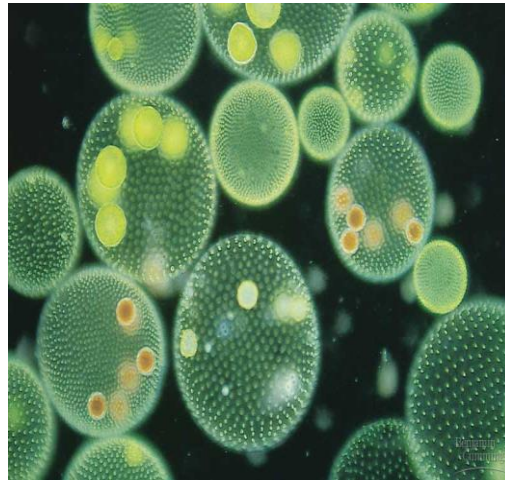
Unicellular

Chlamydomonas •



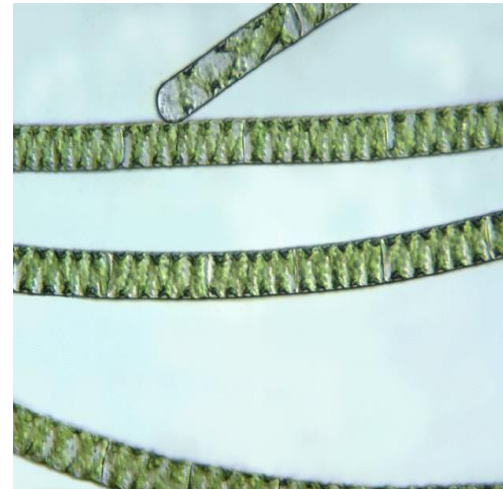
Colonial

Volvox •



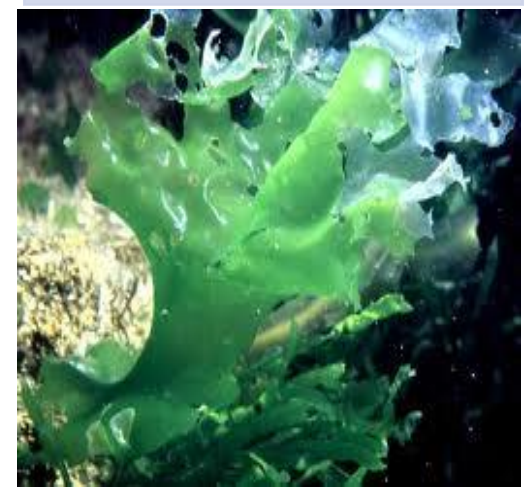
Filamentous

Spirogyra •



multicellular

Ulva sp. •



Where can Algae live ?



• **SOIL** →
NOSTOC SP.



• **SEA WATER** →
DIATOMS



• **FRESH WATER**
→ *VOLVOX SP*



Pictures of different algae

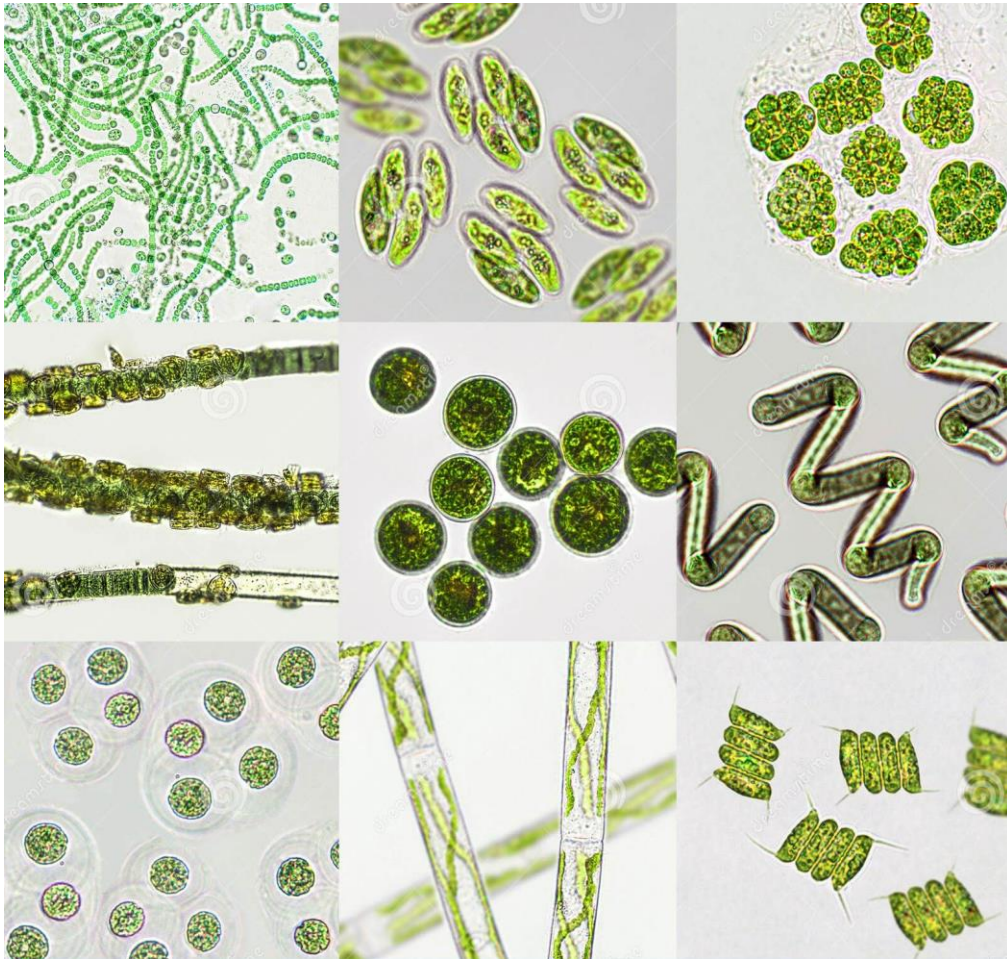


Fig.: **Microalgae** under microscopic view, green algae, cyanobacteria, phytoplankton, diatom, algae mix collage background.



Fig.: Different types of **macroalgae** reported in the literature

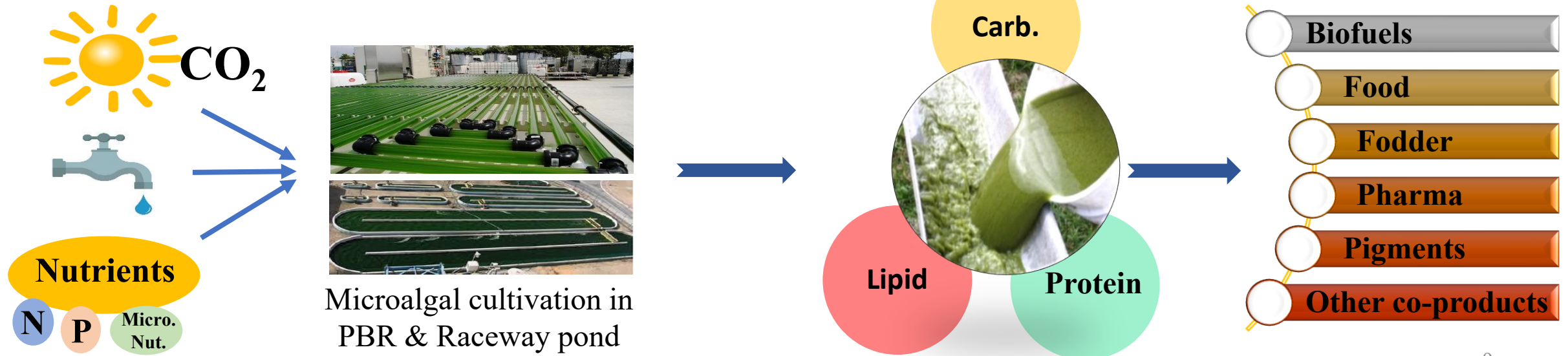
Microalgae Cultivation

Microalgae the green Gold



Microalgal cultivation and bioenergy production: # Clean, Green and Sustainable

- ✓ Superior oil yields.
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- ✓ Low-cost biofuel with limited waste discharge.
- ✓ Production of high-value co-products



Algal cultivation systems

- **Large-scale cultivation systems**

- a) Photobioreactors

- b) Raceway ponds



Photobioreactor (PBR) cultivation

- In general, laboratory-scale photobioreactors are artificially illuminated using fluorescent or other light lamp distributors.
- Some of these reactors include open ponds, flat-plate, tubular, bubble column, airlift column, helical tubular, conical, torus, stirred-tank, seaweed type photobioreactors.



a plate



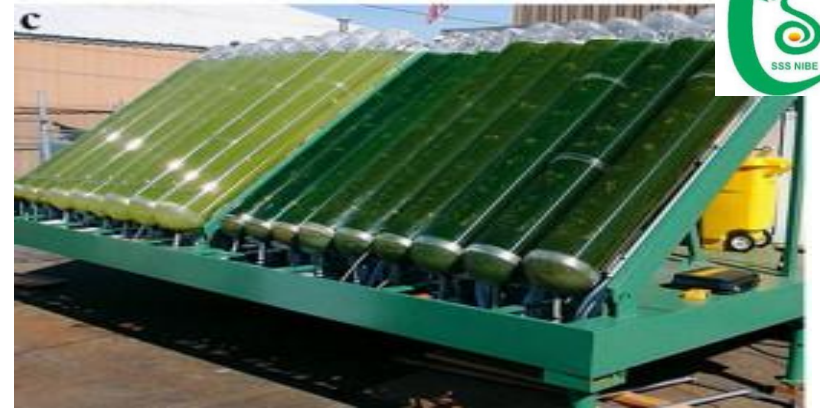
b tubular



c annular

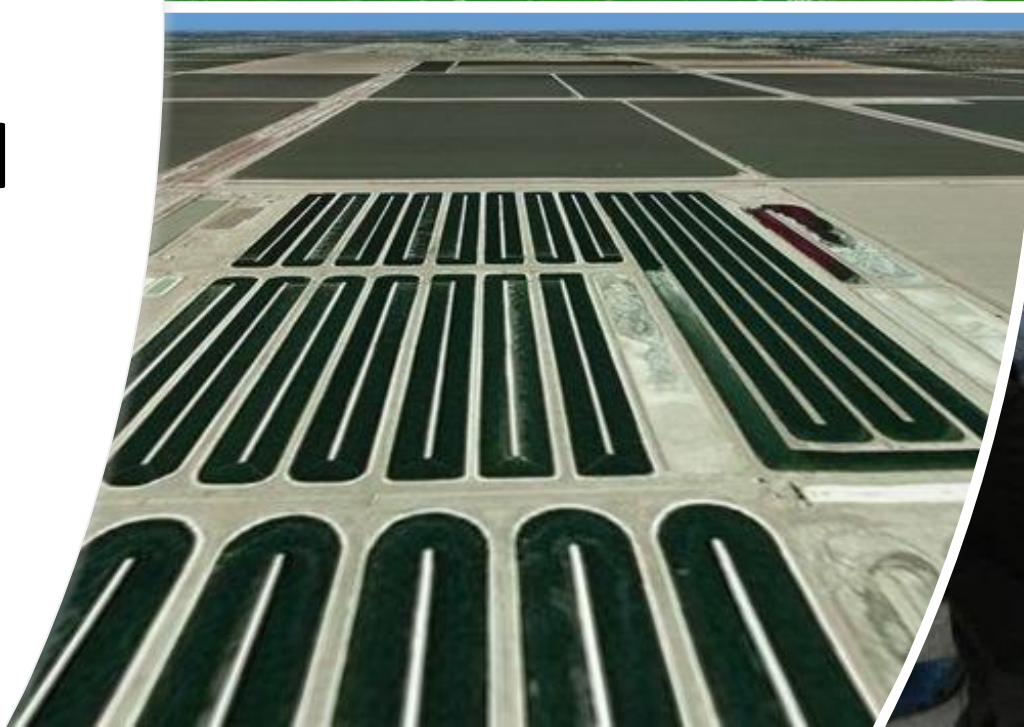


d plate airlift



Algae cultivation in PBR

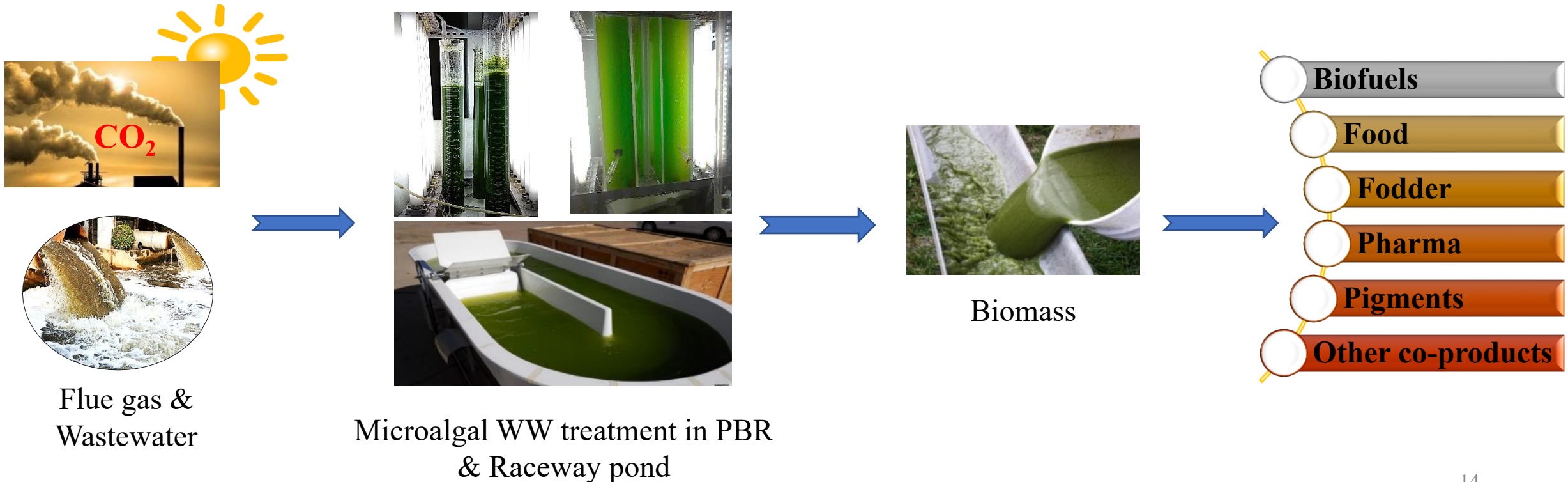
Algae cultivation in Raceway pond



Microalgal-mediated wastewater treatment



- ✓ Reduces freshwater dependency
- ✓ Wastewater as a nutrient source
- ✓ Industrial flue gas as a source of CO₂
- ✓ Production of high-value co-products



Wastewater collection and characterization



- Domestic sewage wastewater (**DSW**) from sewage treatment plant (**STP**) of IITG.
- Facultative aerated lagoon based WTP with 1.35 million L d⁻¹ capacity.
- Clear evidence of algal blooms due to NO₃⁻, PO₄³⁻ and COD presence.



Table: DSW compositions

Components	Raw DSW (RDSW)	Autoclaved DSW (ADSW)
pH	7.81 ± 0.38	7.92 ± 0.11
COD (mg L ⁻¹)	166 ± 12.77	143.7 ± 9.52
NO ₃ ⁻ (mg L ⁻¹)	8.3 ± 0.48	5.88 ± 0.2
PO ₄ ³⁻ (mg L ⁻¹)	10.7 ± 0.42	7.3 ± 0.48
NH ₄ ⁺ (mg L ⁻¹)	44.7 ± 1.92	38.4 ± 3.68

**Algal
Blooms**

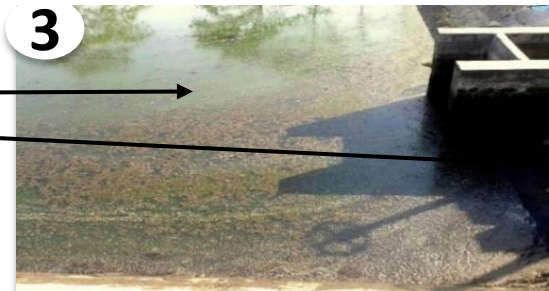
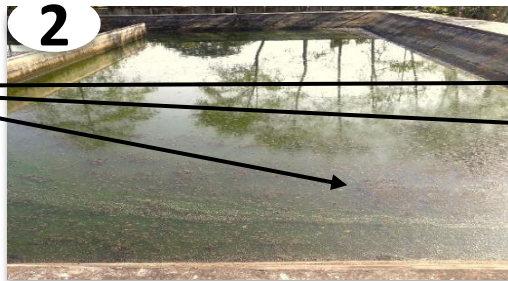
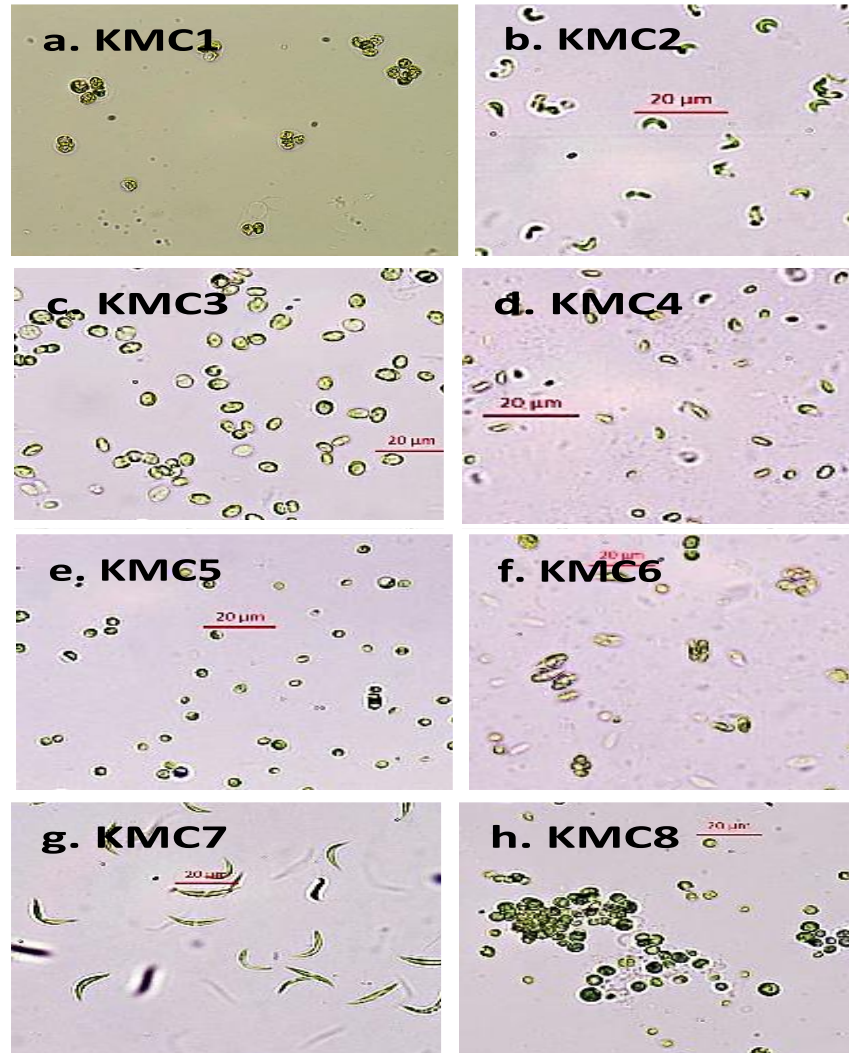


Fig.: Sewage treatment plant, IITG

Isolation and Identification of strains



Strain ID	Microalgal strains Name
KMC1	<i>Chlamydomonas parallestriata</i> (MF179625)
KMC2	<i>Monoraphidium convolutum</i> (MG597604)
KMC3	<i>Desmodesmus abundans</i> (MG597605)
KMC4	<i>Monoraphidium</i> sp. (MH183246)
KMC5	<i>Chlorella sorokiniana</i> (MG597606)
KMC6	<i>Scenedesmus deserticolal</i> (MG597607)
KMC7	<i>Monoraphidium contortum</i> (MG597608)
KMC8	<i>Micractinium pusillum</i> (MG597609)

Fig.: Microscopic images of microalgae (50x)

Process optimization in PBR

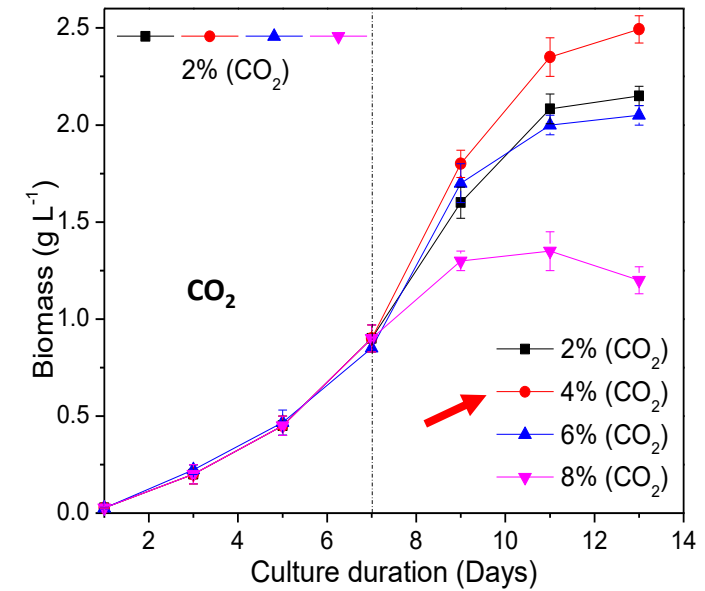
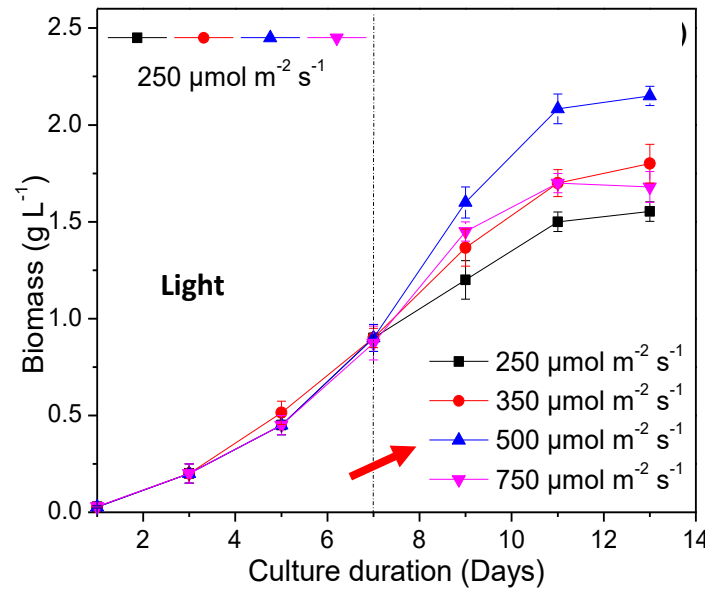
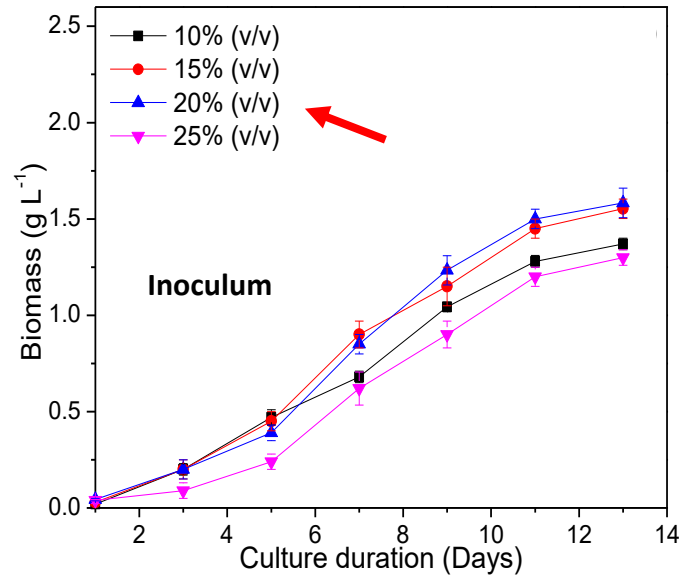


Fig.: Growth profile of KMC4 during optimization of culture conditions

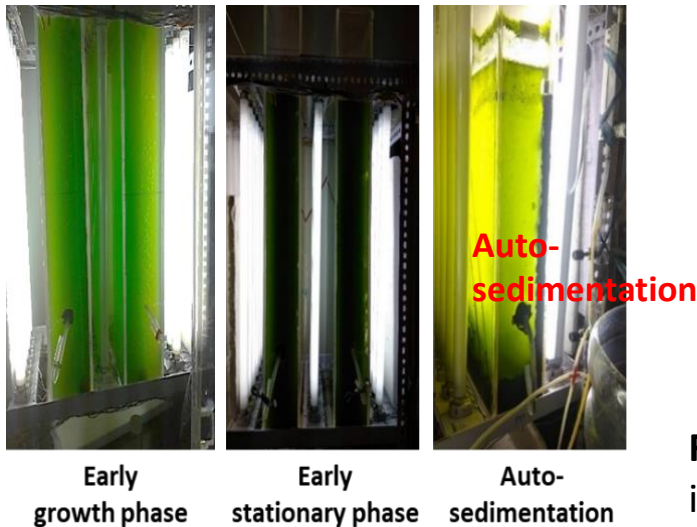


Fig.: Microalgal culture in 25 L PBR

Key Results:

- ✓ Biomass yield: 2.48 g L⁻¹
- ✓ Nutrient removal: >90%

Biomass harvest and composition

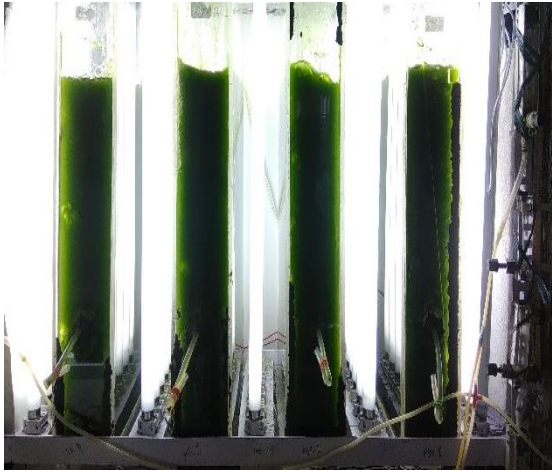


Fig.: Microalgal culture in PBR



Fig.: Auto-sedimentation



Fig.: Biomass slurry



Fig.: Lyophilized biomass

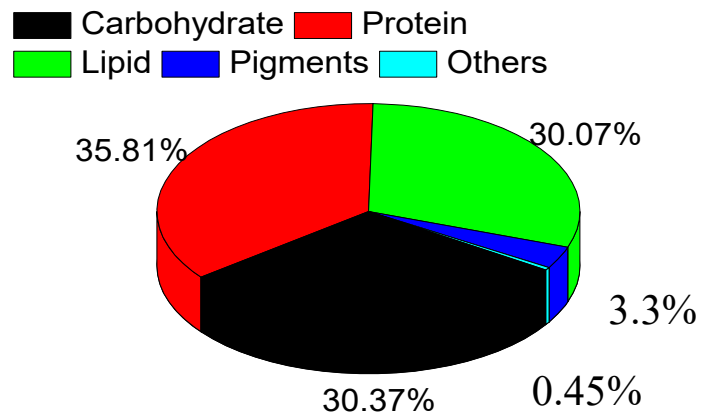


Fig.: Biochemical composition of KMC4

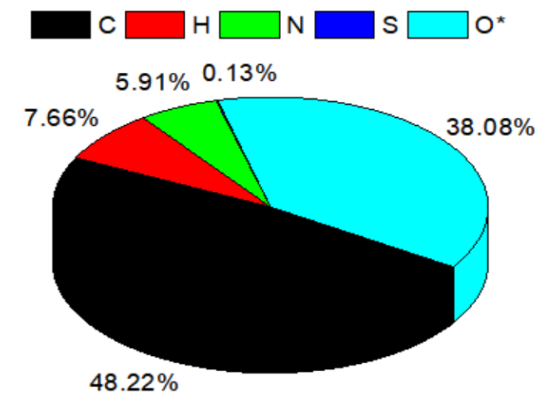


Fig.: Elemental composition of KMC4

Industrial Wastewater for Algal cultivation

Wastewater collection: Canal from Jalandhar industrial zone, Punjab

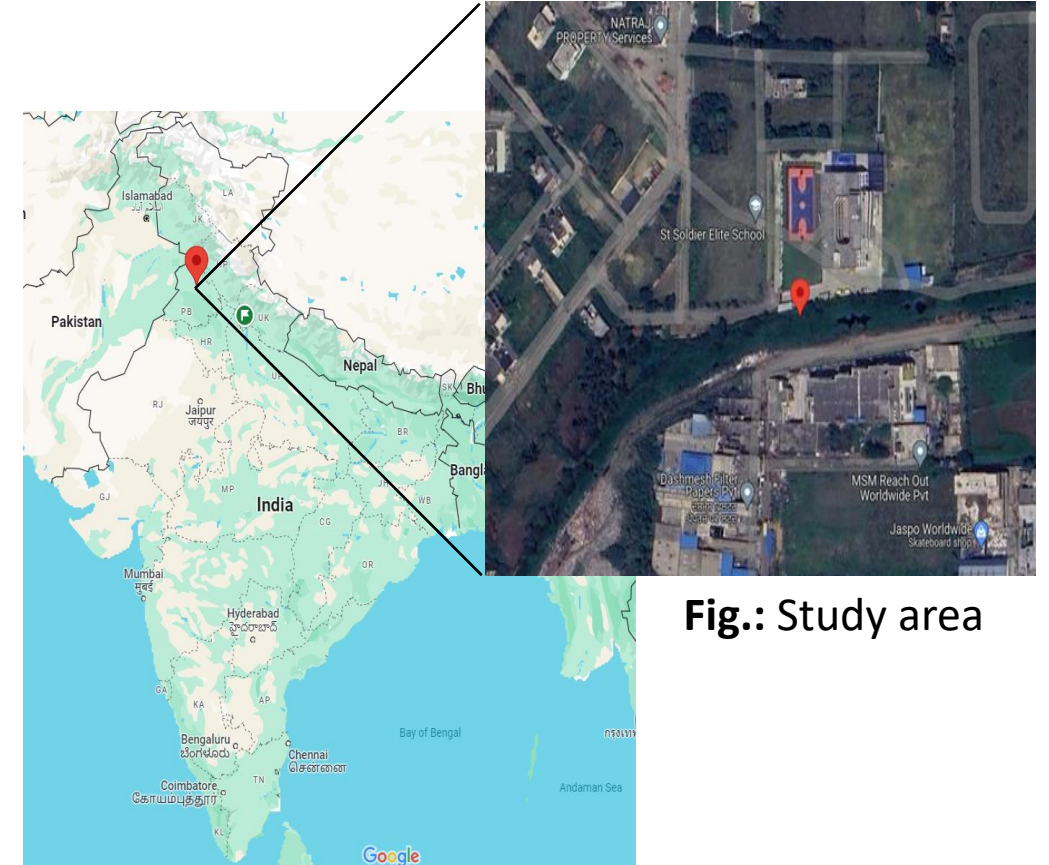
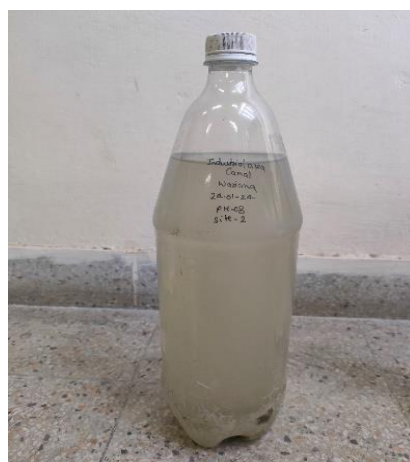
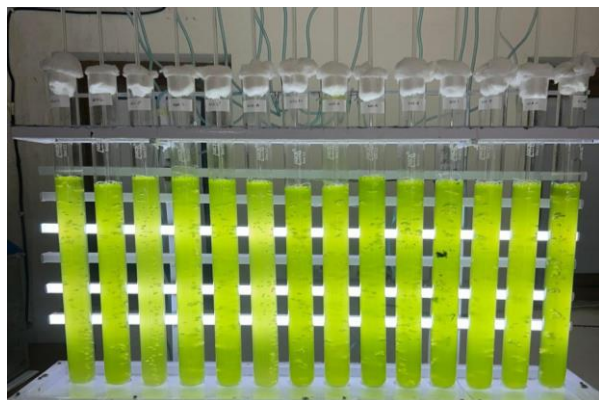


Fig.: Study area

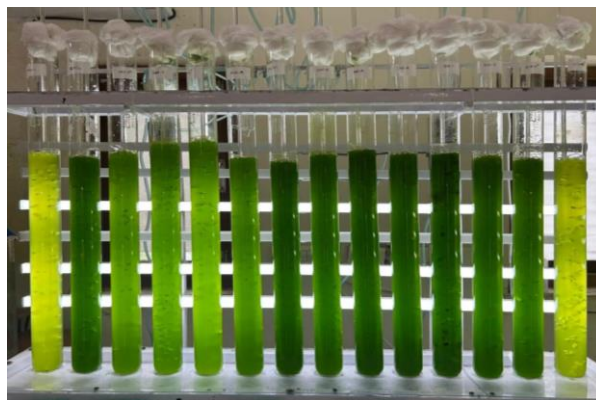
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Fig.: Wastewater collected samples

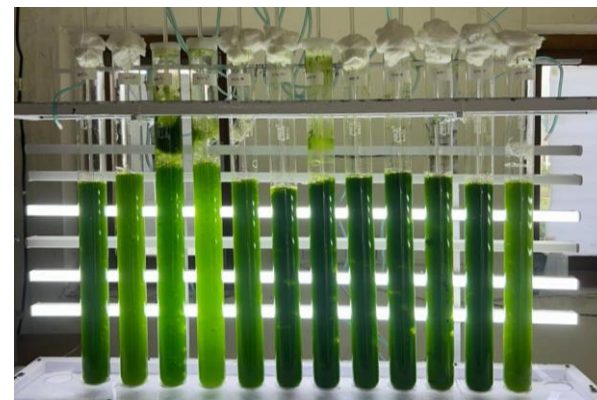
Nutrient removal study of native isolated strains



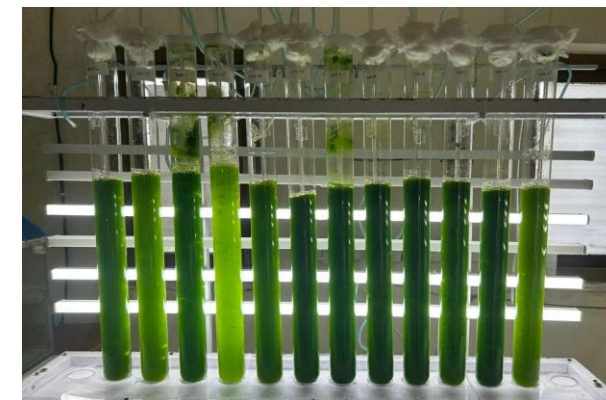
Day-0



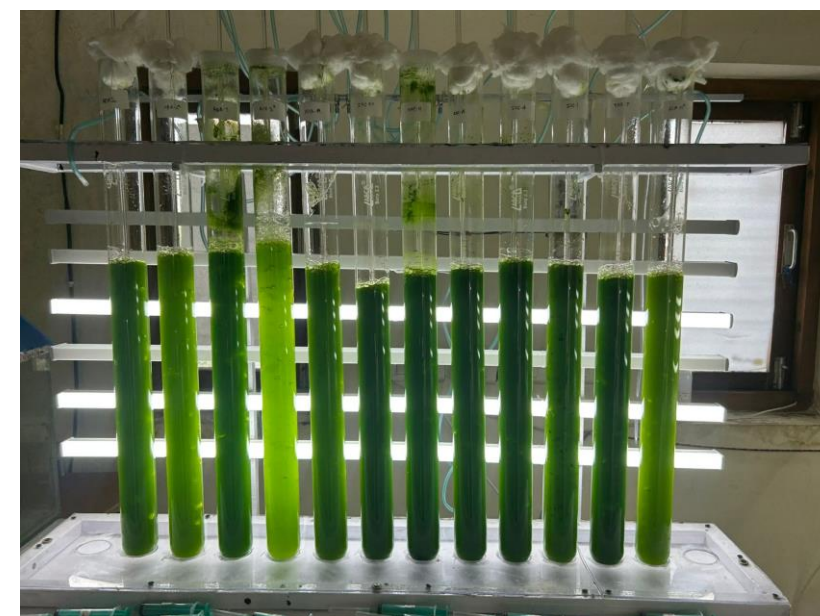
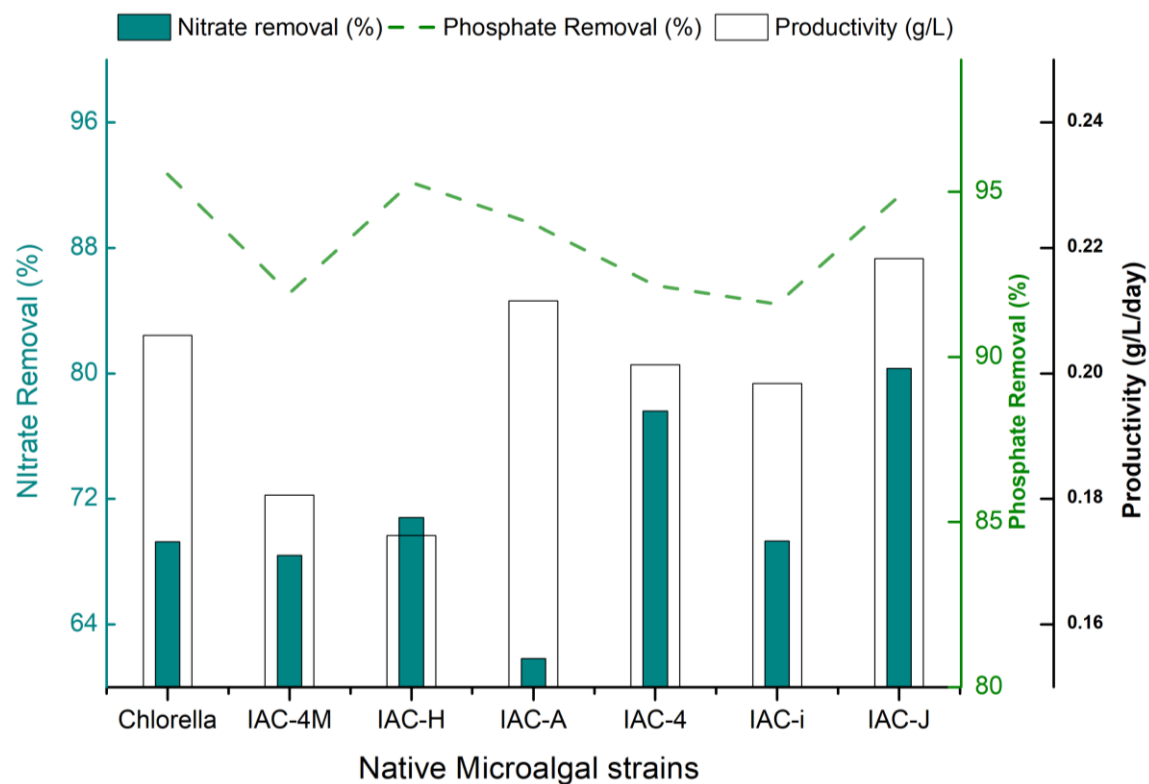
Day-4



Day-6



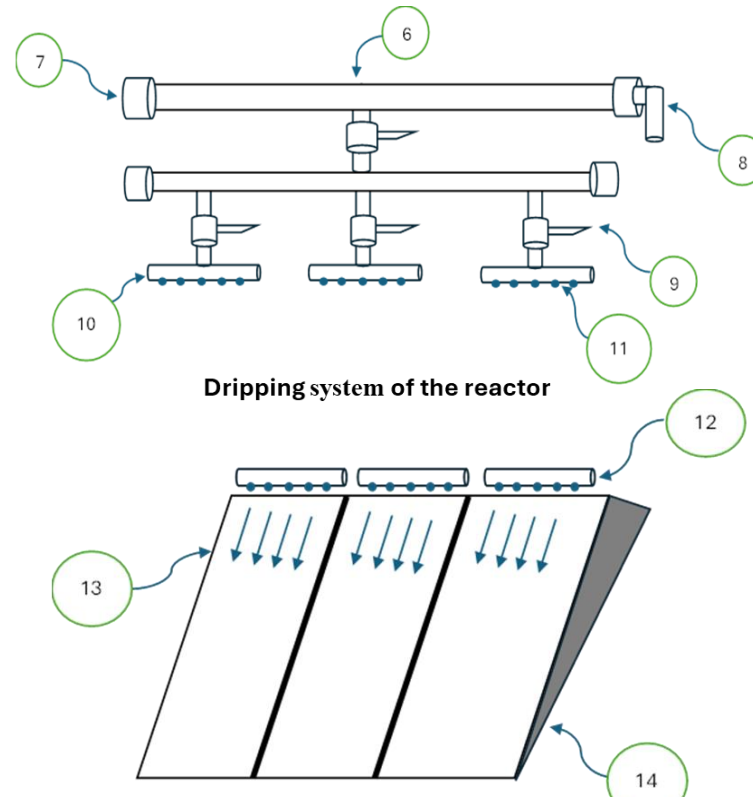
Day-8



Day-12

Design and development of Inclined microalgal biofilm bioreactor (IMBR)

1. 20-inch cut in PVC pipe
2. PVC Cap diameter 3 inch
3. PVC connectors diameter 2 inch
4. PVC pipe Diameter 3 inch
5. Darin valve diameter 1 inch
6. PVC pipe diameter 1.5 inch
7. PVC stopper diameter 1.5 inch
8. Connector Valve diameter 0.5inch
9. Regulators
10. 5.5inch PVC pipe diameter 0.75inch
11. Holes at 0.91cm distance
12. Dripping system
13. Surface for biofilm formation
14. Inclination angle (19°)



Carrier material support surface of the Reactor Front view

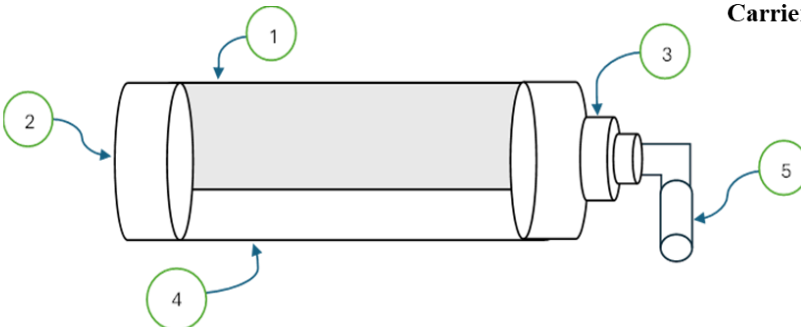
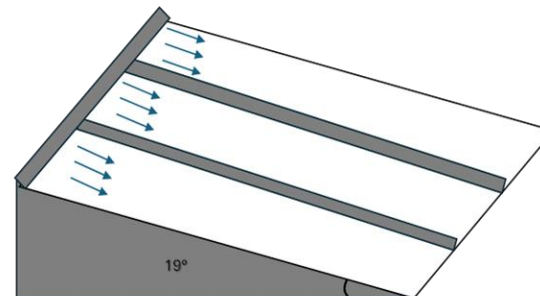
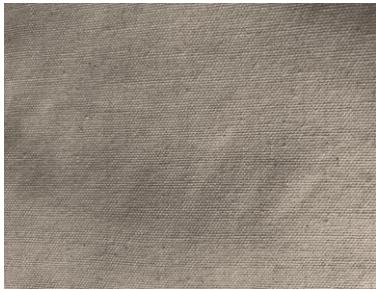
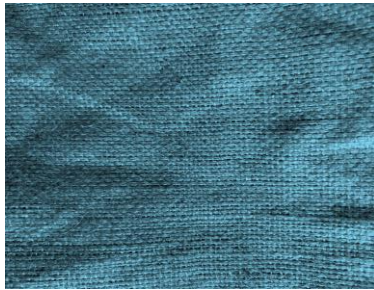


Fig. Lab Scale Incline Microalgal Biofilm Bioreactor (IMBB)

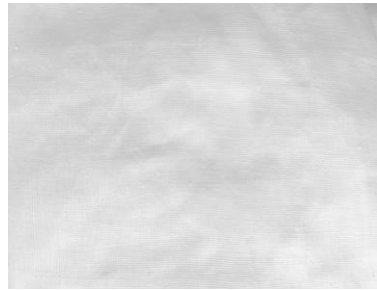
Carrier material selection study



Cotton Canvas



Jute Canvas



Muslin Cloth



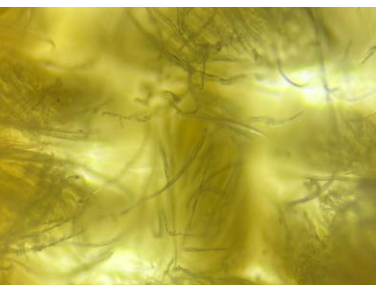
Carrier materials: L-19inch, W-5inch



Pretreatment



Carrier material setup



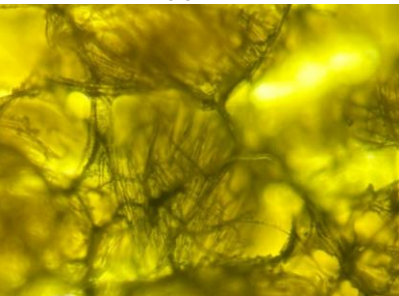
**Cotton Canvas
Microscopic image
100x**



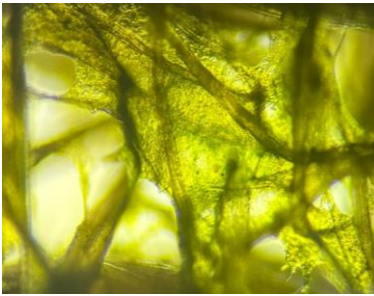
**Jute Canvas
Microscopic image 100x**



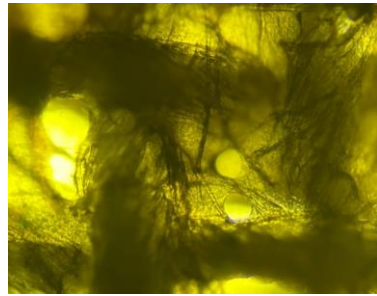
**Muslin Cloth
Microscopic image
100x**



**Cotton Canvas with
algal biofilm
Microscopic image
100x**



**Jute Canvas with
algal biofilm
Microscopic image
100x**



**Muslin Cloth with algal
biofilm Microscopic
image 100x**



Inoculation with 1g DW Biomass

Fixed variables
Flow rate 1L/min
Working Volume: 3L
Inoculum: 1g DW
Harvest: Every 3rd day
L:D 16:8

**Lab to Outdoor
Pilot-scale study**

Biomass harvesting and drying of the biomass



Fig. Algal biomass harvesting



Fig. Auto flocculation



Fig. Filtration of algal biomass



Fig. Mixing of algal slurry



Fig. drying of harvested algal biomass at 105 °C for 48 h

Algal biomass to Biofuel

Biofuels from microalgae

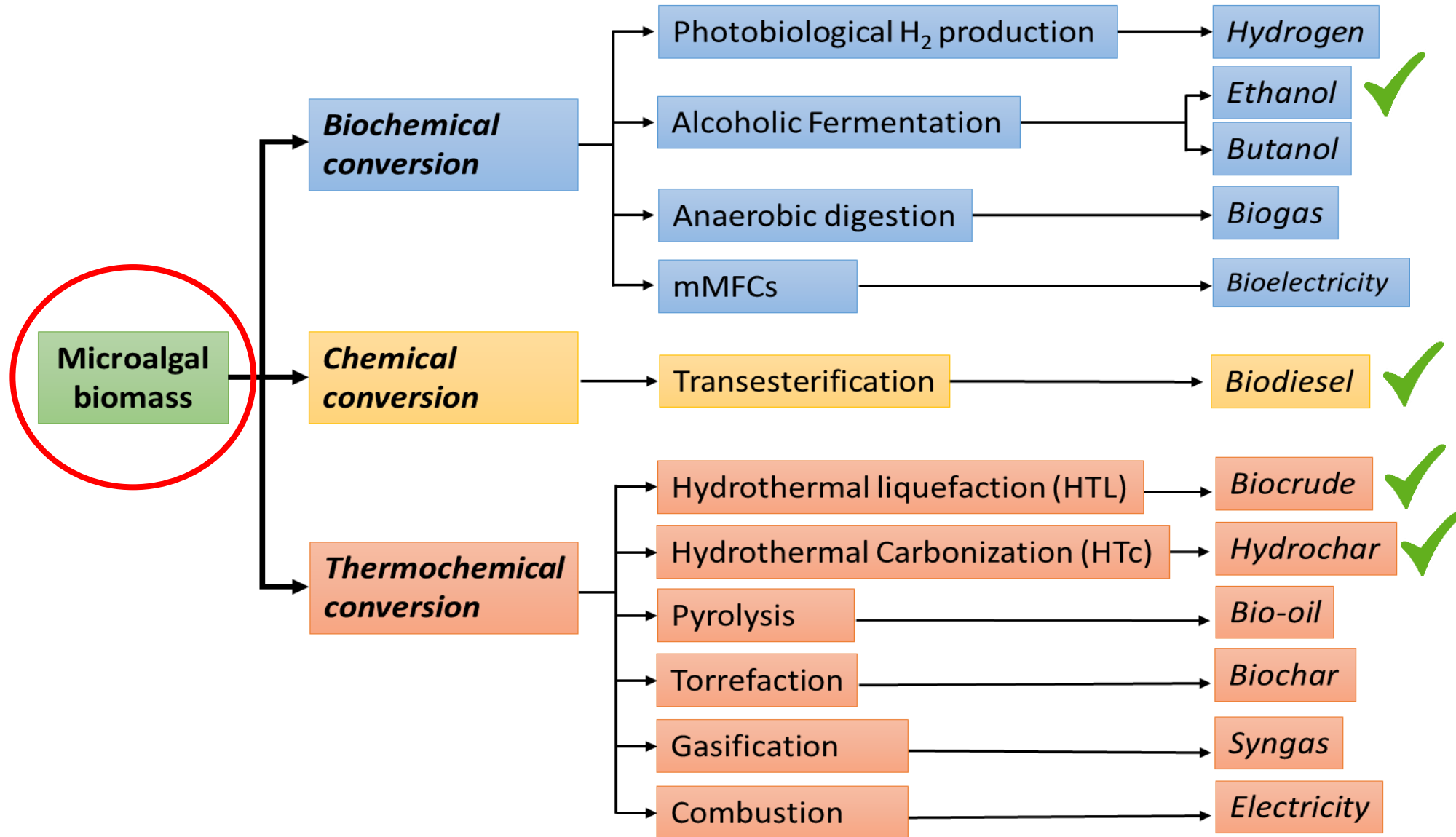


Fig.: A schematic of microalgal biomass to biofuel conversion techniques

Lipid extraction



Fig.: Lipid Extraction in a Soxhlet apparatus



Fig.: Solvent separation (n-Hexane) in rotary evaporator



Fig.: KMC4 lipid (28-32 wt.% of DCW)

Fatty Acid Methyl Esters (Biodiesel)



FAME

Glycerol and
residues

Fig.: 2-step transesterification (H_2SO_4 & NaOH) at 70 °C for 3h

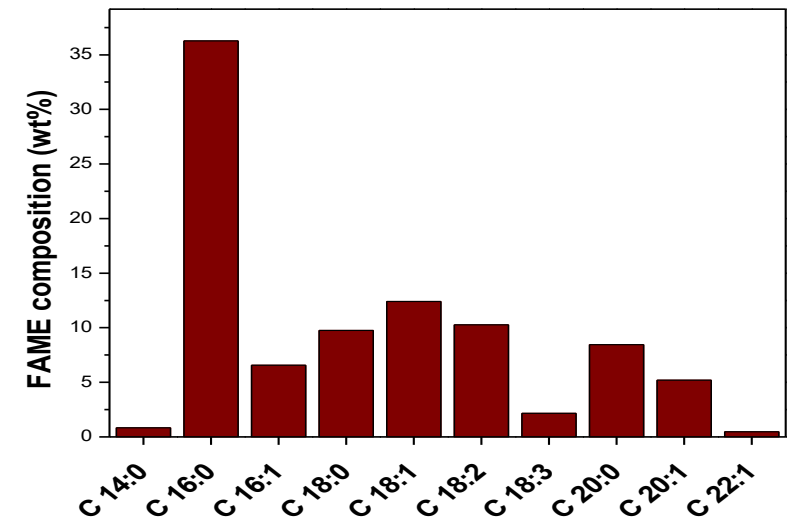
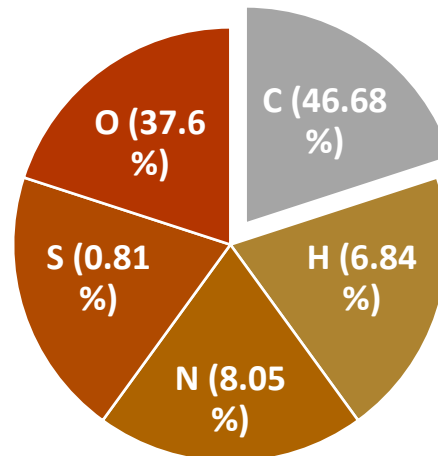
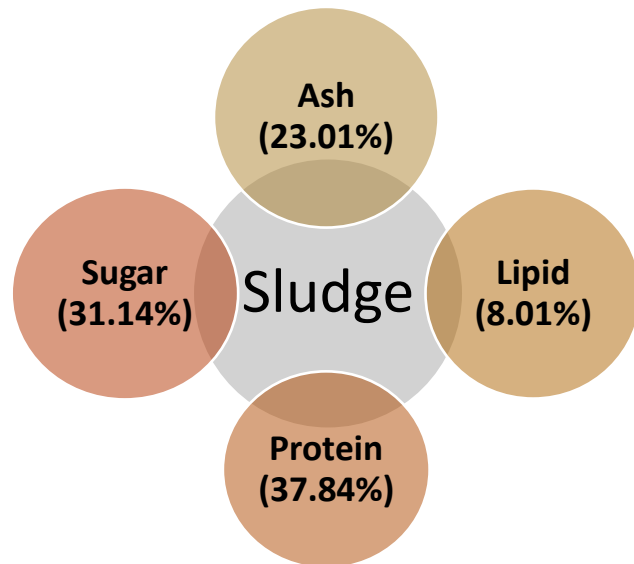
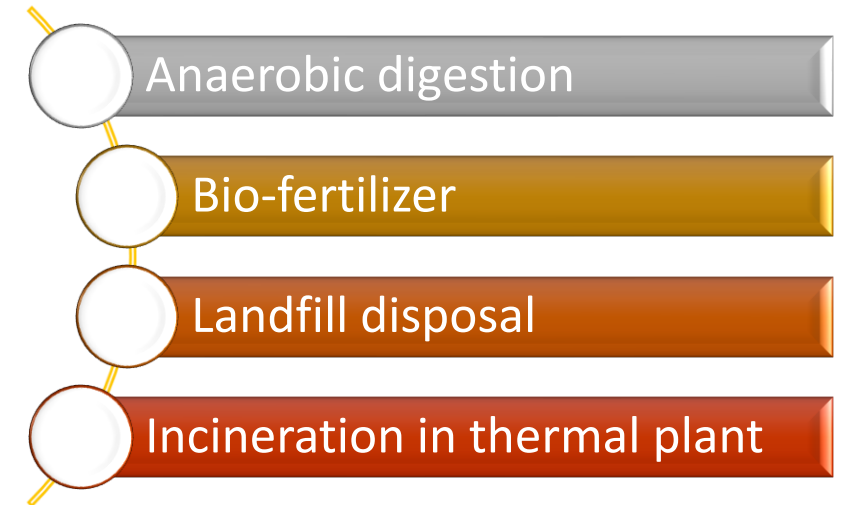


Fig.: FAME profile with 78% C16-C18

Biomass to biocrude *via* Co-HTL



**Integration
with
Algal Biorefinery**



Experimental design



Fig.: Schematic of HTL/Co-HTL experimental process

Distillation profile of biocrude

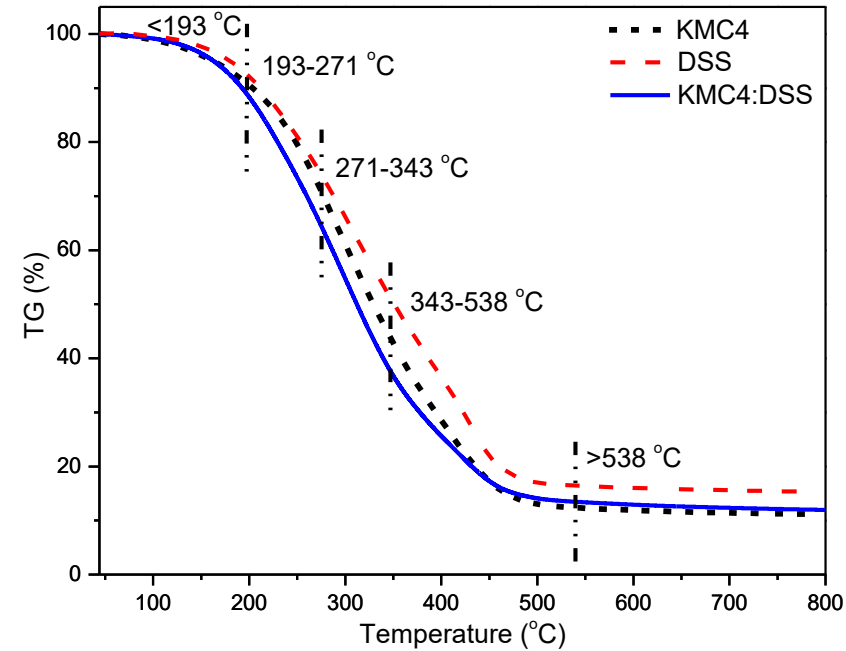
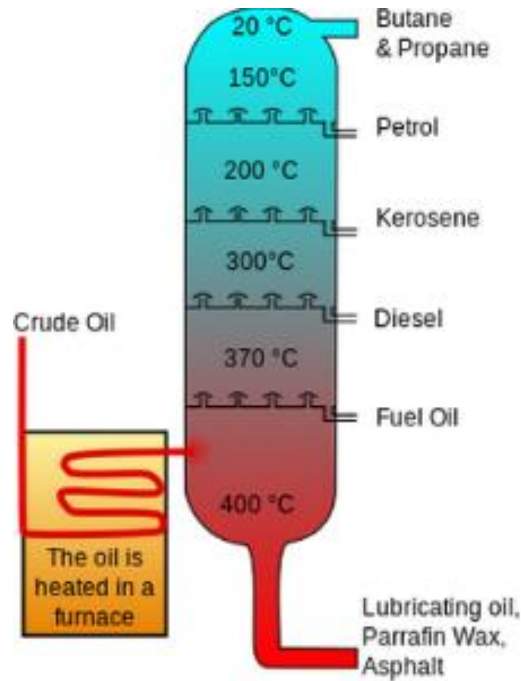
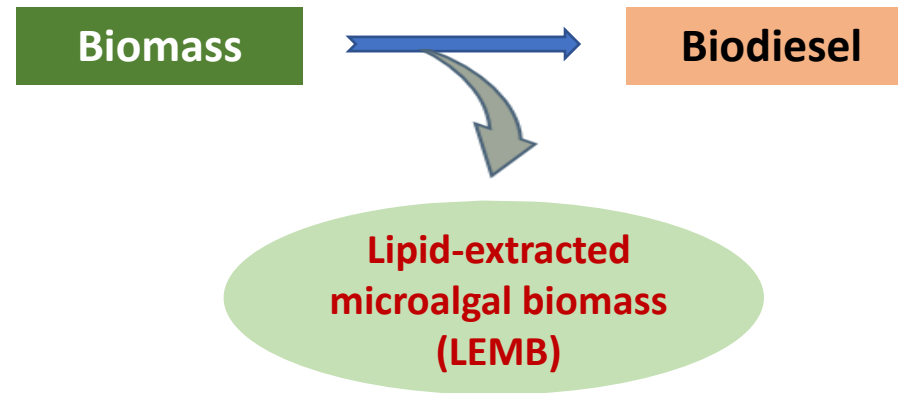


Fig.: Distillation profile (wt%) of biocrudes

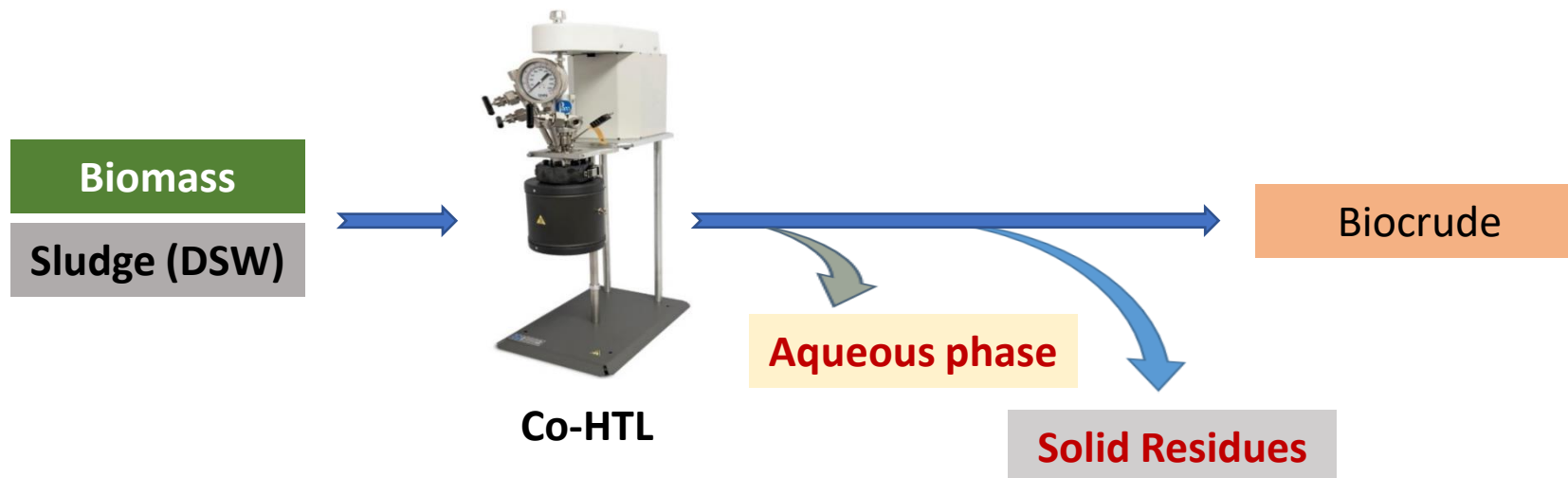
Table: Boiling point distribution (wt%) of biocrudes ^a

Distillation range	Feedstock		
	KMC4	DSS	KMC4:DSS
<193 (Heavy naphtha)	8.53	6.77	10.13
193-271 (Kerosene)	19.1	18.07	23.92
271-343 (Gas oil)	27.23	22.74	27.09
343-538 (Vac. gas oil)	32.75	35.95	25.38
>538 (Vac. residue)	12.39	16.47	13.48

^a Moisture free and DCM free



Valorization of residues for biorefinery applications



Characterization of LEMB

- Lipid extracted microalgal biomass (LEMB) contains **carbohydrates, proteins, pigments, and a few un-extracted lipids** that makes it as a potential bioenergy feedstock
- Potential applications:** Pyrolysis, Combustion, Hydrochar, Fermentation

Table: Composition of KMC4 LEMB

Biomass feedstock	C	H	N	S	O*	H/C (mol/ mol)	O/C (mol/ mol)	N/C (mol/ mol)	HHV (Mj Kg ⁻¹)
KMC4 (LEMB) ^a	47.04	7.29	6.6	0.16	38.91	1.85	0.62	0.12	19.36
KMC4 (LEMB) ^b	50.18	7.51	6.3	0.11	35.9	1.78	0.54	0.1	21.27

*Oxygen content estimated by difference; LMBRs: Lipid extracted microalgal biomass residues;

^a RDSW derived biomass; ^b BG11 derived biomass

Hydrolysis of LEMB & Bioethanol production



Hydrolysis

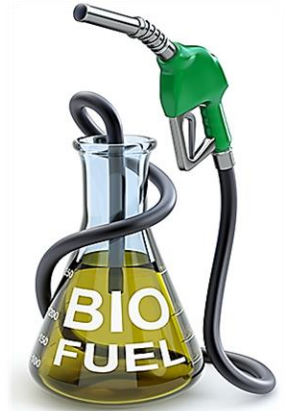
- 121°C, 20 min
- 10% LEMB
- 1.5% H₂SO₄



Hydrolysate

Fermentation

- *S. cerevisiae*
- 30 °C, 120 rpm
- 10% inoculum



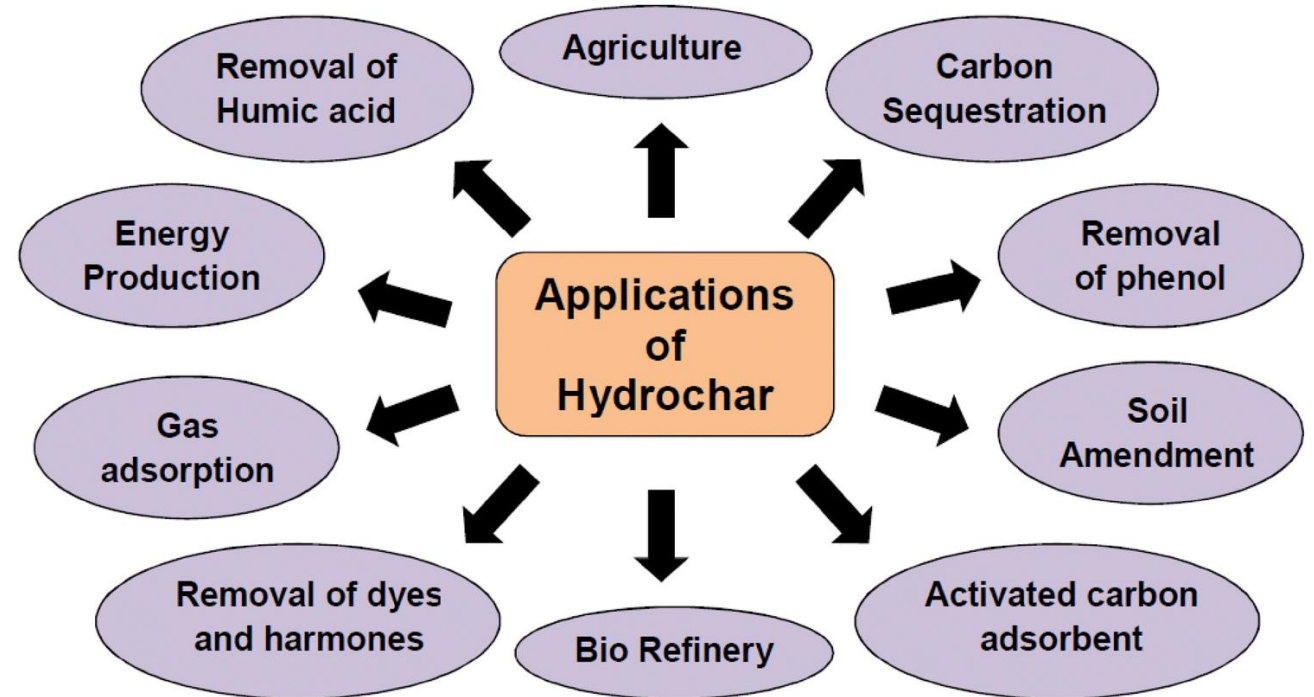
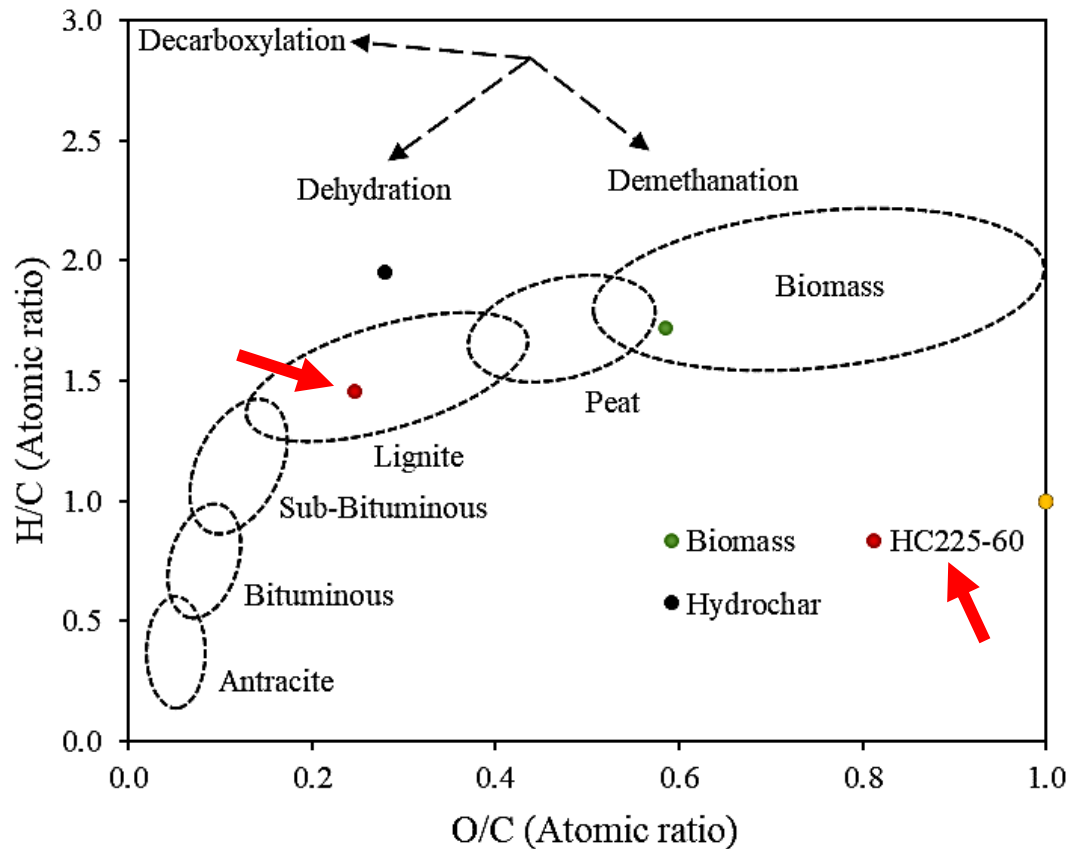
Bioethanol

Key Results:

- ✓ Hydrolysis of LEMB resulted in 258 mg mg⁻¹ LEMB of reducing sugar.
- ✓ Fermentation of obtained hydrolysate was done using *Saccharomyces cerevisiae*.
- ✓ Ethanol yield of 205 mg mg⁻¹ was obtained in 36h.
- ✓ Solid residues obtained after fermentation was dried and processed for hydrothermal carbonization (HTC).

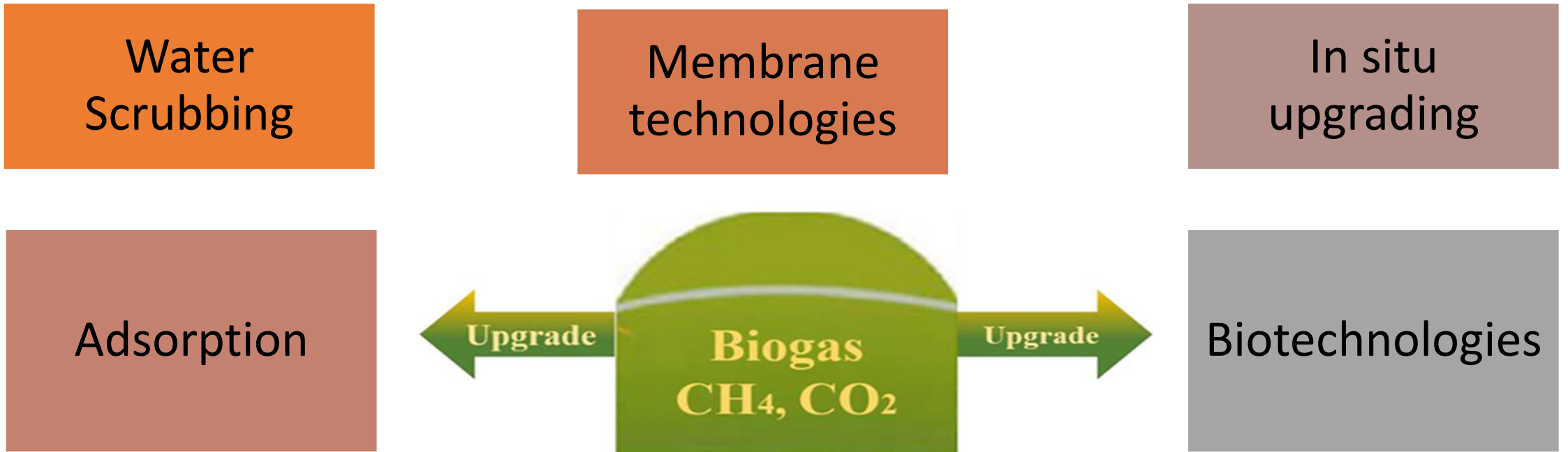
Hydrochar from algal biomass

- **Key Results:**
- Solid residues after the fermentation had 72% VM.
- HTC resulted in 38 wt% of hydrochar.
- Hydrochar had C (43%), H (7%), and HHV of 19 MJ Kg⁻¹.

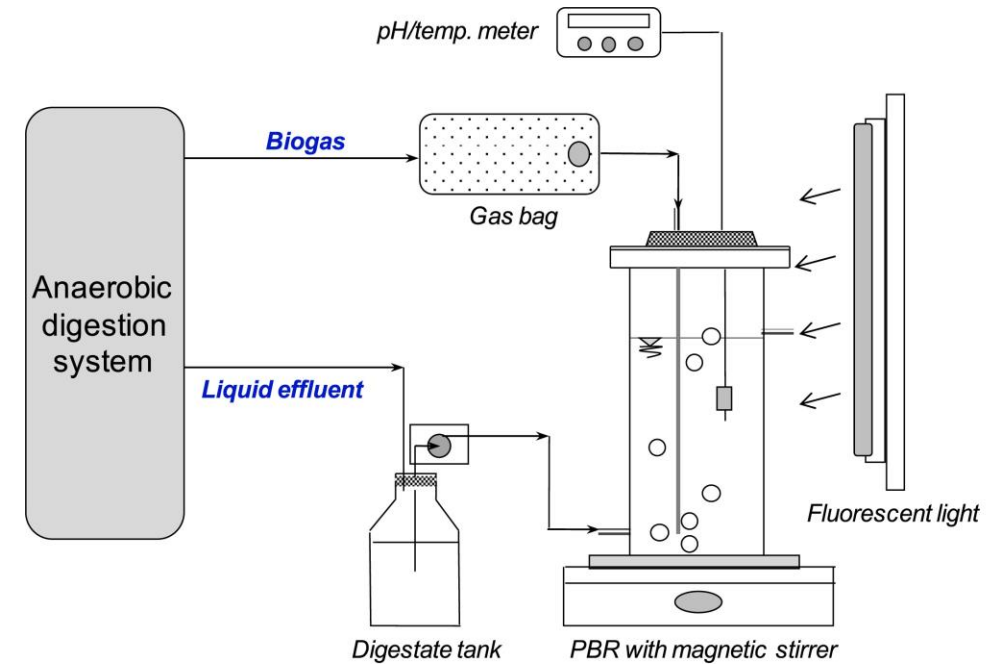
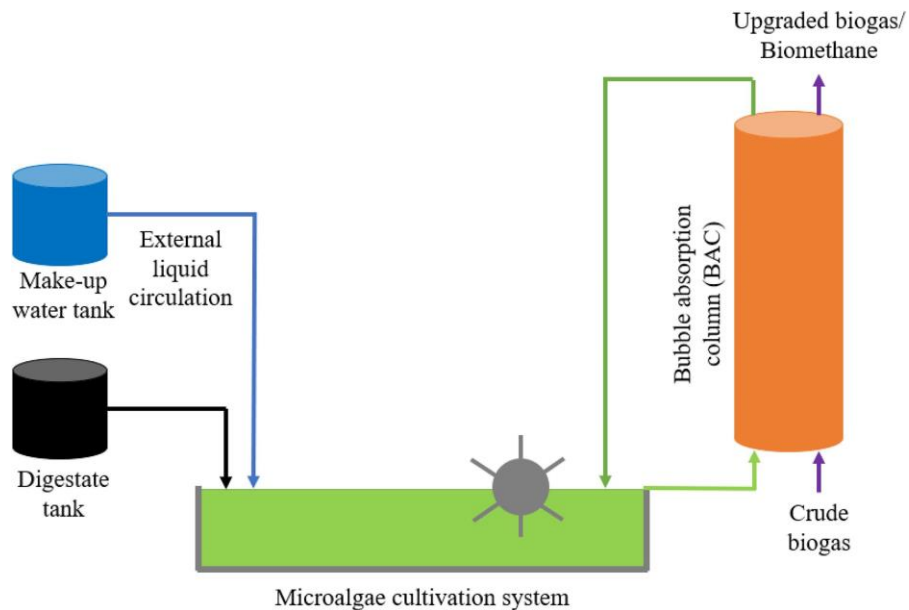
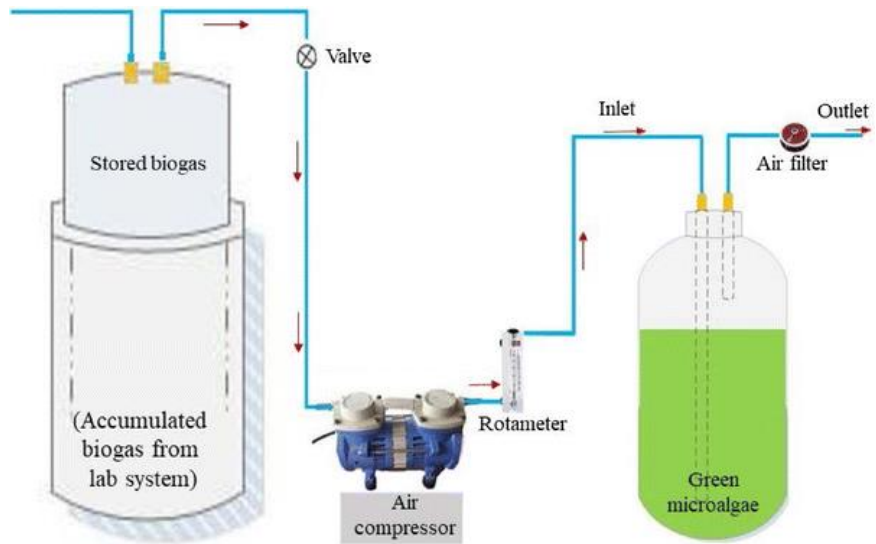


Ways to Integrate Microalgae in CBG Plants

Biogas purification technologies



2. Use of algal biorefinery in CBG plants



Ref.: 2018, Sustainability assessment of biogas...

A futuristic biorefinery approach

A Futuristic biorefinery approach

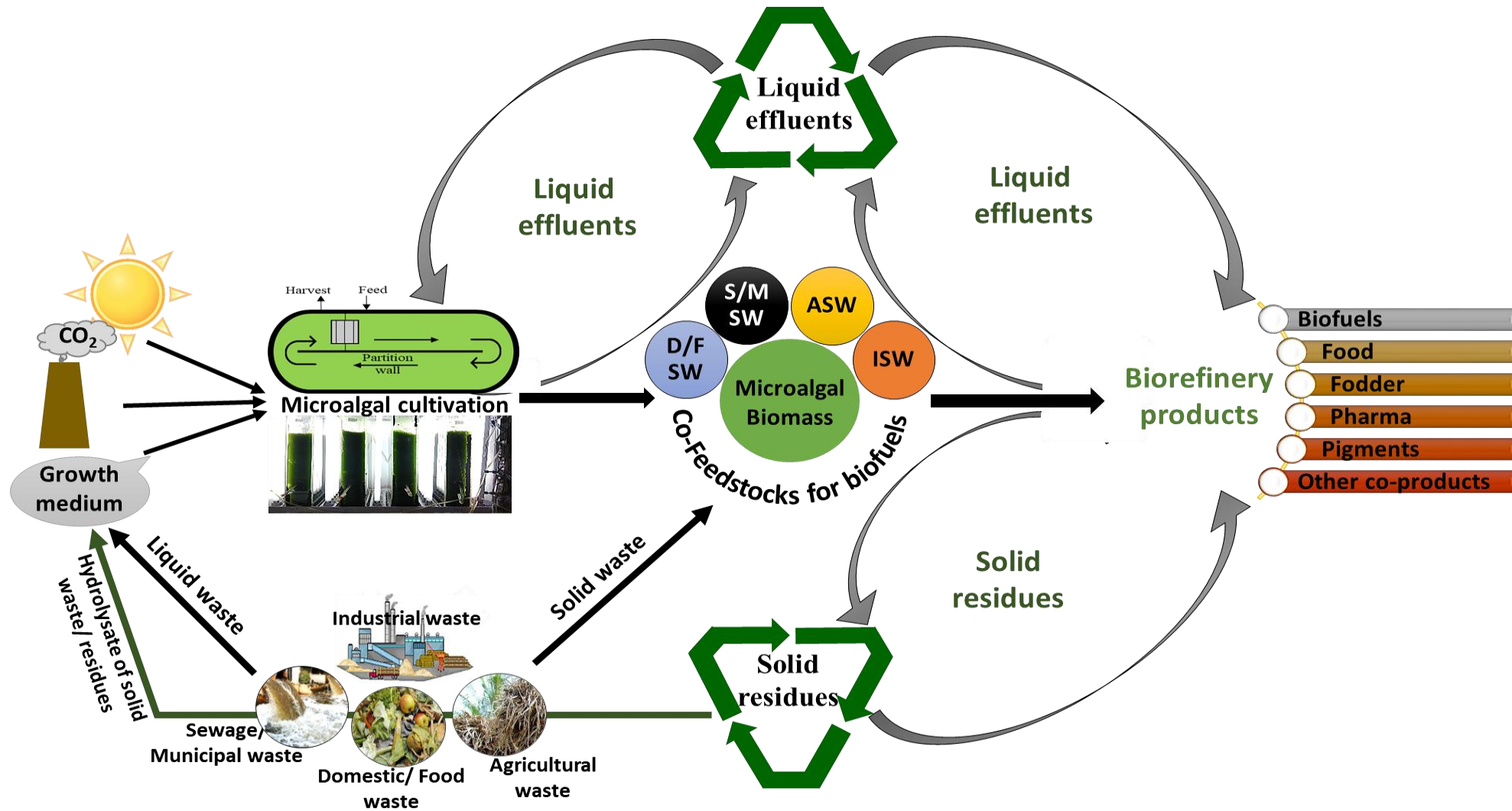


Fig. A sustainable microalgae mediated waste to energy biorefinery approach (D/FSW – Domestic/food solid waste; S/MSW – Sewage/municipal solid waste; ASW – Agricultural solid waste; ISW – Industrial solid waste).

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Thank you...