SUM2024 7th SYMPOSIUM ON CIRCULAR ECONOMY AND URBAN MINING
CAPRI, ITALY / 15-16-17 MAY 2024

# Current Status of the Algae Production Industry in Europe: An Emerging Sector of the Blue Bioeconomy


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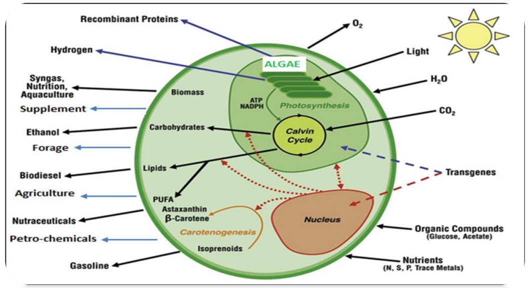
## *WHY ALGAE?*

- able of utilizing solar radiation for growth and biomass production, encompassing prokaryotic cyanobacteria and eukaryotic protists
- fix $CO_2$ from the air and produce lipids, proteins, carbohydrates, food, fodder, biofuel, and biofertilizer
- mixo-heterotrophic, using organic carbon from industrial wastewater
- effective in pollutants removal from wastewater
- rapid growth rates, high productivity in resource-limited conditions, and significant accumulation of fatty acids
- **resilient to extreme environmental conditions**

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- *Already popular in Asia, algae biomass is gaining traction in Western diets for direct consumption and as food additives.*

- *European interest in algae gastronomy is rising due to their nutritional benefits and sustainability.*

- *Spirulina, a cyanobacteria, is recognized as a "superfood" for its nutritional properties and has been a staple in Western nutrition since the 1970s.*


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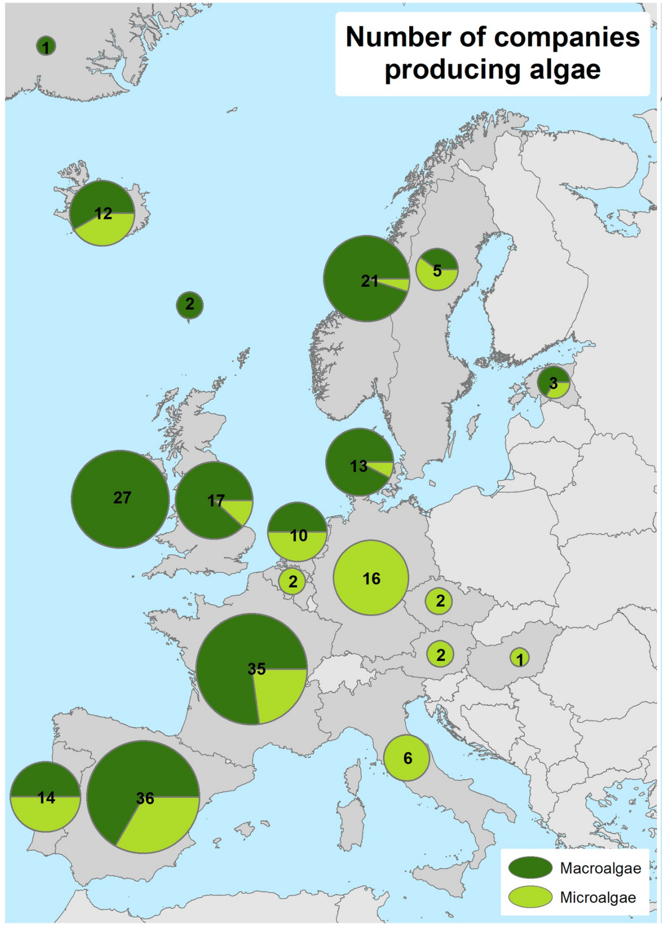


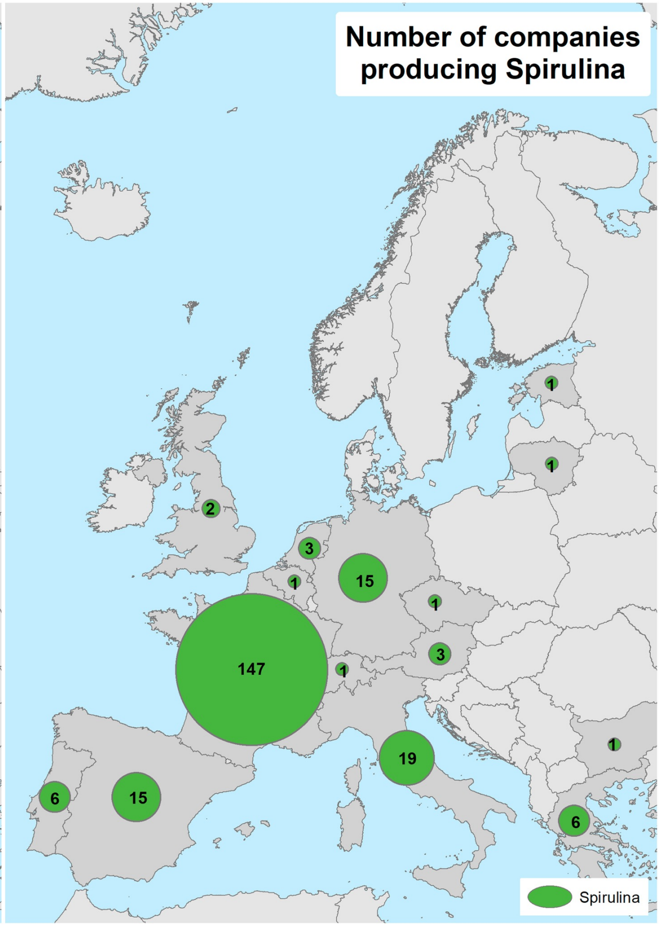


***Company Distribution***: The European algae sector comprises 225 macroalgae and microalgae producers, with an additional 222 *Spirulina* producers identified across 23 countries

***Top Producers***: Spain, France, and Ireland lead in both macro- and microalgae production, with Norway, the United Kingdom, Germany, and Portugal also significant contributors.

**Few companies in Mediterranean area**

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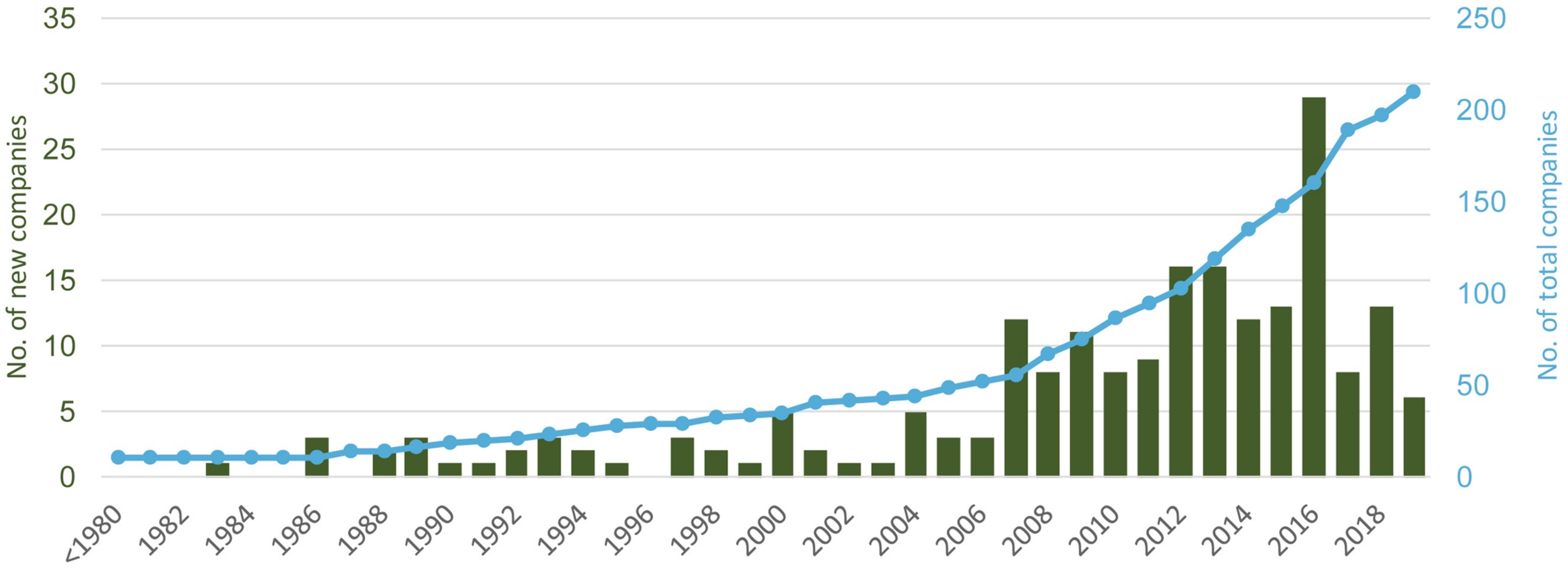
***Growth Trends***: 150% increase in new algae-producing companies over the last decade. Some companies have been operational since before 1980, indicating long-term interest and stability in the sector.

***Market Dynamics***: Despite growth potential, constraints such as small market size, variability in biomass supply, and technological limitations hinder sector expansion.




***Algae biomass production is economically sustainable in the European bio-based industry!***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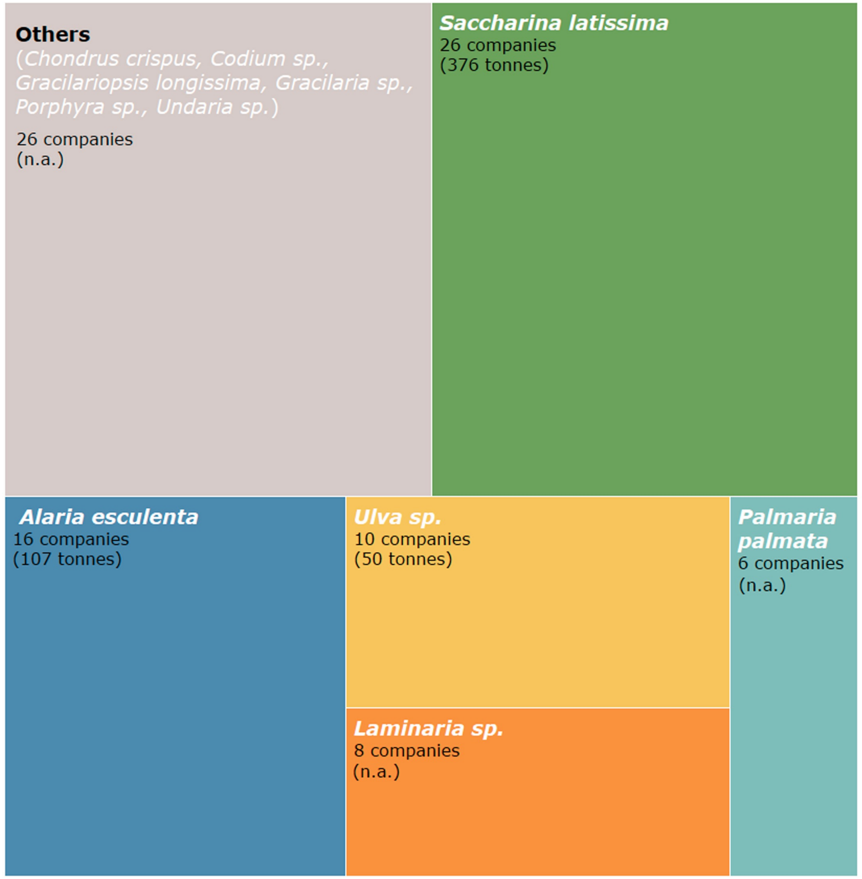
**Aquaculture**




**Harvesting from wild stocks**


Although there are many seaweed species distributed in European waters, only a small part of these are commercially exploited

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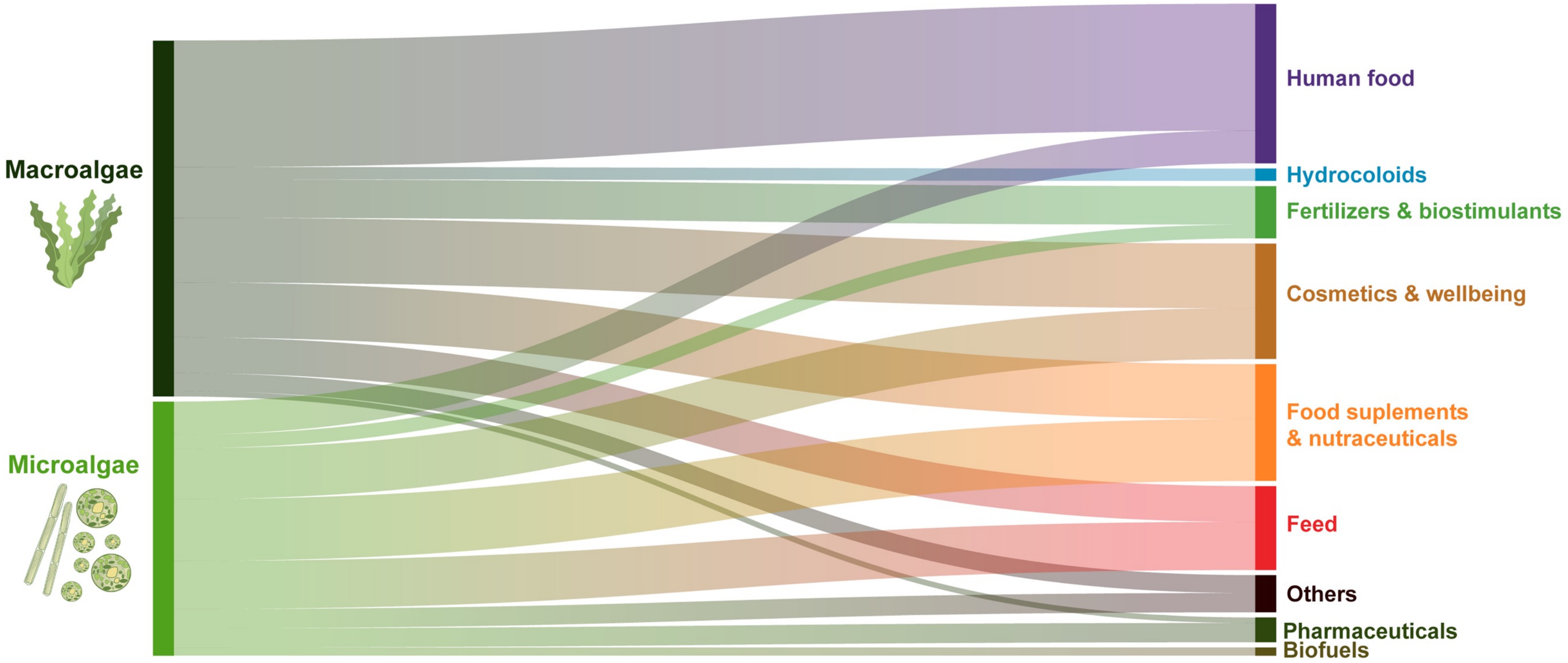
***Market Distribution***: food (36%) and food-related uses (15%), including food supplements, nutraceuticals, and hydrocolloid production.

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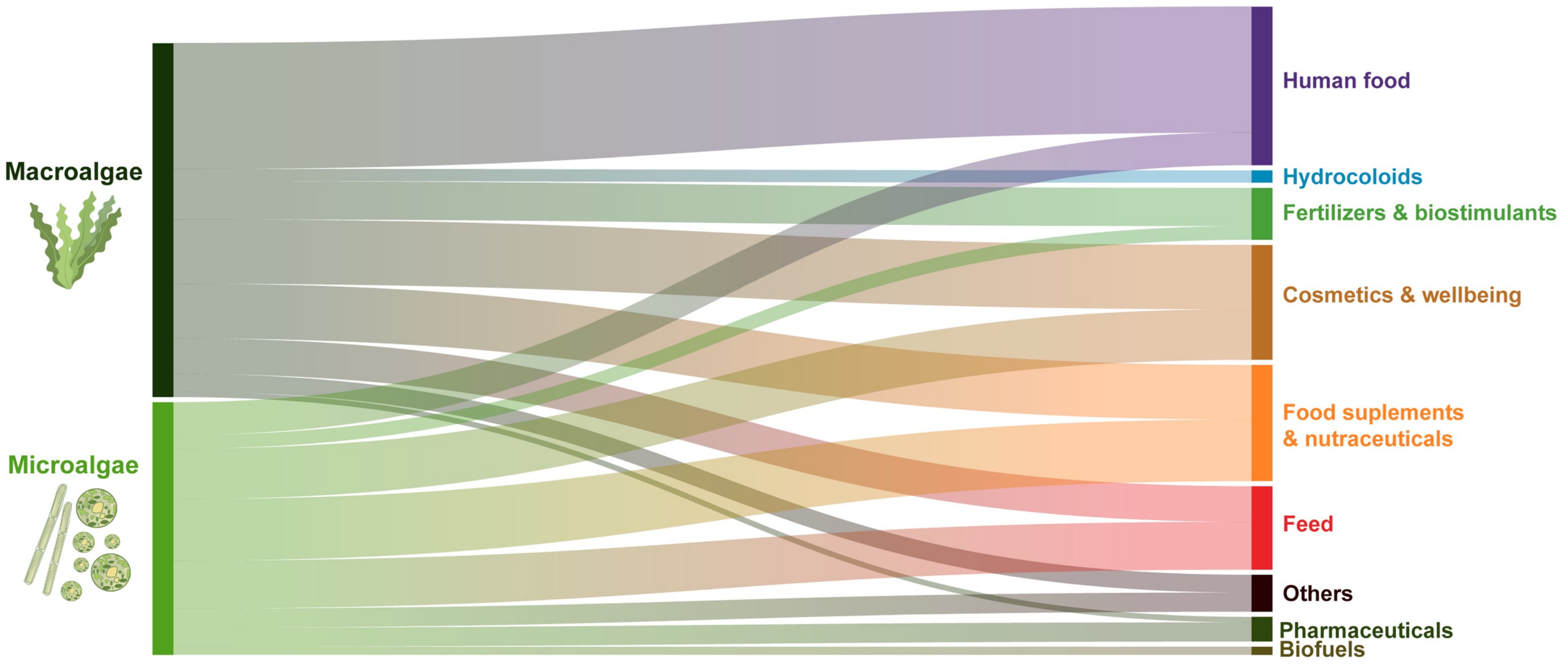
***Cosmetics and Well-being Products***: 17% of seaweed biomass utilized in cosmetics and well-being products

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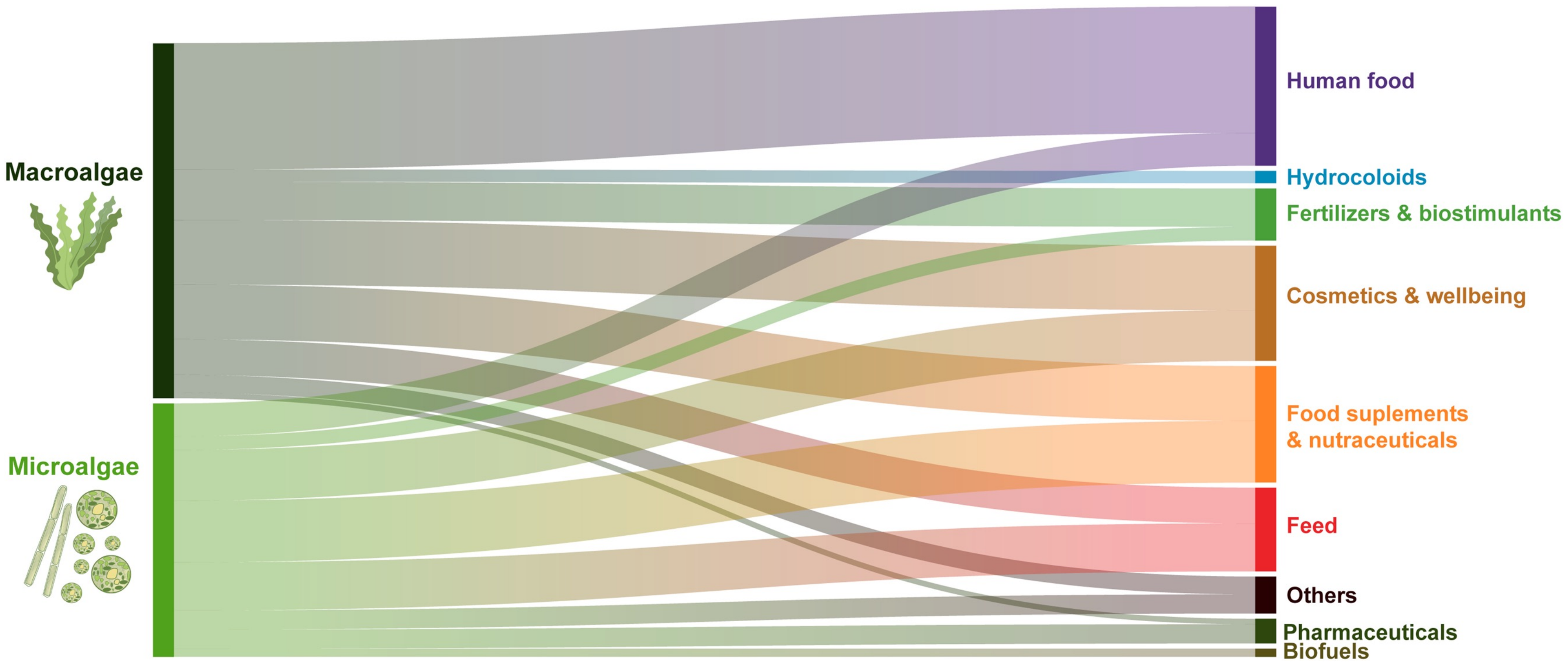
***Other Applications***: Biomass is also used in various other applications, such as fertilizers, biostimulants, biofuels, bioremediation, biomaterials, and pharmaceuticals, albeit with smaller shares in the European market.

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***Commercial Importance***: Species such as *Laminaria hyperborea, A. nodosum, and Gelidium corneum* play crucial roles in industries such as alginate manufacturing, hydrocolloid production, and agar manufacturing

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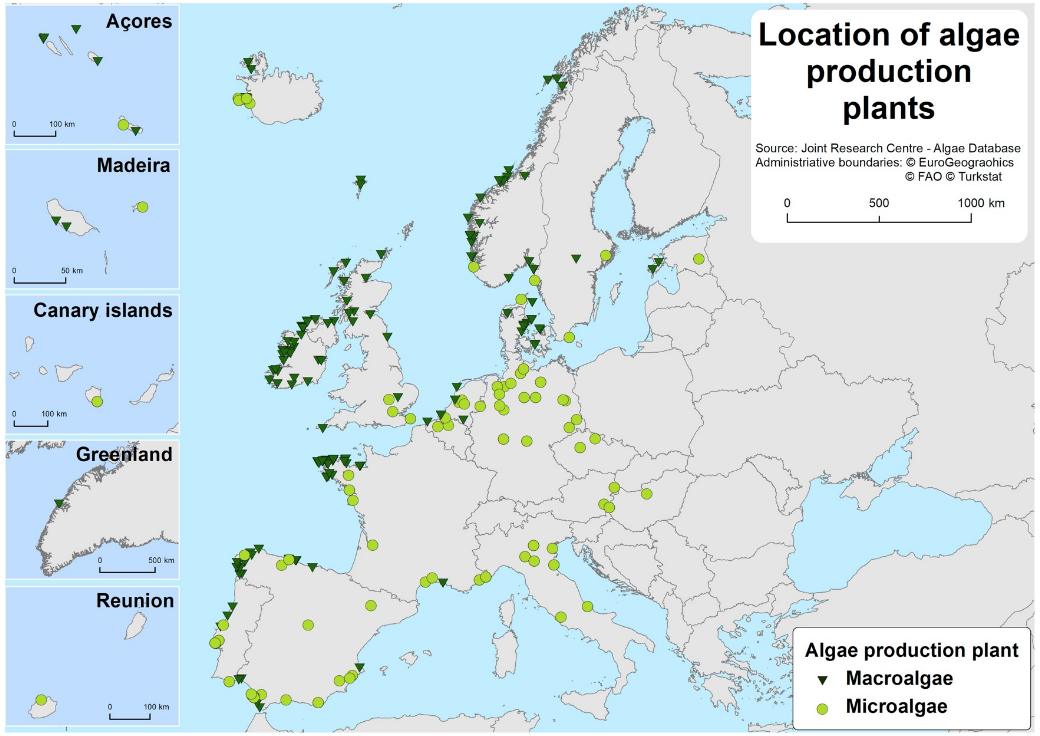
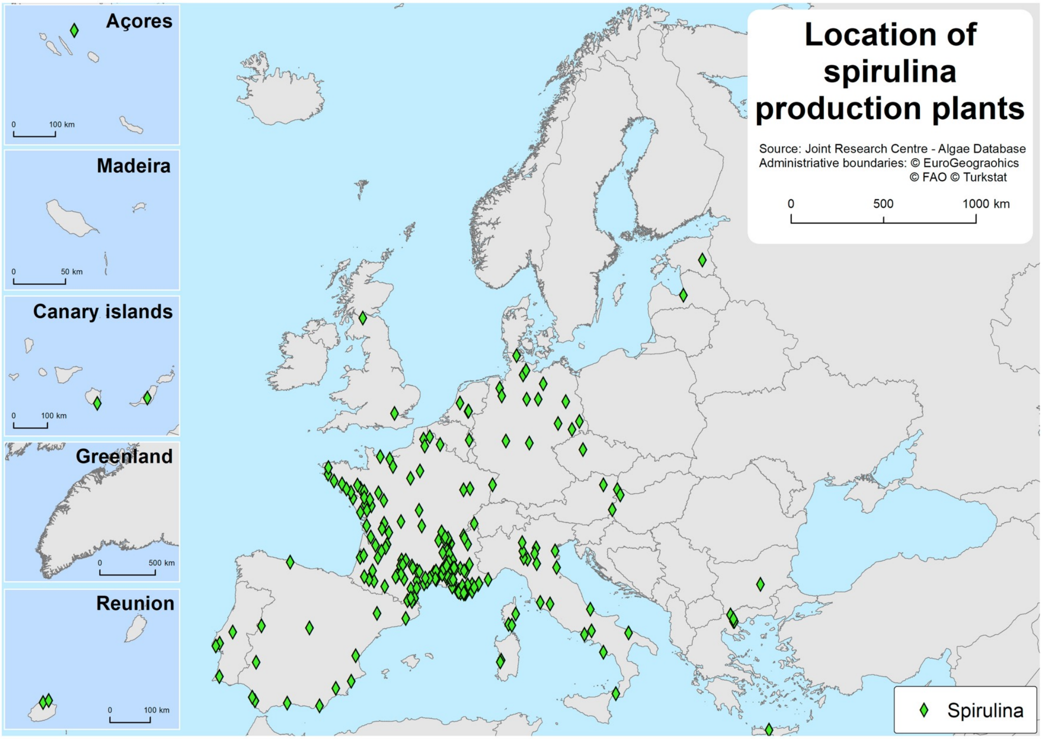
# MICROALGAE and *SPIRULINA*




**Germany, France (65%) and Spain: primary hosts for microalgae producers across Europe.**

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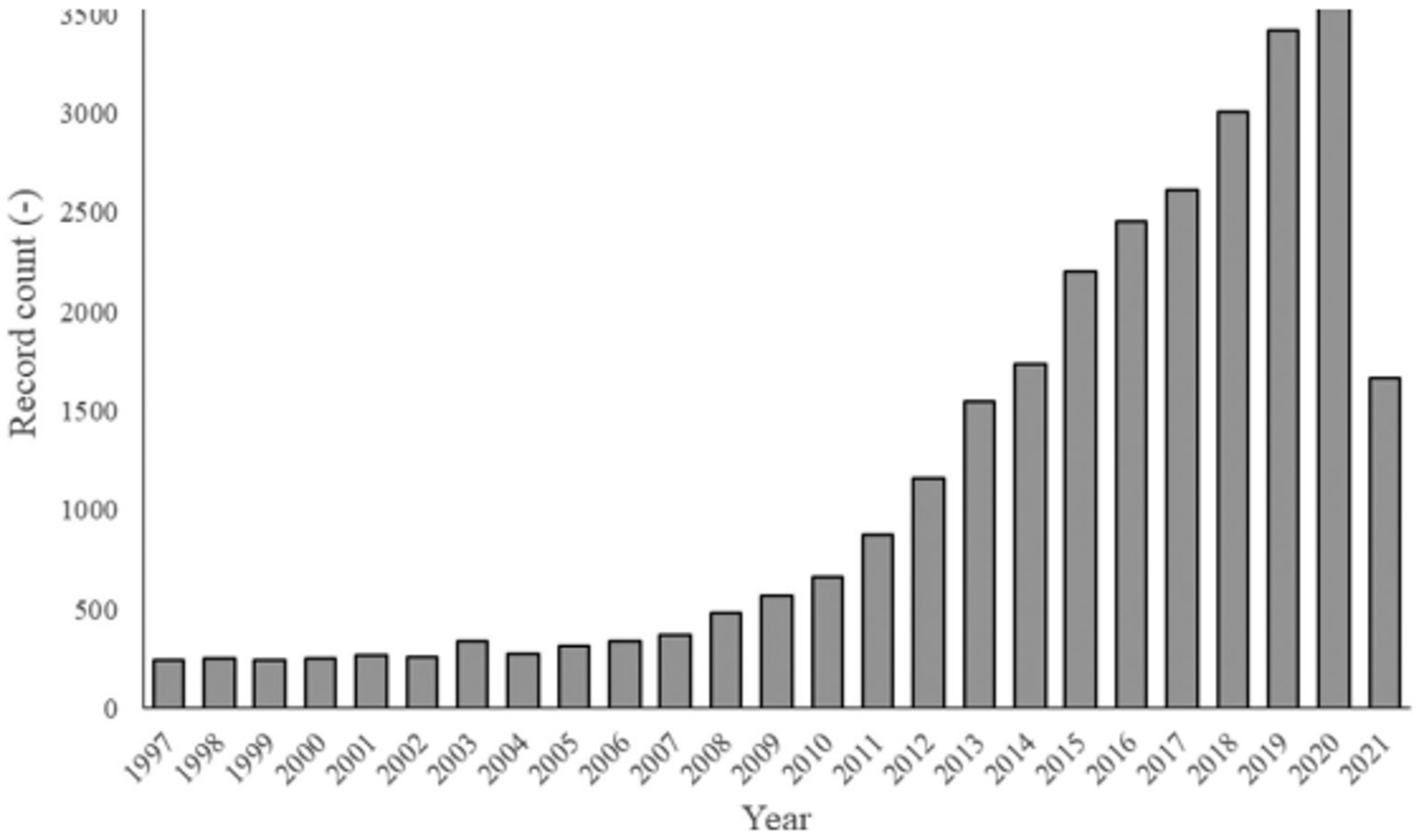
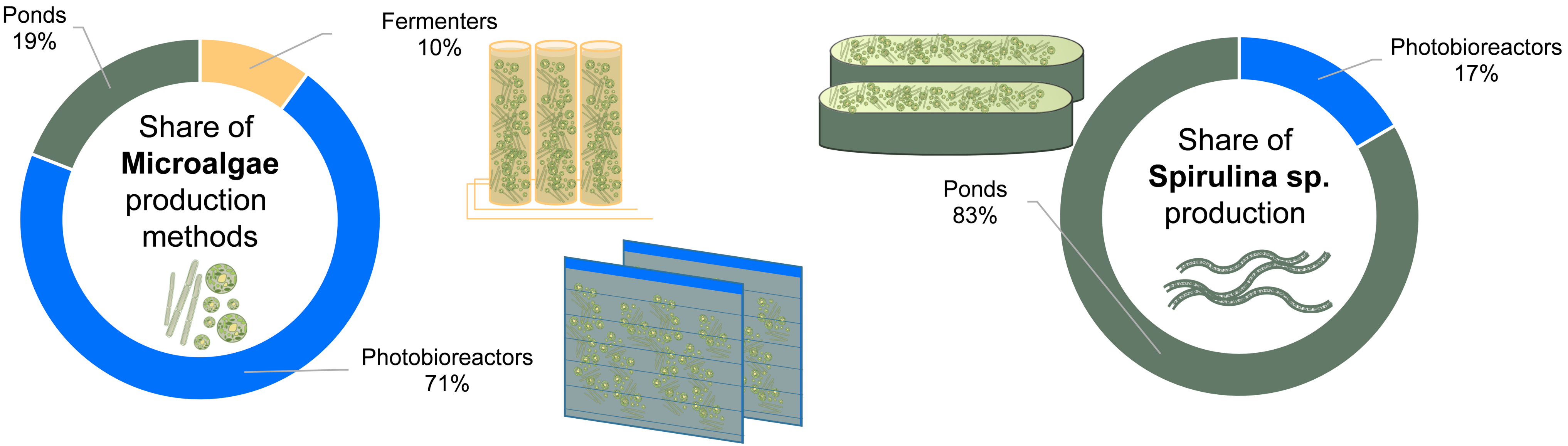



# Growing interest in microalgae application

- Number of microalgae publications published each year in the last 25 years, in which it is possible to see the growing interest in microalgae.
- Analysis made using "Web of Science" database searching "microalgae" as topic on the 15-06-2021

## *Production methods*

-Some production facilities integrate different systems, such as photobioreactors (PBR) with fermenters or open ponds.
-PBR emerges as the most prevalent system for microalgae production (71% of total production units)
-Open ponds and fermenters 19% and 10% respectively.
-For *Spirulina* production, open ponds are the primary method utilized by 83% of companies,

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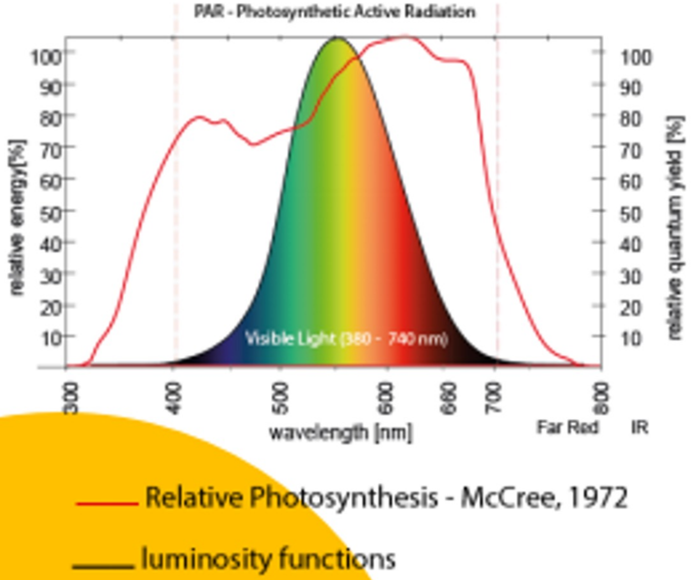
# Open vs close photobioreactors


Open ponds (raceway ponds):
Economic
Poor control on growth
risk of contamination by parasites and predators

Excellent control on culture conditions
minimal risk of contamination
higher initial investment

# Designing a PBR…




- it must allow the cultivation of various species of algae;
- Illumination must be uniform and reach as much as volume
- Sunlight would be better than artificial light
- But it depends on latitude!
- Which artificial light? Fluorescent lamps, led..
- Antifouling

# What about the economy and feasibility of microalgae exploitation?

- Few species are exploited up-to-date
- Administrative burdens: Novel Food regulation (EU, 2015)
- The market value is very much based on their potential as a source of high-value bioactive compounds:

*pigments (carotenoids)*
*antioxidants (astaxanthin, fucoxanthin)*
*long-chai polyunsaturated omega 3-fatty acids (DHA, EPA)*
*phycobiliproteins (hycocyanin)*
*polysaccharides*

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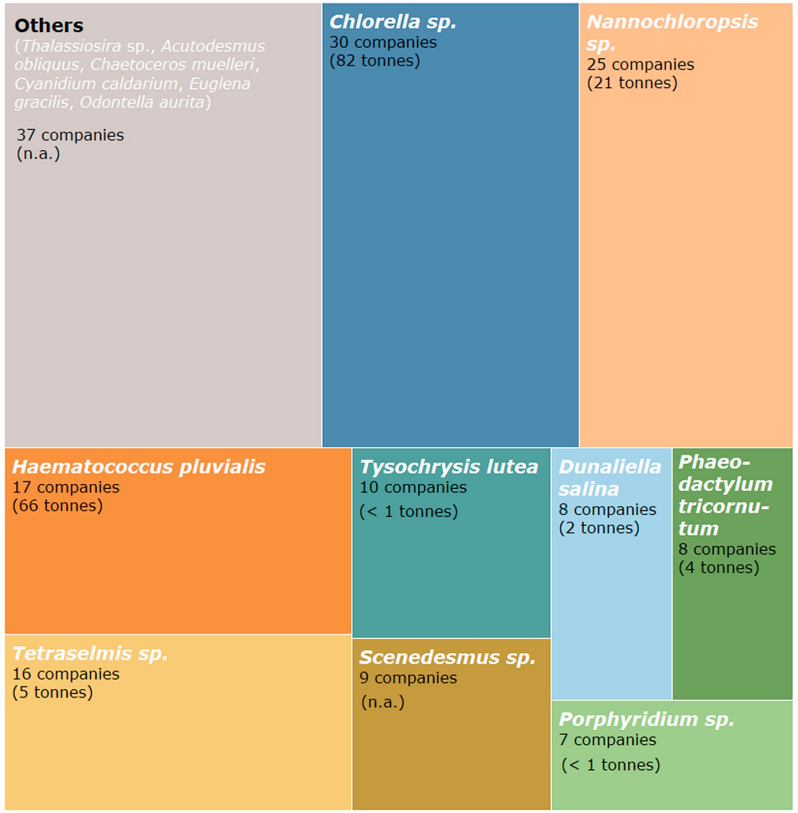
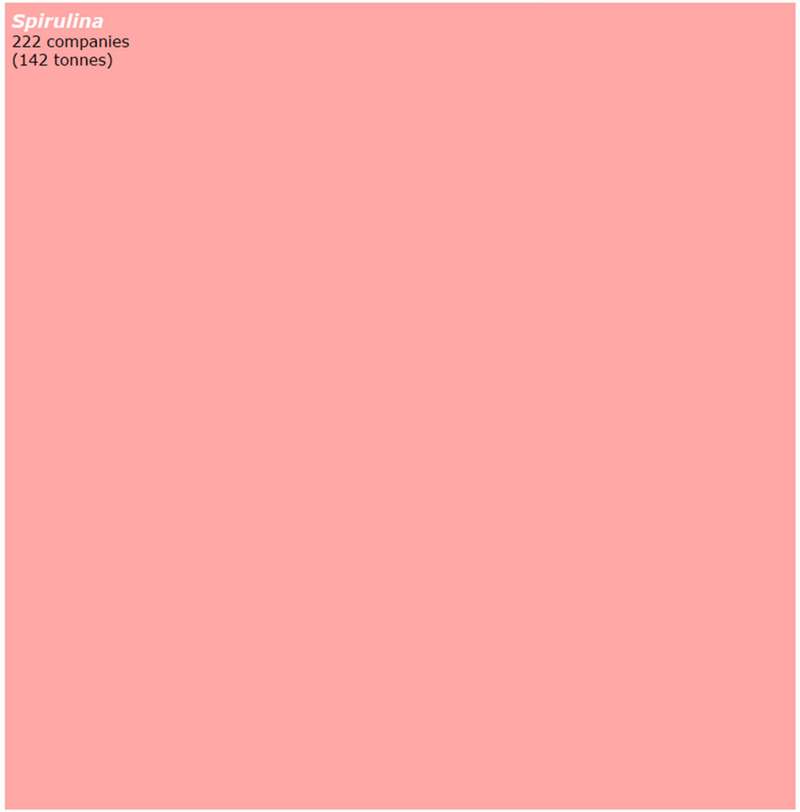
## MICROALGAE (182 tons DW)




## *SPIRULINA* (142 tons DW)

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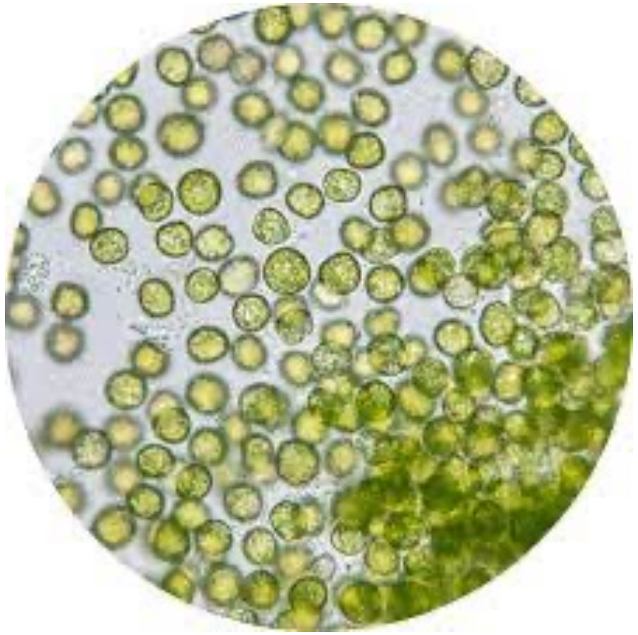


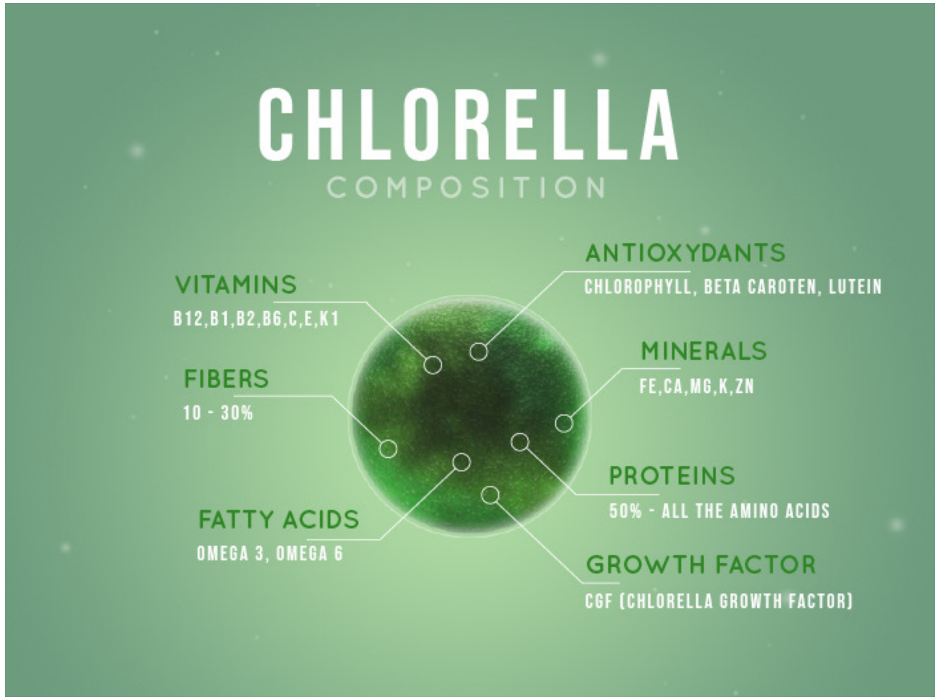


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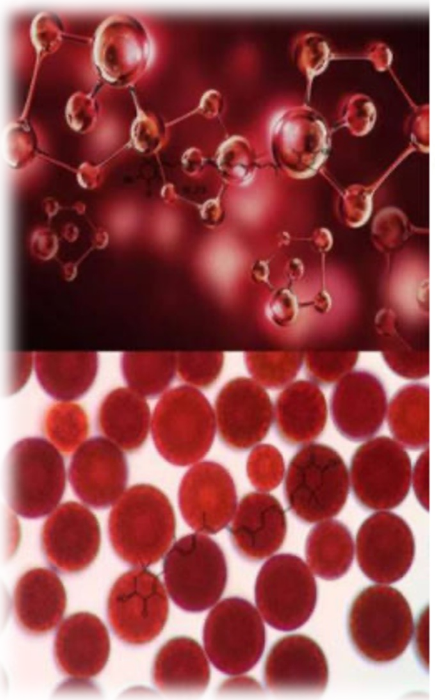
# *Haematococcus pluvialis*

| Composition content (% of DW) | Green stage | Red stage |
|---|---|---|
| Proteins | 29–45 | 17–25 |
| Lipids (% of total) | 20–25 | 32–37 |
| Neutral lipids | 59 | 51.9–53.5 |
| Phospholipids | 23.7 | 20.6–21.1 |
| Glycolipids | 11.5 | 25.7–26.5 |
| Carbohydrates | 15–17 | 36–40 |
| Carotenoids (% of total) | 0.5 | 2–5 |
| Neoxanthin | 8.3 | n.d |
| Violaxanthin | 12.5 | n.d |
| β -carotene | 16.7 | 1.0 |
| Lutein | 56.3 | 0.5 |
| Zeaxanthin | 6.3 | n.d |
| Astaxanthin (including esters) | n.d | 81.2 |
| Adonixanthin | n.d | 0.4 |
| Adonirubin | n.d | 0.6 |
| Canthaxanthin | n.d | 5.1 |
| Echinenone | n.d | 0.2 |
| Chlorophylls | 1.5–2 | 0 |

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# Spirulina is full of nutrition!

Protein 70%
Fat 5~8%
Carbohy-drate 5~10%
Dietary fiber 5~12%
Vitamin
Mineral
Pigment
Nucleic acid
SOD



- boost immunity
- detox heavy metals
- lower cholesterol
- reduce blood pressure
- lower risk of cancer
- improve allergies and sinus problems
- prevent aging
- improve muscle strength
- support brain health

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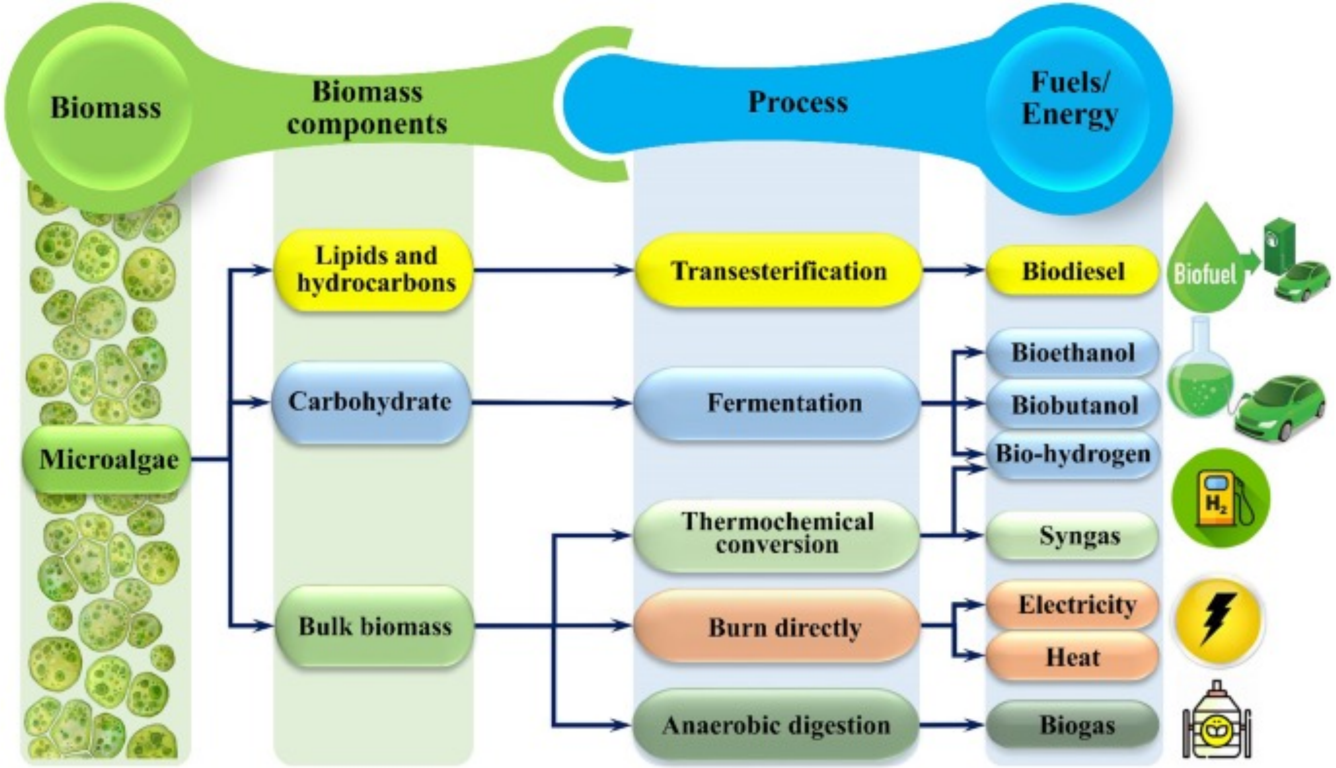


**Microalgae as feedstock for biofuel production**

- ✓ *No competition for arable land with crops*
- ✓ *High lipid content= high oil yields*
- ✓ *High production cost*

Need more technological developments

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# Factors influencing the market value of microalgae biomass

- *- Production system, production costs (energy, labor)*
- *- Geographical origin*
- *- Certification schemes (e.g., organic production)*
- *Step of the value chain*

| Species | B2B (Business to business) €/ kg | B2C (Business to Consumer) €/ kg |
|---|---|---|
| *Chlorella* | 25-50 | 150-280 |
| *Spirulina* | 30-70 | 150-280 |
| *Nannochloropsis* | 30–110 | up to 1000 |
| *Haematococcus* | - | 150-300 |
| *asthaxanthin* | 6000-8000 | - |

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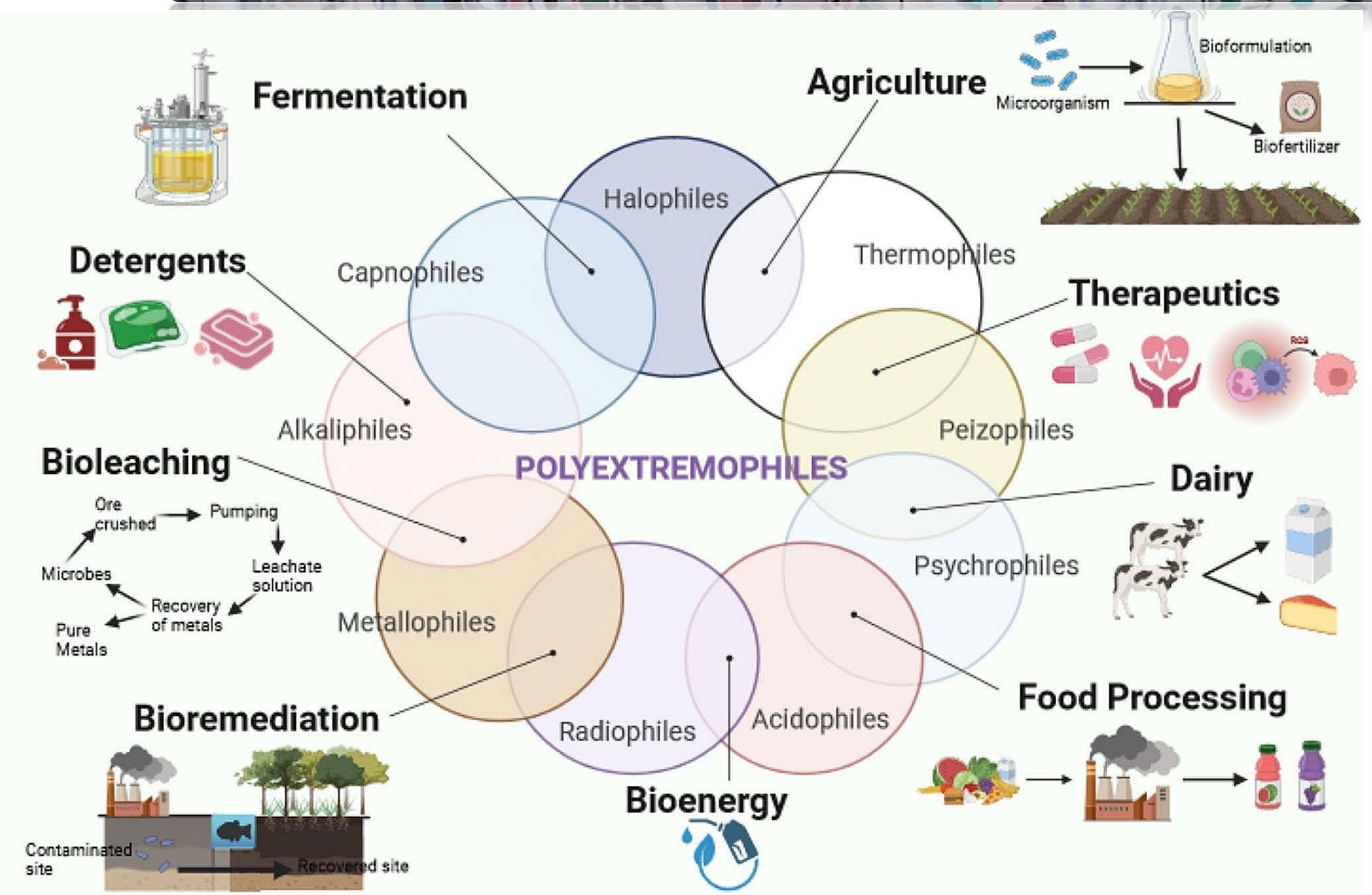


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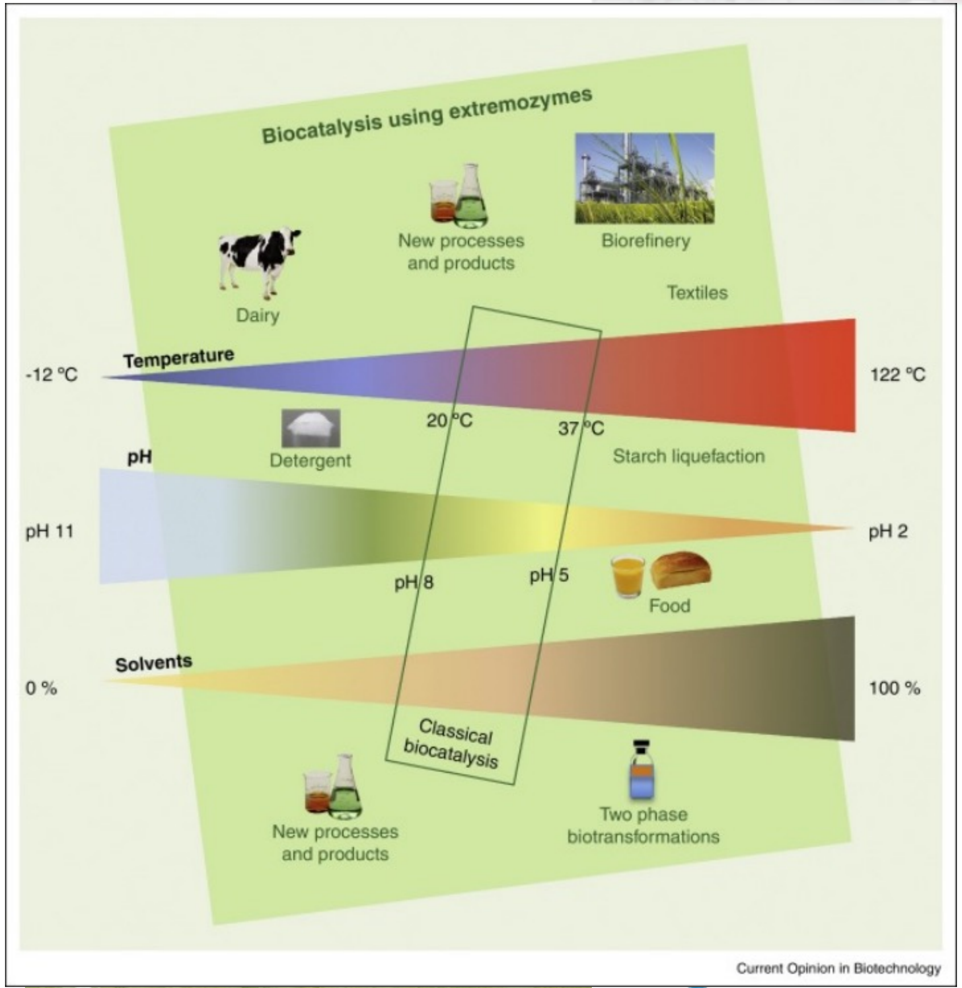


Many of the reactions performed in the process of making algal bioproducts are not optimized because mesophilic enzymes are used at extreme temeperature, pressure, salinity , thus often requiring genetic modifications and chemical optimization, a lenghty, costly enterprise

Nature offers valuable alternatives in the form of **extremozymes**, like as those belonging to **extremophiles**!

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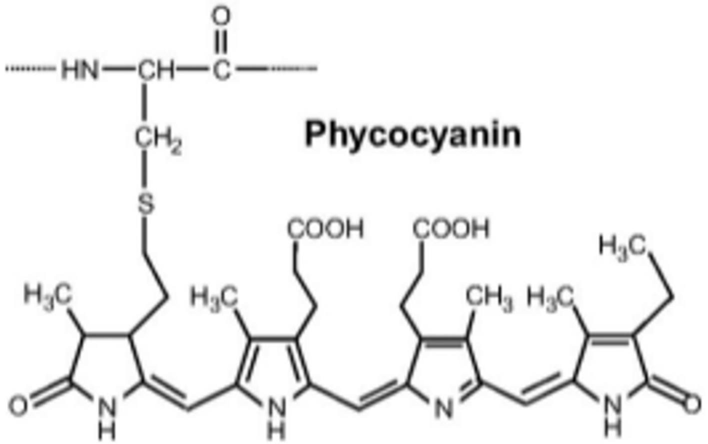
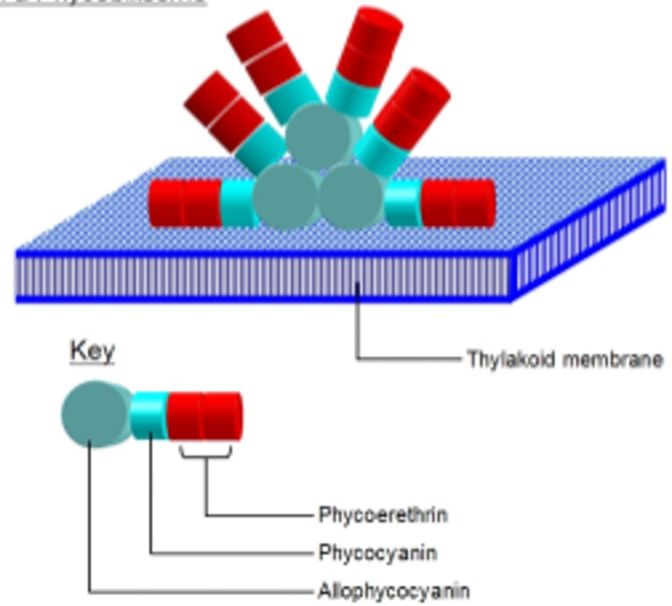
# *Galdieria* as a source of antioxidants: c- phycocyanin




Structure of a Phycobilisome




1) *G. sulphuraria* phycocyanin production was **20–28%** times **higher than** that in photoautotrophic cultures of ***Spirulina platensis*** (Graverholt and Eriksen, 2007).

2) Phycocyanin from ***G. sulphuraria*** can **tolerate temperature** as high as **73°C**, while **phycocyanin** from ***Spirulina*** **deactivated** in temperature higher than **46°C** (Moon et al., 2014).

3) **Total phycocyanin yield** in the heterotrophic cultivation of ***G. sulphuraria*** was **much higher than** that in **phototrophic** cultivation of ***Spirulina*** (Schmidt et al., 2005).

# Global Phycocyanin Market Snapshot (2023 to 2033)

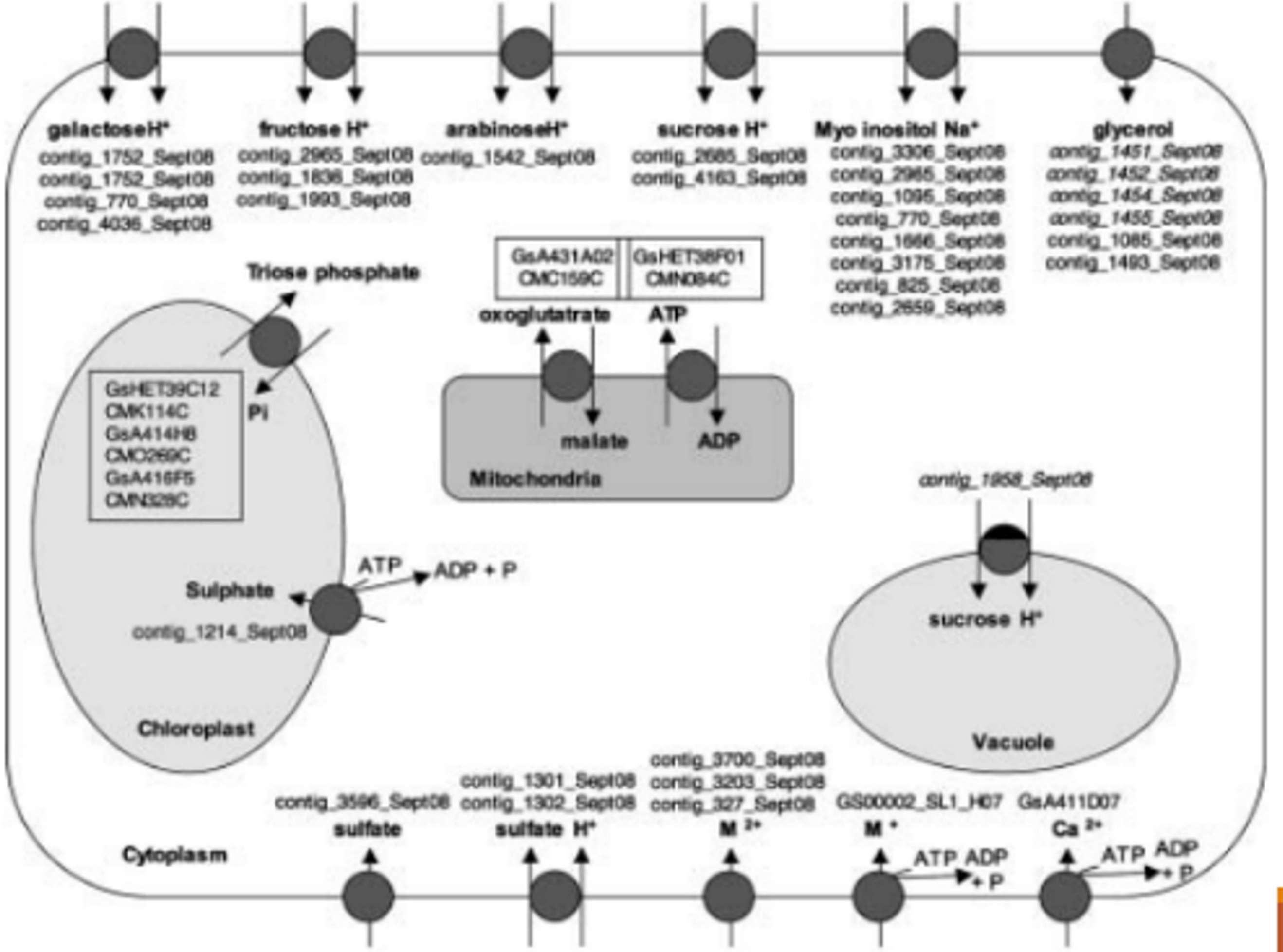
In 2022, the global **phycocyanin market** acquired a valuation of US$ 754.40 million. With consumers gravitating towards natural food-grade substances, the market is expected to reach a sum of US$ 1,487.7 million, garnering a CAGR of 7% during the forecast period 2023 to 2033

| Report Attribute | Details |
|---|---|
| **Estimated Market Value (2022)** | US$ 754.40 million |
| **Expected Market Value (2023)** | US$ 785 million |
| **Projected Forecast Value (2033)** | US$ 1,487.7 million |
| **Anticipated Growth Rate (2023 to 2033)** | 7% CAGR |

# Extreme metabolic versatility of *G. sulphuraria*:

- *Autotrophy*
- ***Mixotrophy***
- ***Heterotrophy***

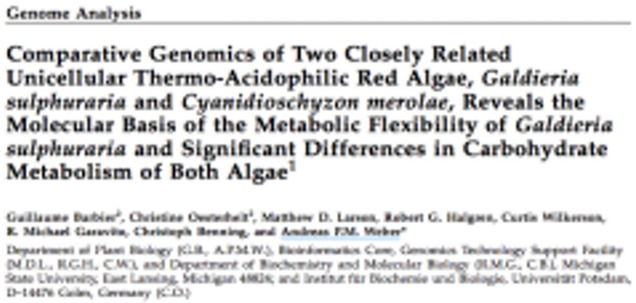
→ ***More than 50 carbon sources***




28 genes encoding putative carbohydrate transporters and 3 genes encoding putative glycerol permeases in *G. sulphuraria*

***Vs***

only a single putative monosaccharide transporter in *C. merolae*


Genome Analysis

**Comparative Genomics of Two Closely Related Unicellular Thermo-Acidophilic Red Algae, *Galdieria sulphuraria* and *Cyanidioschyzon merolae*, Reveals the Molecular Basis of the Metabolic Flexibility of *Galdieria sulphuraria* and Significant Differences in Carbohydrate Metabolism of Both Algae**[1]

Guillaume Barbier[2], Christine Oesterhelt[3], Matthew D. Larson, Robert G. Halgren, Curtis Wilkerson, R. Michael Garavito, Christoph Benning, and Andreas P.M. Weber*

Department of Plant Biology (G.B., A.P.M.W.), Bioinformatics Core, Genomics Technology Support Facility (M.D.L., R.G.H., C.W.), and Department of Biochemistry and Molecular Biology (R.M.G., C.B.), Michigan State University, East Lansing, Michigan 48824; and Institut für Biochemie und Biologie, Universität Potsdam, D-14476 Golm, Germany (C.O.)

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Contents lists available at ScienceDirect
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Growth and phycocyanin synthesis in the heterotrophic microalga *Galdieria sulphuraria* on substrates made of food waste from restaurants and bakeries

Jenni Katrine Sloth [a], Henriette Casper Jensen [a], Daniel Pleissner [b], Niels Thomas Eriksen [c,*]

**Algae Cultivation as Measure for the Sanitation of Organic Waste—A Case Study Based on the Alga *Galdieria sulphuraria* Grown on Food Waste Hydrolysate in a Continuous Flow Culture**

by Daniel Pleissner [1,2,*] and Nicole Händel [2]

1 Sustainable Chemistry (Resource Efficiency), Institute of Sustainable Chemistry, Leuphana University of Lueneburg, Universitaetsallee 1, 21335 Lueneburg, Germany
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* Author to whom correspondence should be addressed.

*Sustainability* **2023**, *15*(19), 14313; https://doi.org/10.3390/su151914313

Bioresource Technology
Volume 340, November 2021, 125637

Cultivation of the heterotrophic microalga *Galdieria sulphuraria* on food waste: A Life Cycle Assessment

Anne Karolin Thielemann [a b], Sergiy Smetana [c], Daniel Pleissner [a b]

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Engineering in Life Sciences
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**Removal of sugars in wastewater from food production through heterotrophic growth of *Galdieria sulphuraria***

Philipp Scherhag, Jörg-Uwe Ackermann

First published: 21 December 2020 | https://doi.org/10.1002/elsc.202000075 | Citations: 13

This article is dedicated to Prof. Thomas Bley on the occasion of his 70th birthday.

Bioresource Technology Reports
Volume 22, June 2023, 101446

Use of an extremophile red microalga (*Galdieria sulphuraria*) to produce phycocyanin from tangerine peel waste

Jin-Kyu Lim [a], Kyoungseon Min [b], Won-Kun Park [a]

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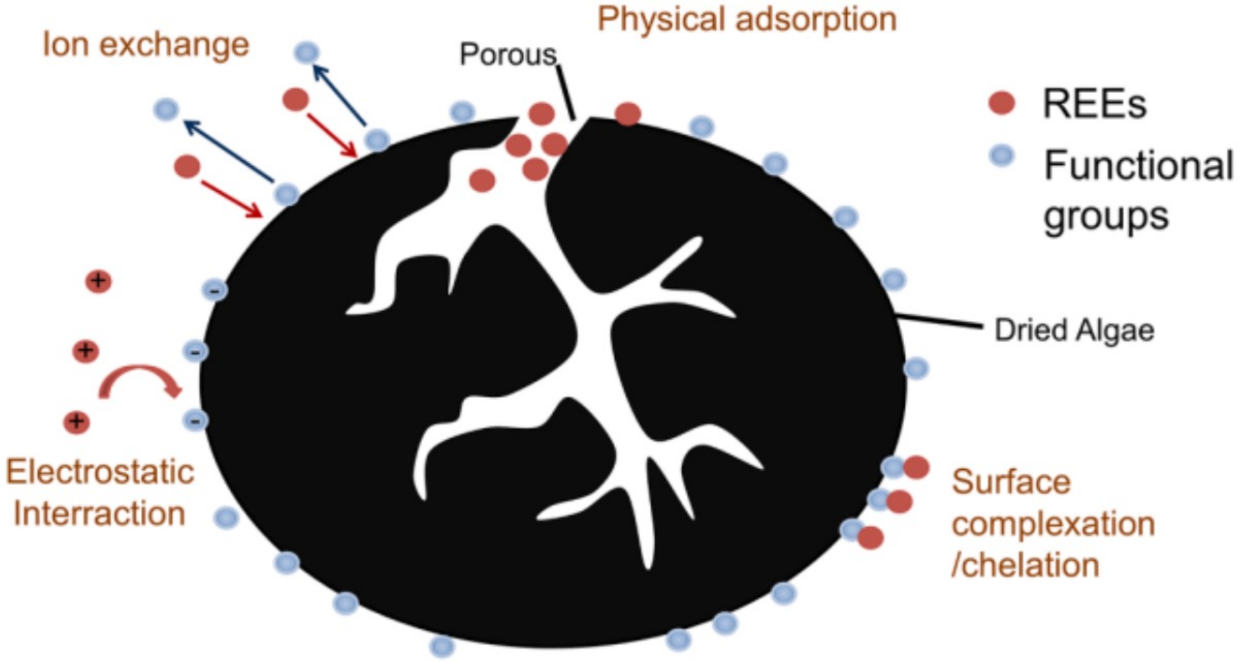
Dipartimento di Scienze e Tecnologie Ambientali Biologiche e Farmaceutiche

SUM2024 7th SYMPOSIUM ON CIRCULAR ECONOMY AND URBAN MINING
CAPRI, ITALY / 15-16-17 MAY 2024

# Bio-removal of rare earth elements from hazardous industrial waste by *Galdieria*





Prof. CLAUDIA CINIGLIA

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# PHYRE (PhycoRecycling): biorecovery of rare and precious earth from e-waste

**Graduatoria dei progetti del Bando per il cofinanziamento di progetti di ricerca finalizzati allo sviluppo di nuove tecnologie per il recupero, il riciclaggio ed il trattamento dei rifiuti di apparecchiature elettriche ed elettroniche (RAEE) Edizione 2021, istituito con decreto n. 84 del Ministero della transizione ecologica in data 9 dicembre 2021 - ASSEGNAZIONE PUNTEGGI**

| N. Istanza | Proponente | Titolo del Progetto | Pa | Pb1 | Pb2 | Pc | Pd | Pe | punteggio totale |
|---|---|---|---|---|---|---|---|---|---|
| N09 | Universita della Campania"L. Vanvitelli" | PHYcoREcycling (PHYRE) | 30,00 | 15,00 | 15,00 | 15,00 | 7,50 | 4,16 | **86,66** |
| N04 | Università degli Studi di Milano | RAEE: una risorsa per un riciclo innovativo di materie prime critiche | 22,50 | 11,25 | 11,25 | 20,00 | 10,00 | 6,08 | **81,08** |
| N01 | Università degli Studi di Napoli Federico II | Processi rigEnerativi ecoSOstenibili per il recupero e la valorizzazione di Metalli Nobili da RAEE | 22,50 | 15,00 | 11,25 | 15,00 | 7,50 | 6,15 | **77,40** |
| N011 | Università degli Studi di Cagliari | Recupero Selettivo Sostenibile Metalli RAEE | 30,00 | 11,25 | 11,25 | 10,00 | 5,00 | 6,08 | **73,58** |
| N07 | Università degli Studi di Parma + Tuscia | Piattaforma collaborativa seconda vita RAEE (PiCo2RAEE) | 15,00 | 7,50 | 7,50 | 10,00 | 7,50 | 5,69 | **53,19** |
| N02 | Università degli Studi di Firenze-Dipartimento di Ingegneria Industria | Riciclare Motorl contenenti Terre Rare | 15,00 | 7,50 | 7,50 | 15,00 | 5,00 | 2,24 | **52,24** |

**Pa** = Originalità e innovatività della proposta progettuale;
**Pb1** = Rispondenza agli obiettivi previsti dal presente Bando, tenendo conto degli impatti ambientali, sanitari, sociali ed economici, della fattibilità tecnica e della praticabilità economica, ai sensi dell'articolo 179 del decreto legislativo 3 aprile 2006, n. 152;
**Pb2** = grado e tempo di raggiungimento dell'obiettivo programmato (anche in relazione al "livello di maturità tecnologica" previsto dallo stesso progetto);
**Pc** = Riproducibilità su scala industriale delle tecnologie e/o prodotti oggetto dell'iniziativa progettuale;
**Pd** = Rappresentatività del soggetto proponente, singolo o associato. Esperienza maturata e capacità della struttura organizzativa dei soggetti coinvolti; curricula dei componenti il gruppo di lavoro e relativo monte ore definito;
**Pe** = Importo del progetto e capacità di autofinanziamento del proponente.

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# Employment of *Galdieria* in urban wastewater treatment



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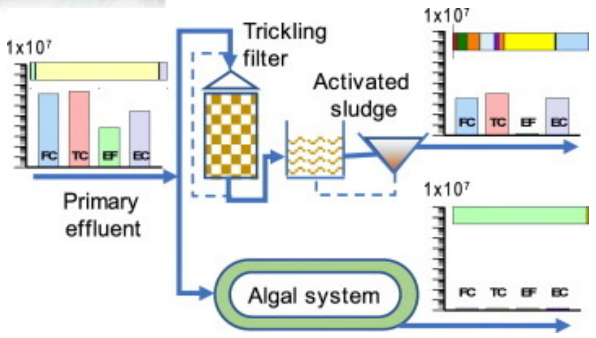
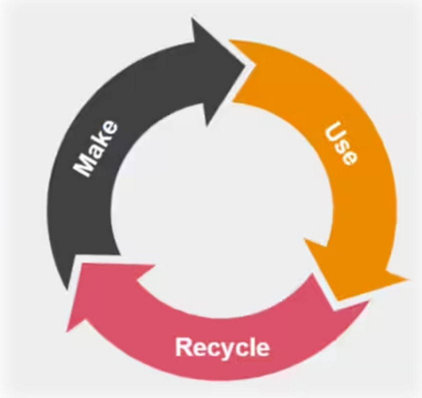
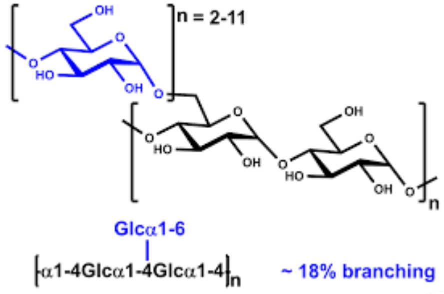
***Make*** *Galdieria biomass by using urban wastewater*

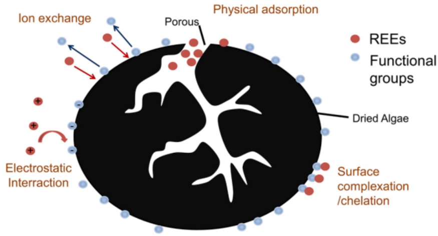



***Use Galdieria biomass for high valuable compounds extraction***


***Recycle*** *Galdieria discharge to recycle REE*



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# Acknowledgements

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