Marine micro algae -A global perspective

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The surging usage of marine microalgae ingredients and proteins in the production of aquaculture, pharmaceutical, and nutraceutical products is set to drive sales in the market. Increasing government initiatives to standardize the cultivation process of microalgae is expected to be a key factor propelling the growth. Rapid technological advancements to develop new strains that enhance energy efficiency and handle high salinity boost the market further. The vital need for the early detection of contaminants is anticipated to create new growth opportunities for novel photobioreactor microalgae producers. *Arthrospira* and *chlorella* are the most common species of algae photobioreactors that provide high-quality proteins. These species contain amino acid compositions similar to conventional protein sources, such as soybeans and eggs. The usage of *chlorella* in hair care products is estimated to surge as it improves the keratin level and strengthens hair roots. The increasing humanization of pets is leading to the high demand for healthy foods from pet owners, thereby propelling the usage of algae photobioreactors in the pet food industry. The demand for high-quality premium pet food is expected to augment sales significantly. Algae photobioreactor contains substantial amounts of vitamins E, C, and A and Beta-carotene, making it an ideal ingredient in pet food. It helps boost the pet's appetite and strengthens its immune system, unlike regular foods available in the market. Many countries are investing on applying algae for solving wastewater treatment issues by deploying novel photobioreactor microalgae and to purify water resources and make them fit for consumption. Many prominent companies are also expected to use microalgae in the automotive industry due to pressure on fossil fuels The Microalgae Market is estimated to secure a valuation of USD 11.8 billion in 2023 and is predicted to reach USD 25.4 billion by 2033. The market is capturing a CAGR (Compound Annual Growth Rate)of 8% during the forecast period. Renowned Microalgae Companies are Introducing Spirulina Infused Products. Rising Number of Research Programs to Create Growth Opportunities for Microalgae Companies. Adoption of Novel Photobioreactor Microalgae to Grow in Wastewater Treatment Plants. Growth is attributable to this industry's surging utilization of fermented algae as a food additive.

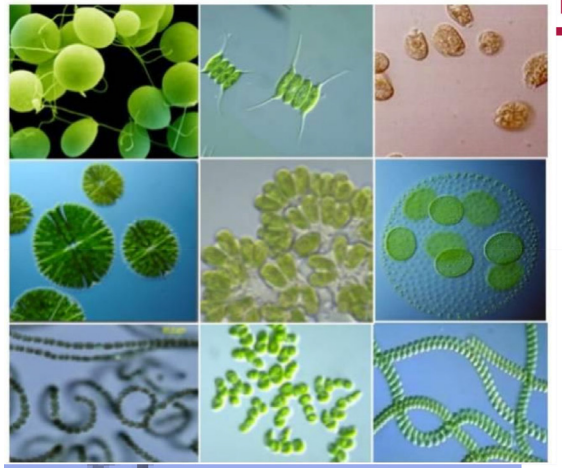
The United States	25.7%
Germany	5.3%
Japan	3.0%
Australia	2.8%
China	4.5%
India	14.8%
The United Kingdom	5%

In November 2021, Honeywell Technology declared that its UOP Ecofining technology successfully supported the world's first jet flights using sustainable aviation fuel from algal oil. Two commercial flights combined microalgae feedstock and renewable jet fuel through Ecofining. Developing other types of fuels based on fermented algae is expected to augur well for the United States market. In February 2022, Ful, an Amsterdam-based provider of sustainable and nourishing food and beverages, launched its new vivid blue-colored soda infused with spirulina. The company aims to reduce the food system's carbon footprint by using algae to make a popular ingredient. By source, the marine water segment is likely to dominate the global market in the forthcoming years. Marine microalgae can be easily produced on unproductive and desert soil using specialized growth chambers. The issue of land rivalry is also eliminated as food crops may not be fully grown in these areas. This type of microalgae does not require freshwater, which is considered an expensive and significantly diminishing resource. Microalgae can improve food products' aroma, flavor, texture, and taste. It provides high nutritional value. Thus, many food and beverage manufacturers are using it in salad dressings, snacks, meat, confectionery, soups, eggs, ice creams, sauces, and fish globally.

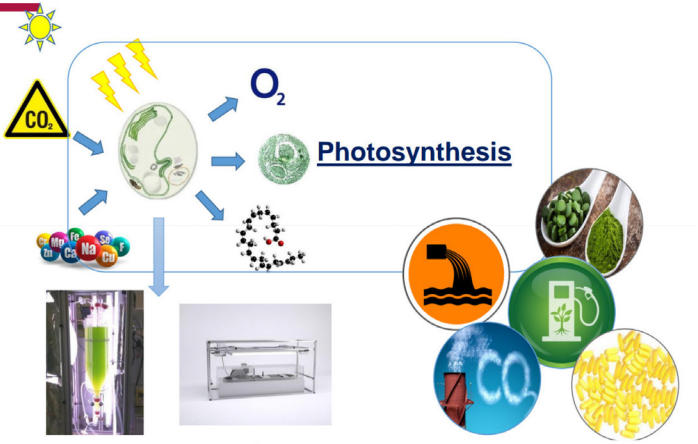
Microalgae ? Microalgae: a global view of culture systems

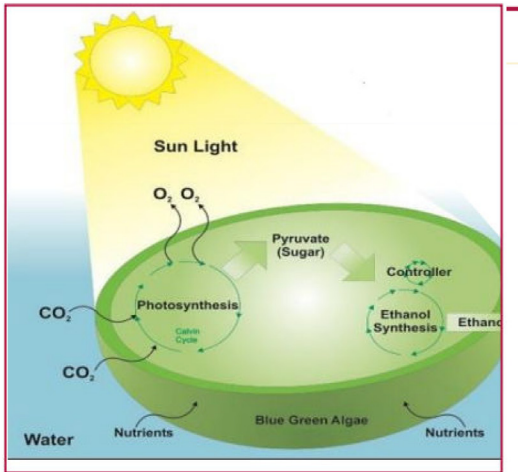
- Lower aquatic plants: photosynthetic microorganisms
- Several morphologies (0.2 to 2 mm in diameter)
- High biodiversity: 1 to 10 million algae species
- Habitat: Marine or fresh algae
- Environmental benefits (fixation of CO2, wastewater treatment)
- Pigments: chlorophyll, carotenoids and phycobiliproteins: biotechnological applications

"Phytoplankton" the first producers of oxygen essential to the majority of living beings.

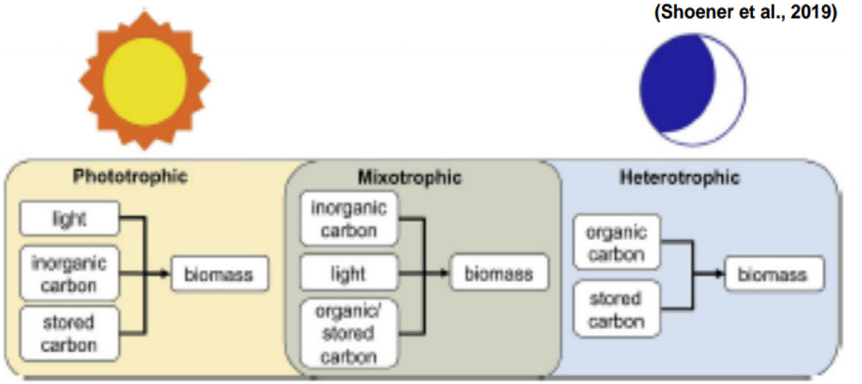


Microalgae, a photosynthetic micro-plant !

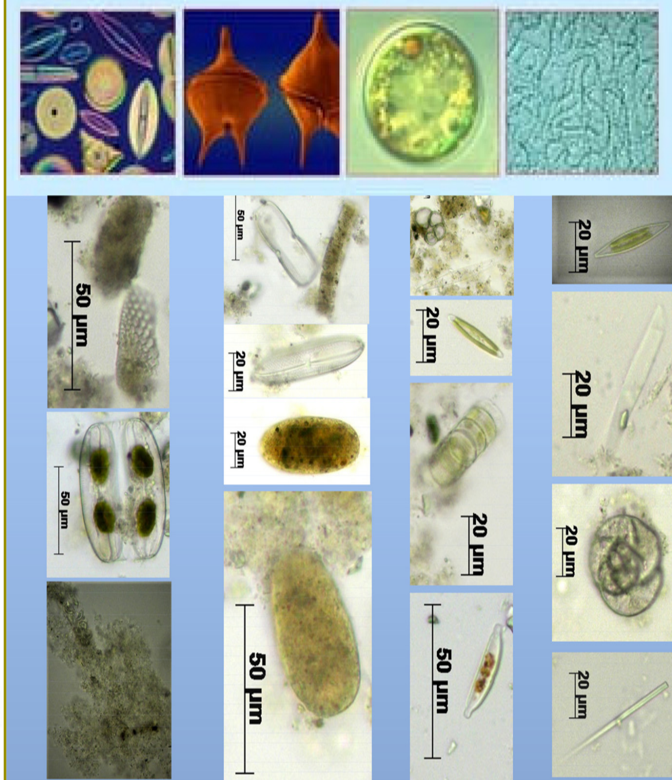


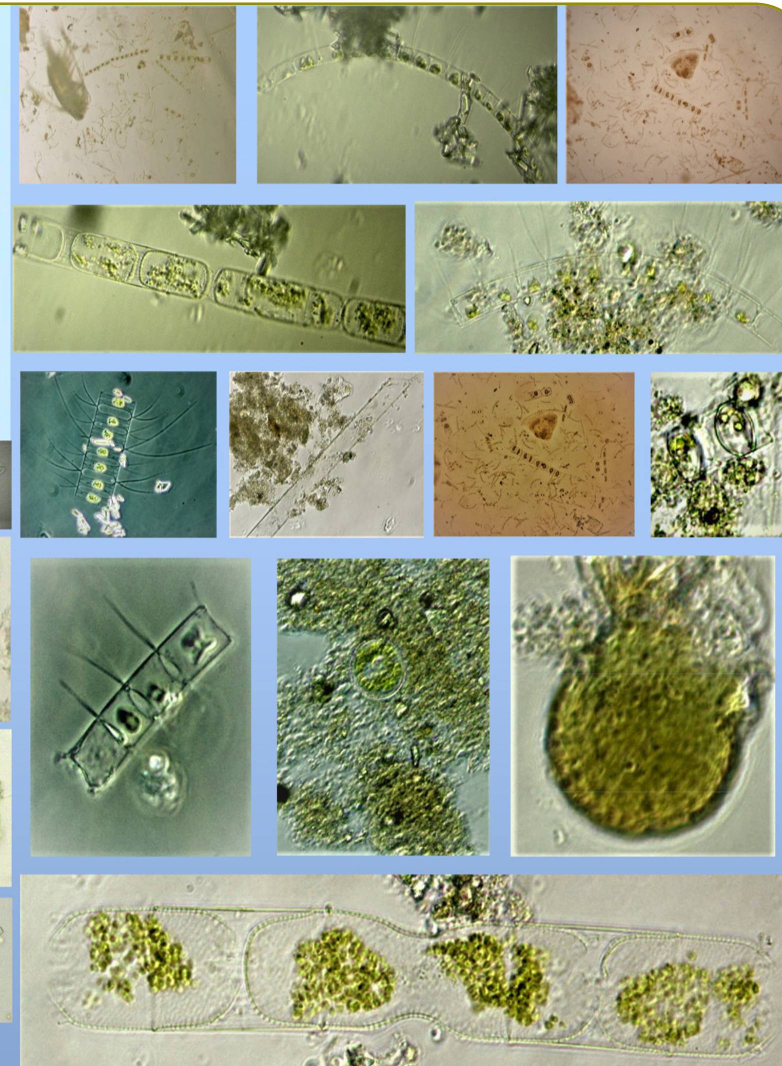


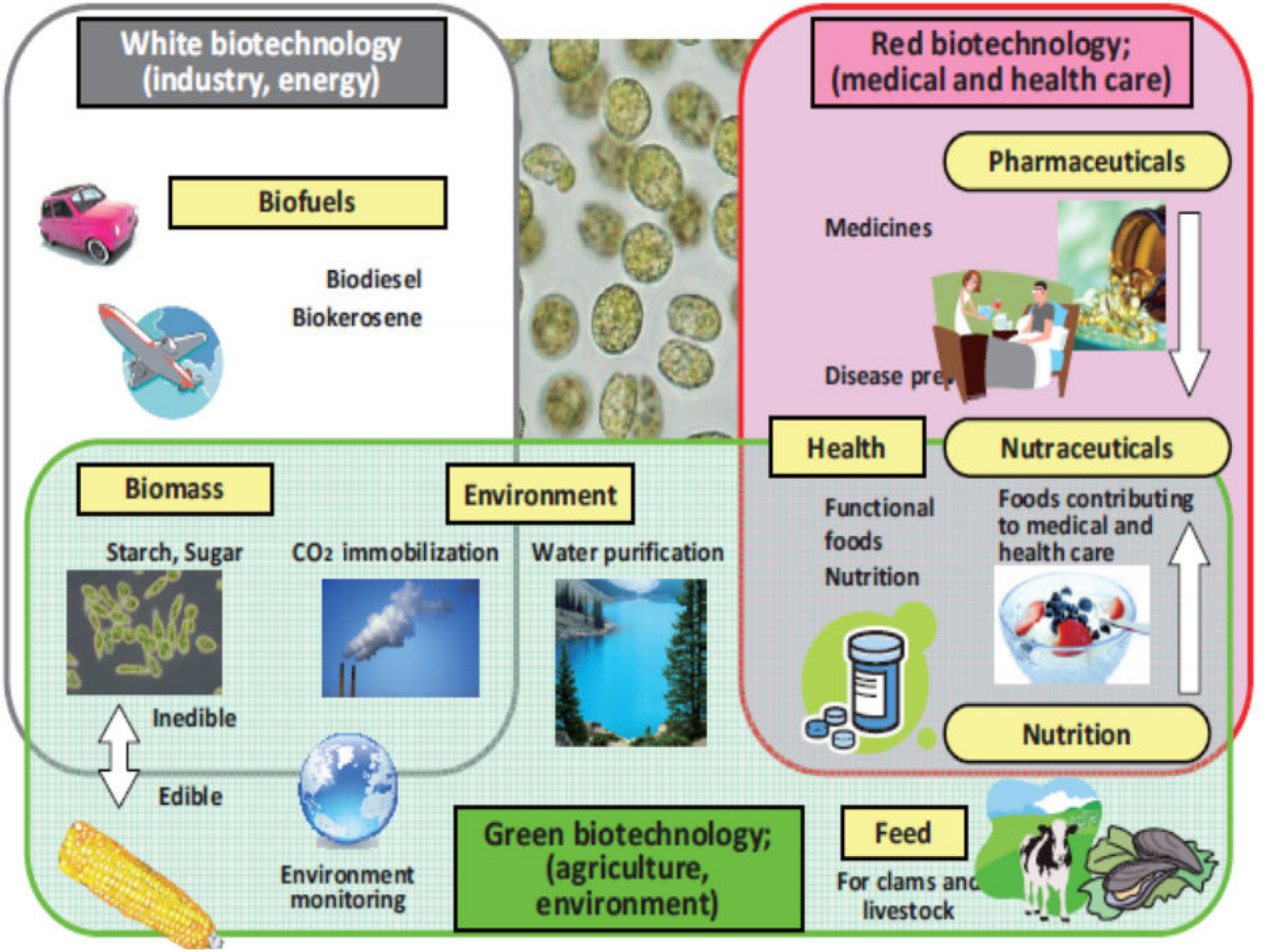
(Shoener et al., 2019)



- Classification based on morphology, pigmentation , chemical nature of photosynthetic product & organization of photosynthetic membranes
- Diatoms (bacillariophyta), dinoflagellates (dinophyta), green and yellow-brown flagellates (chlorophyta; prasinophyta; prymnesiophyta, cryptophyta, chrysophyta and rhaphidiophyta) and blue-green algae (cyanophyta).
- Micro algae are found in both benthic and littoral habitats and also throughout the ocean waters as called phytoplankton



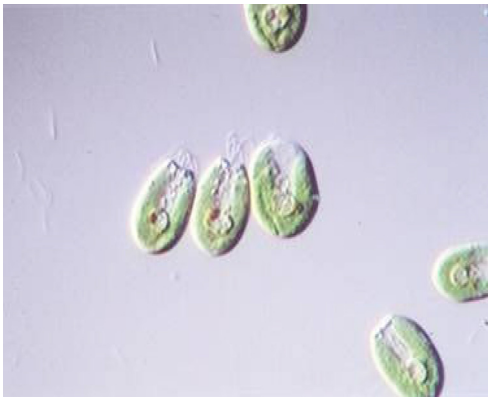



White biotechnology (industry, energy)
Biofuels
Biodiesel
Biokerosene
Red biotechnology; (medical and health care)
Pharmaceuticals
Medicines
Disease pre
Health
Nutraceuticals
Functional foods
Nutrition
Foods contributing to medical and health care
Nutrition
Biomass
Starch, Sugar
Inedible
Edible
Environment
CO2 immobilization
Water purification
Environment monitoring
Green biotechnology; (agriculture, environment)
Feed
For clams and livestock

Different algal species are grown for different species of fish or shrimp depending on the culture technique.

Shrimp culture	Fish culture	
Tetraselmis chuii	*Tetraselmis suesica*	*Nannochloropsis sp.*
Isochrysis galbana	*Isochrysis galbana*	*Chlamydamonas sp.*
Chaetoceros gracilis	*Monochrysis lutheri*	*Nannochloris atomus*
Skeletonema sp	*Chrorella sp.*	*Nannochloropsis oculata*
Spirulina platensis	*Spirulina platensis*	*Pavlova lutheri*
	Dunaliella sp.	*Pseudochrysis galbana*

Prasinophyceae – greenish coloured algae



Tetraselmis chuii

Large green flagellate, often used in larval rearing of shrimp, fish and shellfish

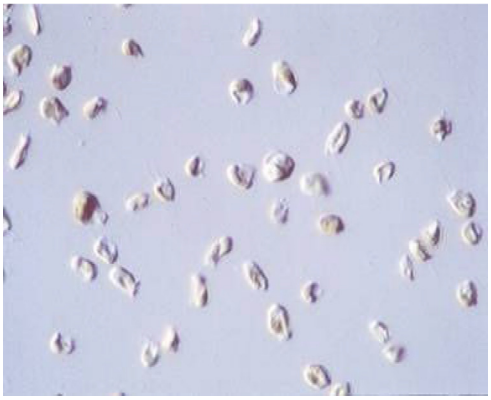
Optimal salinity 15 - 36 $^{0}/_{00}$

Optimal temperature 15 - 33°C

Typical densities in mass culture 300-450 cells/ml

Very high lipid content

Prynesiophyceae - golden brown flagellate



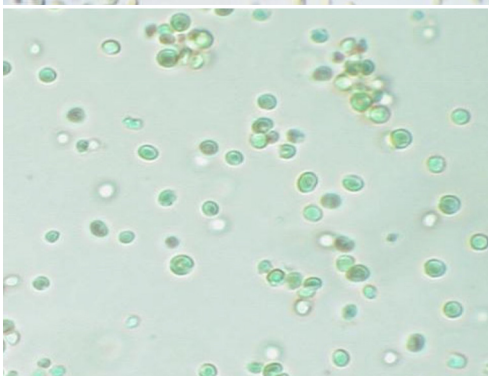
Isochrysis sp.

- Used especially as a primary algae in shellfish hatcheries
- Size: 3-5 um
- Spherical to pear shaped

Isochrysis galbana tahition

- Size: 5-6 um
- Prefer temperatures up to 30 °C and high light intensities
- High DHA level and is therefore used for growing rotifers

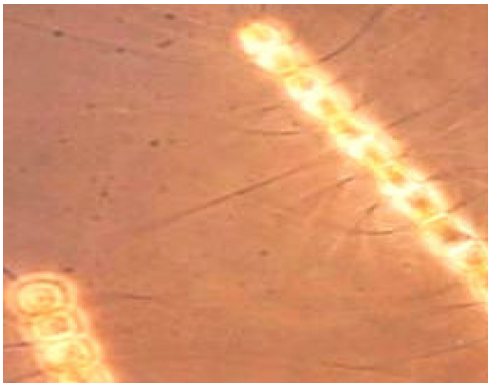
Eustigatophyceae - greenish yellow algae



Nannochloropsis

- Small green flagellate
- Size: 2-4 um
- Used in rotifer production
- Popular as greenwater
- Keeps suspended in the water column
- High total lipid content and EPA level.

Bacillariophyceae - Diatoms

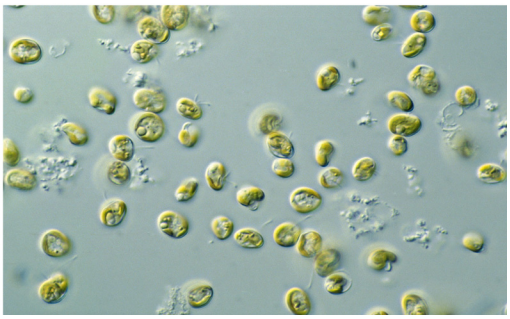


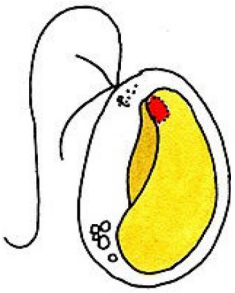
Chaetoceros sp.

- non-chain forming marine diatoms
- golden brown, rectangular in shape
- Size:4-6 um
- Optimal temperature: 25 and 30 °C
- Optimal salinity: 17 and 25 ppt
- Light intensity: 500 to 10,000 lux

Nutritional value in some species

Microalgae	Vit C (Ascorbic Acid)	Chlorophyll A	Protein	Carbohydrate	Lipid	EPA (20:5) (% of Lipid)	DHA (22:6) (% of Lipid)
Tetraselmis	0.25%	1.42%	54.66%	18.31%	14.27%	9.3%	0%
Nannochloropsis	0.85%	0.89%	52.11%	12.32%	27.64%	10.1%	0%
CHGRA	1.60%	1.04%	27.68%	23.20%	9.29%	5.0%	0.5%
T-ISO	0.4%	0.98%	46.69%	24.15%	17.07%	0.25%	8.5%





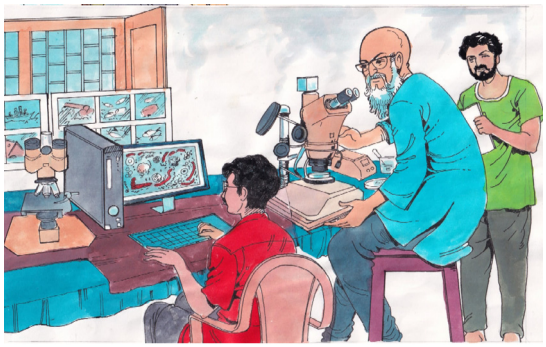
PAVLOVA

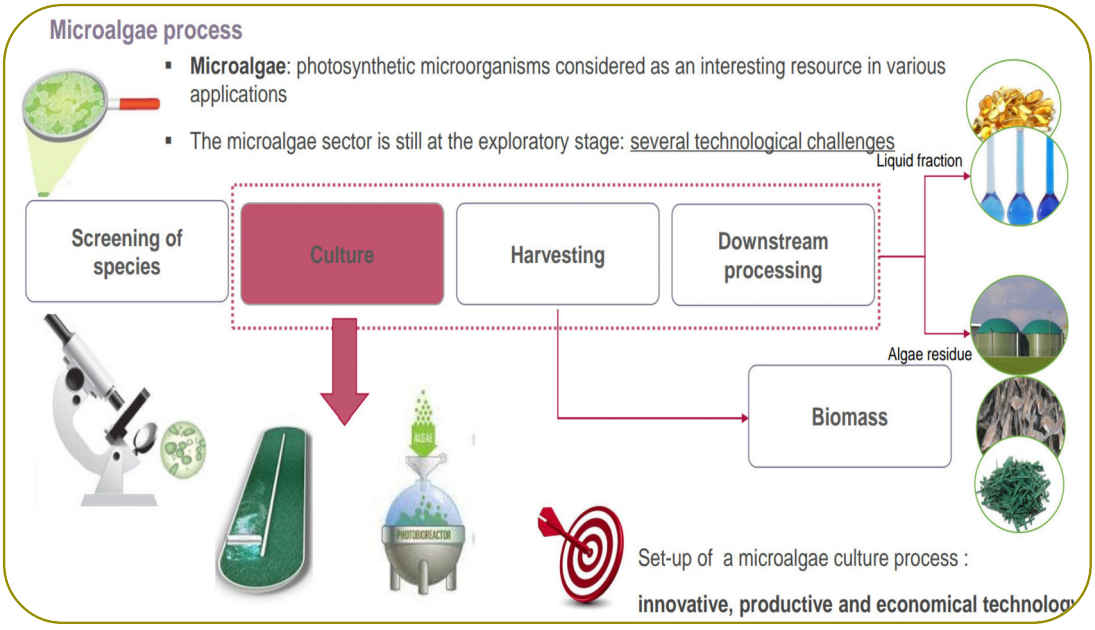
Summary algae species

Microalgae Culture	Type	Cell Size	Animals
Nannochloropsis	Green Flagellate	1.5-3 microns	Zooplankton, Marine Fish Larvae
CHGRA (Chaetoceros gracilis)	Diatom	6-9 microns	Zooplankton, Shellfish, Penaeid Shrimp
T-ISO (Isochrysis galbana)	Yellow Flagellate	5-6 microns	Zooplankton, Shellfish, Shrimp
T-ISO (Isochrysis galbana)	Yellow Flagellate	5-6 microns	Zooplankton, Shellfish, Shrimp
Pavlova (Pavlova pinguis)	Brown Flagellate	5-6 microns	Zooplankton, Shellfish
Tetraselmis	Green Flagellate	14-23 microns	Zooplankton, Shellfish, Penaeid Shrimp, Abalone Larvae

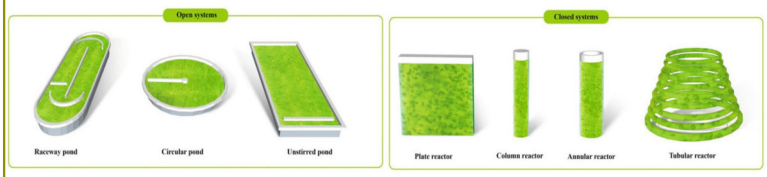
Summary algae species

Culture	Paste Concentration (cells/ml)	Typical Culture Density (cells/ml)
Tetraselmis	1.0 Billion	400,000
Nannochloropsis	51 Billion	20 Million
CHGRA	3.2 Billion	1.5 Million
T-ISO	6.2 Billion	22 Million

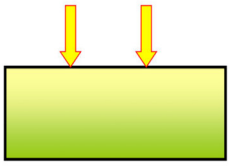




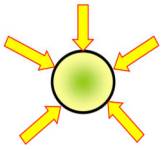
Microalgae culture systems



(Zerrouki et al., 2019)



Productivity:
0,06 – 0,1 g/L day

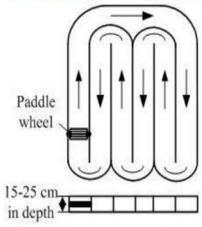


Productivity:
0,09 – 2,7 g/L day

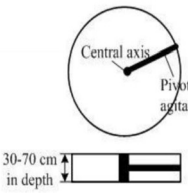
	Open system	Closed system
CO_2 biofixation yield	Low	High
Water losses	High	Low
Growth rate	Low	High
Control law	Difficult	Easy

Importance of culture system selection
Potential of hybride systems

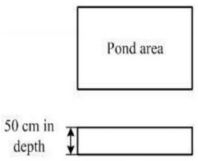
Open systems



(a) Raceway pond



(b) Circular pond

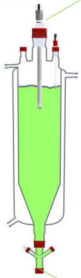


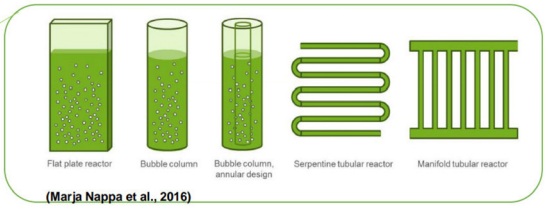
(c) Unstirred pond

(Ying Shen, 2009)

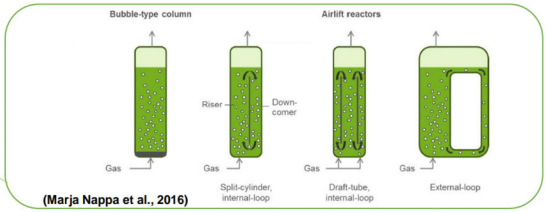
- Raceway pond: widely used for large-scale algal biomass production
- Low cost of construction and simplicity of installation and maintenance
- Biomass productivity impacted by evaporative losses, easily contaminated cultures, photoinhibition in the summer, light used by the cells, and diffusion of CO_2
- Most important design parameters of a raceway pond: the working depth and the hydraulic retention time (HRT)

Closed Systems, PBR



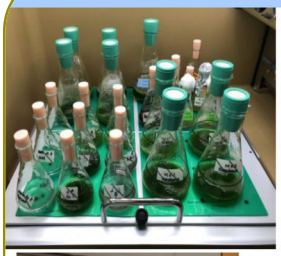


(Marja Nappa et al., 2016)



(Marja Nappa et al., 2016)

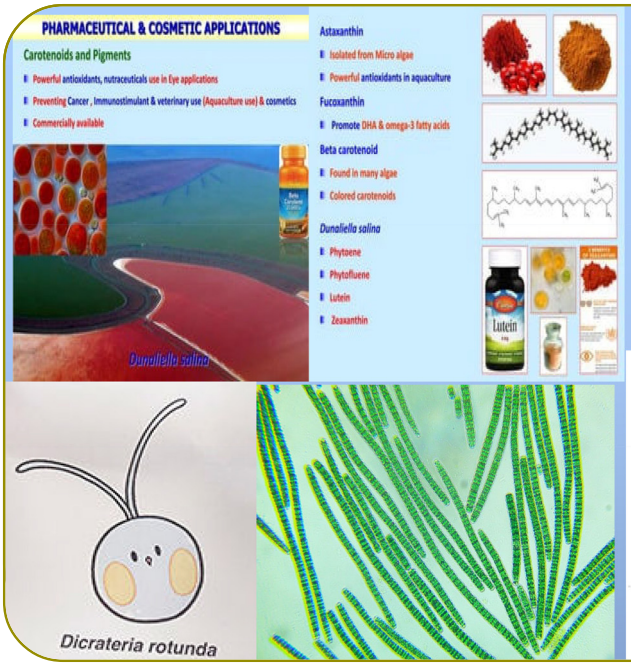
- Various design and mode of operation
- Construction materials: glass or plastic; rigid or flexible
- System adapted to algal species that cannot be grown in open systems
- Higher productivities and cost investment than ponds
- Energy requirement
- Scale-up is more difficult because of engineering issues related to gas/liquid mass transfer, energy efficient mixing and cooling of the culture



Experimental design

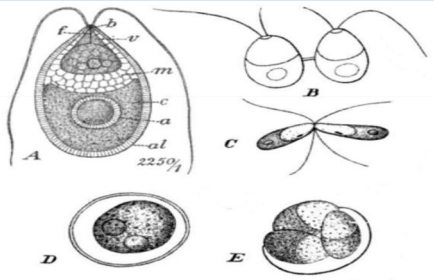
- Temperature
  - Cellular chemical composition
  - Uptake of nutriement and CO_2
  - Growth rate
- Light
  - Biomass accumulation
  - Lipid accumulation
  - Chlorophyll content

Sustainability of algae species for growing over all the year



Dunaliella β-carotene has an increasing demand and a wide variety of market applications: colouring agent in food industries; component in pharmaceutics, cosmetics and health foods; dietetic industries; diagnostics and biomedical research

D. salina is the richest algal source of β-carotene and glycerol *D. salina* can produce β-carotene up to 14% of its dry weight under conditions of high salinity, light and temperature, as well as nutrient limitation. Rich source of Phytosterols with 9 carbon atoms .



Open Recirculation pond for commercial production of marine microalgae

- Commercial scale microalgae culture are becoming more realistic for ecofriendly bioenergy production – renewable fuel.
- LC-PUFA rich vegan oil – Bio oil
- Microalgal production systems, open ponds are most widely used for large scale cultivation.

Algae paste

Mother Ponds (4 ton capacity)

Production pond (49.5 m^3)

Tubular bowl centrifuge unit

Poly house drying unit

Algae paste and meal

Positioning the paddle wheel (35degree) (15cm leaf width) – 6 leafs

Source Dr P Kalidas, PS /SIC RS of ICAR CMFRI Karwar

Nutrient or Fertilizer feeder to the culture ponds

Source Dr P Kalidas, PS /SIC RS of ICAR CMFRI Karwar

Injection of one ppm of CO_2 for 3 h per day

Source Dr P Kalidas, PS /SIC RS of ICAR CMFRI Karwar

Suction pump (2 hp) fitted with 50 micro bag filters

Source Dr P Kalidas, PS /SIC RS of ICAR CMFRI Karwar

Suction pump (2 hp) fitted with 50 micro bag filters

Source Dr P Kalidas, PS /SIC RS of ICAR CMFRI Karwar

Microalgae Harvesting unit

Bowl capacity:
6 L (SS)
16000 rpm

Filtration efficiency:
1000 L / h

Motor:
2 hp

Industrial Tubular Bowl Centrifuge

Source Dr P Kalidas, PS /SIC RS of ICAR CMFRI Karwar

Standardized Procedure for the commercial production of marine microalgae

I. Inoculums
(Stock culture to Mother culture: 2 t capacity) (4-5 days)

II. i.e
(Mass culture) (15 days to mature) - Feeding commercial fertilizer (every 5 days interval)

III. Microalgae quality and Water quality analysis (cell counts : 3 times / day)

1 ppm of CO_2 for 3 h/day. Position of paddle wheel aerator : Proper mixing and water flow

IV. Microalgae wet biomass harvesting unit
(Tubular bowl centrifuge attached to micron filters) (5 h / every alternative day) continue harvest (120 days) & recirculated of filtered seawater

V. Poly-house drying unit (Dry biomass and algae meal production) (2 days under 45-48 ^{0}C to remove 90% moisture)

VI. Package, Storage
(-2 to - 4^{0}C), (90 days)

Source Dr P Kalidas,
PS /SIC RS of ICAR CMFRI Karwar

Economics (Indian Rupees): Operational / Sensitivity Analysis

Present unit production capacity :
10 kg wet wt / day

(2.9 kg dry wt / day)

- Capital Cost (CC) = 120.00 lakhs
- Operation cost (OC): 73.8 Lakhs
- Gross Income (GI): 115.35 Lakhs
- Net income (NI) (GI-OE): 29.55 Lakhs
- Net operating income (GI-OC): 41.55 Lakhs
- Operation ratio =OC/GI = 0.64
- Net-benefit earnings ratio = NP/GI =36.33%
- Rate of return on Investment (ROI) = 33.77%
- BCR for 10% discount rate : 1.56 BCR 30%: 1.51
- IRR % : 69.25%

The given BCR is for the Open pond for commercial production of marine microalgae *Nannochloropsis gaditana,*

it may vary with the selected marine microalgae production and market price ($).

Source Dr P Kalidas,
PS /SIC RS of ICAR CMFRI Karwar

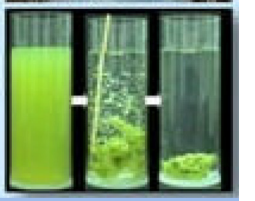
How to produce more oils ?

- The lipid content of an algae species can be increased by imposing a stress factor, such as starving of nitrogen or silicon.
- In this manner, lipid fractions up to 70-85% have been reported for nitrogen starvation and 60% for silicon starvation

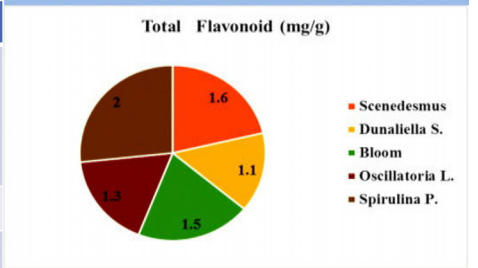
Algal Cell Harvest

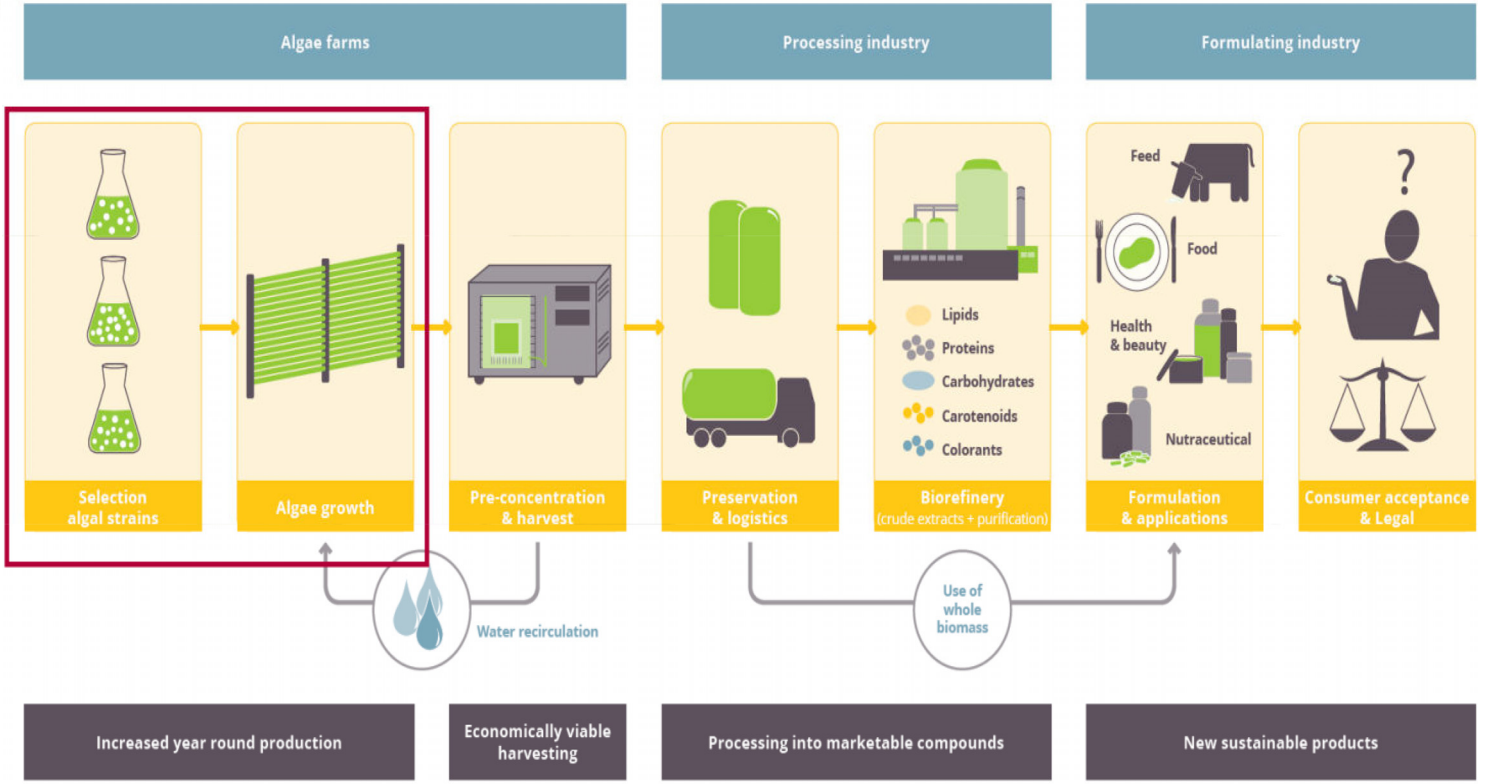
- Centrifugation- small microalgae
- Filtration- different size of algae
- Flocculation- Change of pH

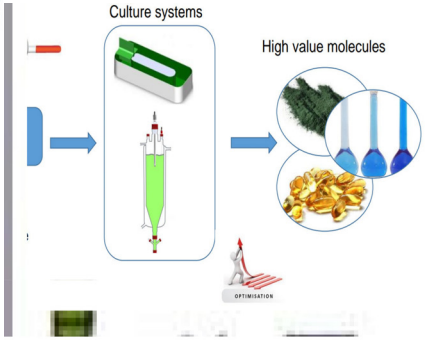
❖Acid flocculation – using alum and sulphuric acid
❖Alkali flocculation – using NaOH and KOH
❖Autoflocculation – Interrupting the CO_2 level



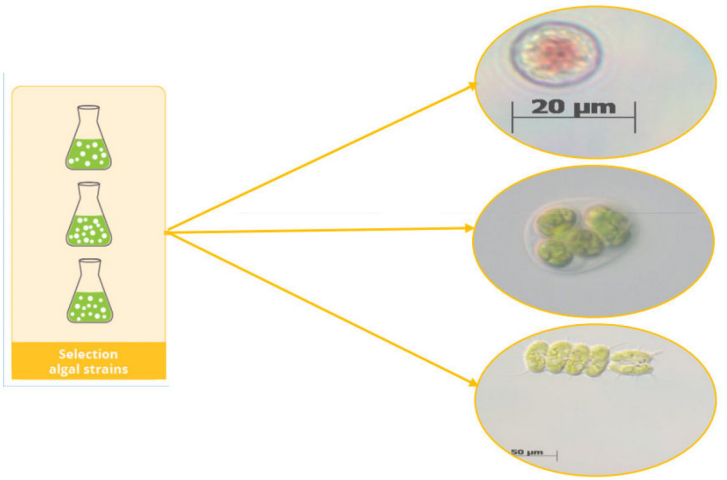
		20;5w3 EPA	Ew3HUFA	Protein%dw
ALGAE	CHAETOCEROS	13.6	16.4	24.4
	TETRASELMIS	4.7	5.2	49.8
	Spirulina			17.5
	Scenedesmus			21.0
Live feeds zoo	rotifers	2.5	3.1	62
	Artemia nauplii	2.8	3.7	55




Algae farms
Processing industry
Formulating industry
Selection algal strains
Algae growth
Pre-concentration & harvest
Preservation & logistics
Biorefinery (crude extracts + purification)
Formulation & applications
Consumer acceptance & Legal
Lipids
Proteins
Carbohydrates
Carotenoids
Colorants
Feed
Food
Health & beauty
Nutraceutical
Water recirculation
Use of whole biomass
Increased year round production
Economically viable harvesting
Processing into marketable compounds
New sustainable products



REED MARICULTURE USA



Porphyridium purpureum

THOMAS MORE

Chloromonas Typhlos

Chaire de Biotechnologie CentraleSupélec

Mixed culture: *Chlorella, Scenedesmus& Synechocystis*

JÜLICH FORSCHUNGSZENTRUM

Manufacturers can expand the market in several ways. The various end-use industries, such as cosmetics, agriculture, and pharmaceuticals, drive the global market. A few ways can expand the global market are:

- Increase Productivity: Manufacturers can expand the market by investing their million dollars in research and development activities. They offer affordable products to attract consumers by growing their microalgae-based production.
- Sustainable and Healthy Ingredients: Manufacturers are developing sustainable and eco-friendly microalgae rich in nutrient value. They also promote their sustainable products as a better health alternative to their consumers.
- Educate Customers: Many consumers are unknown about the benefits of microalgae. The manufacturers educate these consumers. Educating customers, raising awareness, and promoting microalgae-based products to increase sales volume.
- Collaborations: Manufacturers collaborate with several end-use industries to reach their relevant consumers. They develop advanced and sustainable products for various industries, such as food and beverages, cosmetics, etc.

In January 2022, Yemoja Ltd., a startup company that developed advanced ingredients from microalgae and further announced its plan to create red microalgae for plant-based steaks and burgers. Ounje, its new brand, resembles the red juices of animal meat without the requirement of artificial colors. The patented microalgal heme substitute congeals and browns like natural meat juices if cooked, apart from delivering the initial red pigment to plant-based meats.

In January 2022, Bharathidasan University based in Tamil Nadu signed a memorandum of understanding (MoU) with ZIGMA Global Environ Solutions for initiating a joint project worth Rs. 8.05 lakh on 'microalgae-based bioremediation of municipal solid waste leachate.' Algae production is a far more sustainable industry

than continuing to harvest 30% of the world fish catch for fishmeal and fish oil at ever increasing cost. The release in fishing pressure could have a dramatically favorable effect on marine ecosystems. The Global market would be ten times more profitable, If microalgae were used to replace fishmeal and fish oil globally, the effect would be to remove 30% of fishing pressure at the lower end of the food web and would contribute to a restoration of marine ecosystems

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