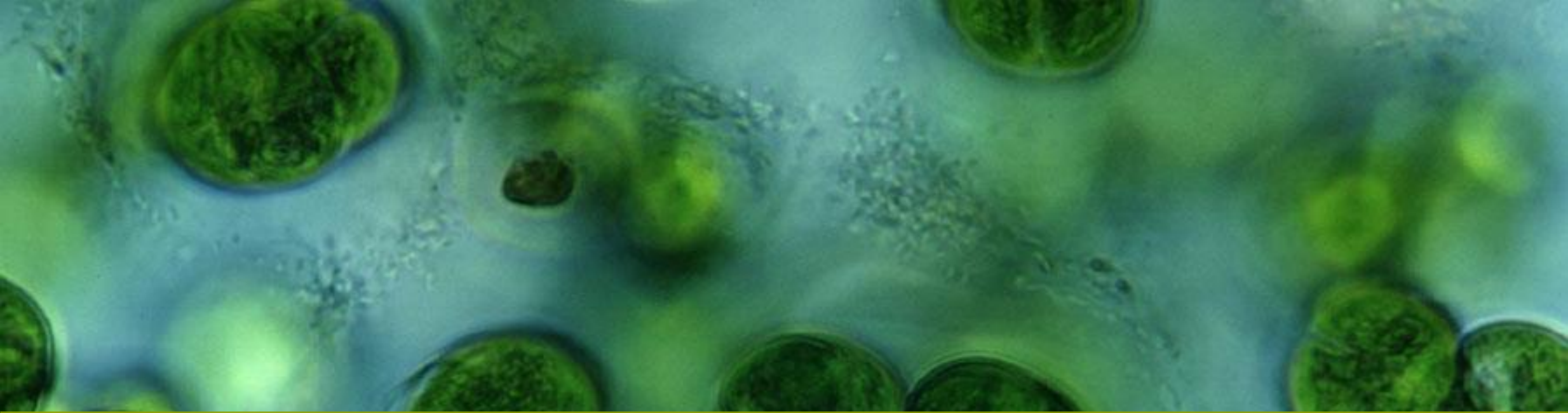
ENHANCE
MICROALGAE

EnhanceMicroAlgae Project

High added-value industrial opportunities for microalgae in the Atlantic Area

Jean-Paul CADORET ALGAMA

La Rochelle 20 Octobre 2022



01

Bottlenecks

limiting the development
of the algae biomass sector

Bottlenecks

limiting the development of the algae biomass sector

Understanding the most relevant **concept boundaries** in the algae biomass sector to overcome the limiting bottlenecks.

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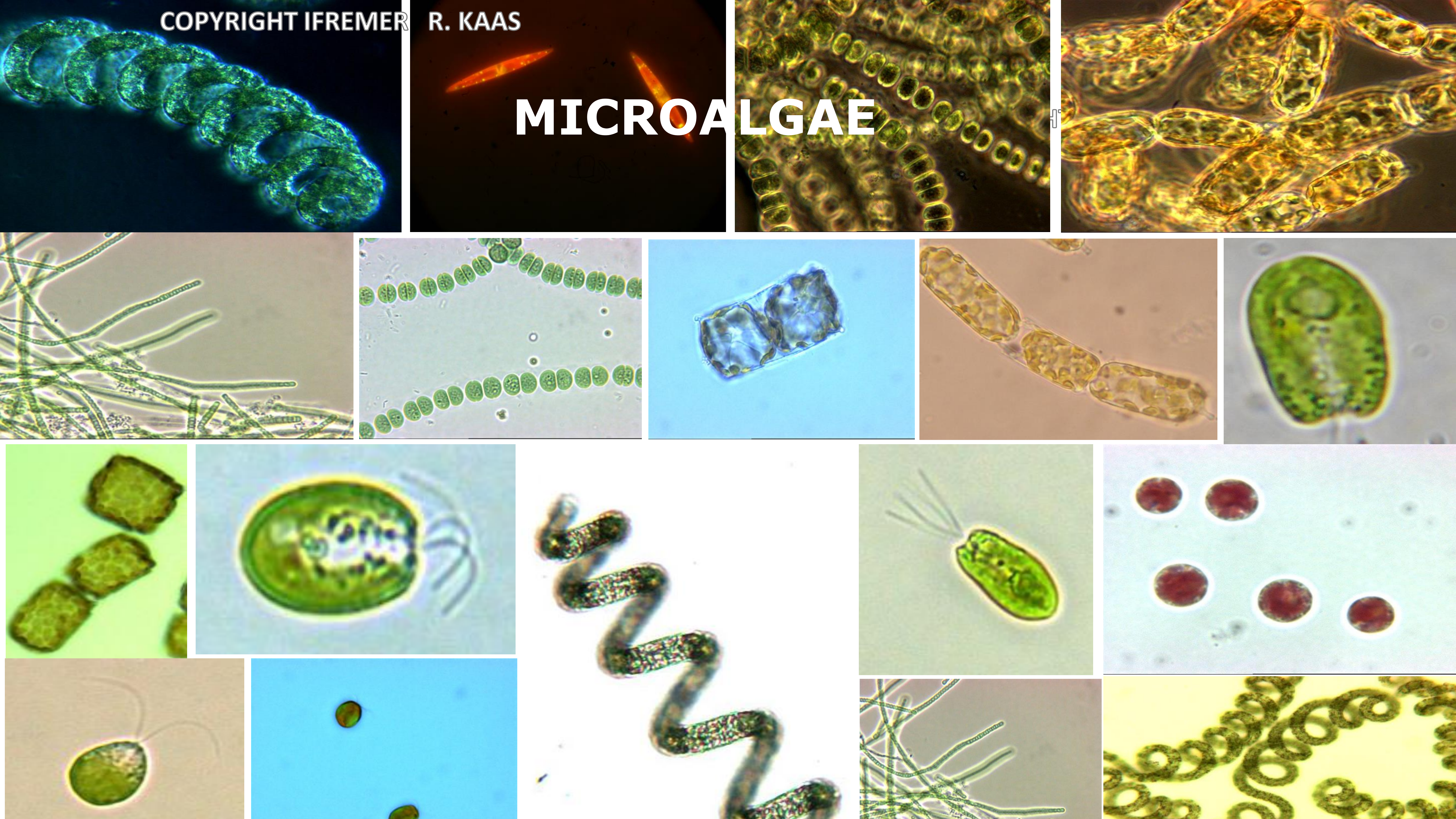
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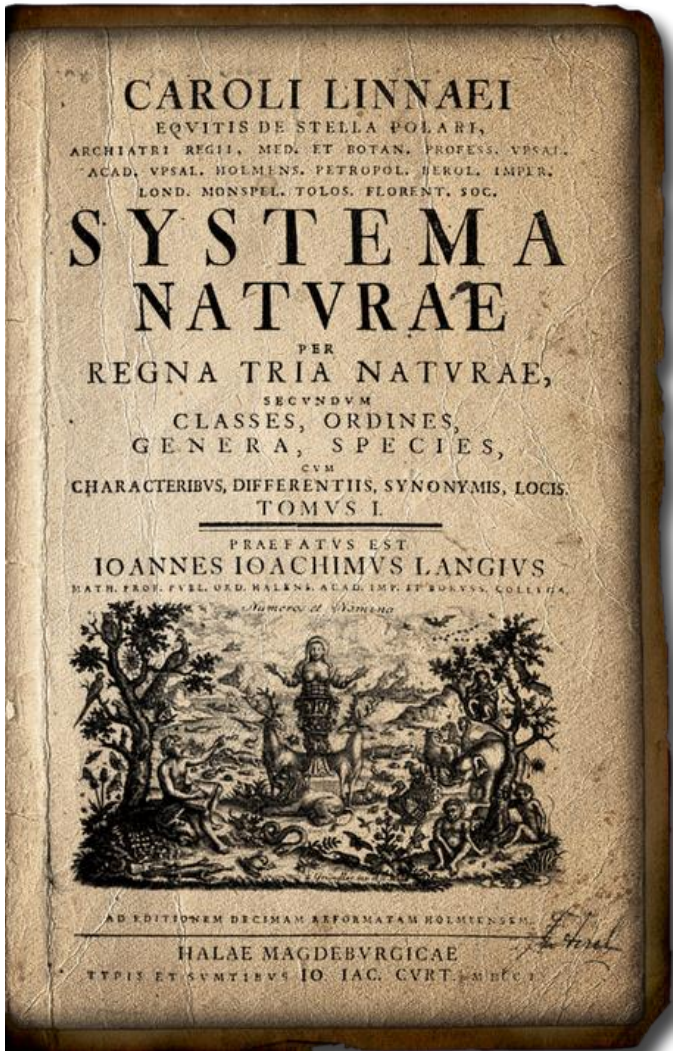
MICROALGAE

MACROALGUES

01

INTRODUCTION

Algae references and classification



In **1735**, Carl Linnaeus published his Systema Naturae, which contained his taxonomy for organizing the natural world. Linneaus proposed three kingdoms, which were divided into classes. From classes, the groups were further divided into orders, families, genera (singular: genus), and species. An additional rank beneath species distinguished between highly similar organisms. While his system of classifying minerals has been discarded, a modified version of the Linnaean classification system is still used to identify and categorize animals and plants. When identifying an object, Linnaeus first looked at whether it was animal, vegetable, or mineral. These three categories were the original domains. Domains were divided into kingdoms, which were broken into phyla (singular: phylum) for animals and divisions for plants and fungi. Phyla or divisions were broken into classes, which in turn were divided into orders, families, genera (singular: genus), and species. Species were divided into subspecies. In botany, species were divided into varietas (singular: variety) and forma (singular: form).

According to the 1758 version (10th edition) of the *Imperium Naturae*, the classification system included algae as:

- **Classis 24. Cryptogamia: organisms that resemble plants but don't have flowers, which included fungi, algae, ferns, and bryophytes.**

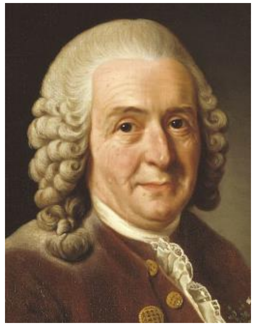
Adapted from: www.thoughtco.com/linnaean-classification-system-4126641

Seaweeds and red tides have been known since ancient times. While both the ancient Greeks and Romans knew of algae, and the ancient Chinese even cultivated certain varieties as food, the scientific study of algae began in the late 18th century with the description and naming of ***Fucus maximus* (now *Ecklonia maxima*) in 1757 by Pehr Osbeck**. This was followed by the descriptive work of scholars such as Dawson Turnerand Carl Adolph Agardh, but it was not until later in the 19th century that efforts were made by J.V. Lamouroux and William Henry Harvey to create significant groupings within the algae.

Linnaeus (1735) established Cryptogamia Algae and the three main algal series (brown, red and green) were proposed by Harvey (1836).

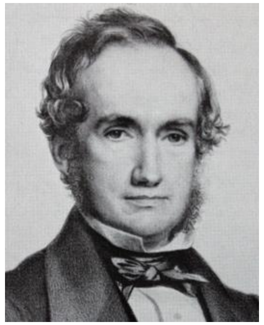
Harvey has been called the father of modern Phycology that is now a well-established discipline, with societies, journals, international symposia, and modern textbooks

Adapted from: Mark Ragan (1998) On the delineation and higher-level classification of algae, European Journal of Phycology, 33:1, 1-15, https://doi.org/10.1080/09670269810001736483



Carl Linnaeus
(1707-1778)

Ecklonia maxima
previusly
Fucus maximus



William Henry Harvey
(1811-1866)

First microalgae *discovered*:

Drawing of *Tabellaria by Mr. C, 1703.*
This image is © The Royal Society.

In the late 17th century, **Leeuwenhoek** almost certainly saw diatoms – they are certainly present in some of the samples he took (Ford 1991) – but none of his published illustrations can be convincingly argued to show diatoms.

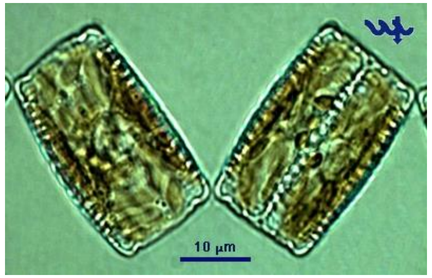
In **1703**, another early microscopist sent a paper to the Royal Society of London, which was published in its Philosophical Transactions.

His name is not recorded, either on the paper itself or in the Royal Society archives, and the paper was communicated to the Royal Society via another unnamed person referred to as 'Mr. C', who could be any one of four Fellows.

Perhaps the mystery of authorship will one day be solved, but there is no mystery about what the anonymous microscopist saw: his drawing is a careful and lovely representation of the freshwater diatom *Tabellaria*.

Antonie van Leeuwenhoek (1632-1723)

The first compound microscopes date to 1590, but it was the Dutch Antony Van Leeuwenhoek in the mid-seventeenth century who first used them to make discoveries.



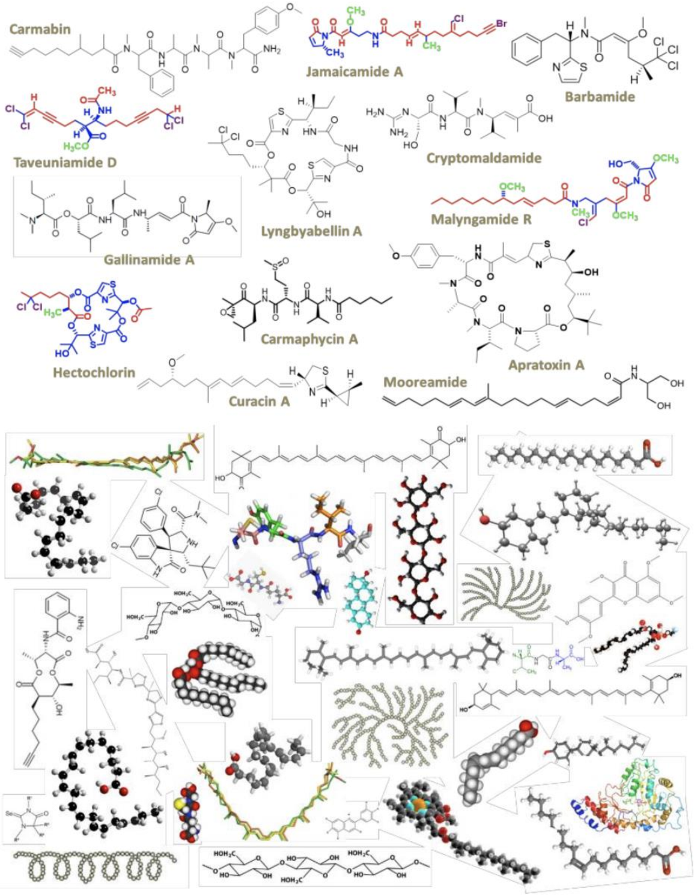
Tabellaria floculosa

http://rbg-web2.rbge.org.uk/algae/diatoms_introduction1.html

From Algae in Nature to Applications

HIGHLY DIVERSE SPECIES

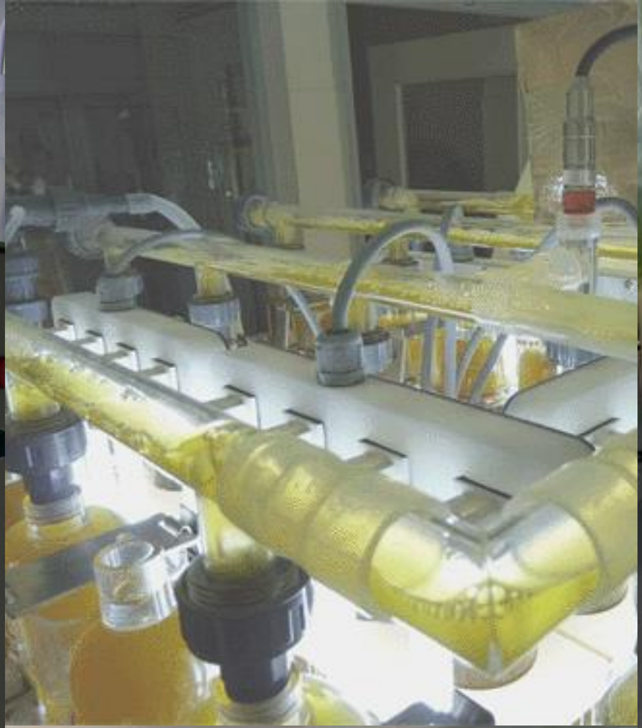
HUGE VARIETY OF CHEMICALS



BROAD APPLICATIONS

- FUNCTIONAL FOOD
- NUTRACEUTICAL
- PHARMACEUTICAL
- COSMETICS
- ANIMAL FEED
- BIOFERTILIZER
- FINE CHEMICAL
- BIOFUEL & BIOGAS


Jouin




HPT63

Applications

PREDICTING THE FUTURE ?

1 Biology

- Choice of organisms
- Oriented selection
- Mutants and genomes
- GMOs
- Phototrophy/Heterotrophy
- Predation Control
- Pathogens
- Risks of dissemination
- By products (biorefinery)
- Industrial property

3 Bioreactor and process

- Photobioreactor choice (Light)
- New materials
- CO_2 transfer and O_2 management
- Mixing, bubbling, shearing
- control and regulation of physico-chemie
- Time of culture
- Automatization of process
- Modelisation

2 Input management
2.1 Water

- Water supply
- Open systems
- Circular flow
- Water treatment

2.2 Substrate and nutrients

- CO_2 supply
- Nutrients (In, Out, Costs)
- Energy balance

4 Biorafinery

- Biomass concentration
- Post treatements
- Extraction

5 Business

- Prospecting
- Sampling
- Branding
- Marketing
- Packaging
- Logistics
- Public awareness
- Public acceptance
- Public demand
- Risk taking

5 LCA
Transversal

6 Regulation
Transversal

02

Relevant Concepts

THE FRAMEWORK IN A NUTSHELL

The Boundaries

01. What are algae?
02. Why are algae important?

03. Algae cultivation is aquaculture?
04. Algae are plants and therefore vegetables?
05. Algae culture is agriculture?
06. What is marine agronomy?
07. What is algae industry?

08. Algaculture x Aquaculture x Agriculture

09. What is algae biomass?
10. What are organic algae?
11. Algae grown in wastewater is algae biomass?
12. What are toxic algae?

13. Microalgae are ubiquous?

14. The algae production scale-up bottlenecks

Once we understand the most relevant **concept boundaries** in the algae biomass sector – then we are able to **overcome** the **limiting bottlenecks**.

Top 10 Bottlenecks

a. Logistics
b. Contamination
c. Market demand
d. Value chain
e. People
f. Investability
g. Produtech
h. Business model
i. Bioprocessing
j. Political

Regulatory is transversal to most bottlenecks

processes

MDPI

Communication

Clarification of Most Relevant Concepts Related to the Microalgae Production Sector

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Abstract: Microalgae (including cyanobacteria) are the basis for an emerging worldwide industry but still face significant bottlenecks in contributing to the global economy. It is an enormous challenge to translate experiences from established industries such as aquaculture and agriculture to the microalgae sector. In particular, this includes the challenge of adapting regulations that apply to such macroscopic production and mindsets, to the microscopic world of microalgae and to the scale-up to a million times smaller. Current European and country-based regulations do not always, indeed rarely, consider relevant specific issues that limit the path for innovation and growth applicable to the microalgae sector. In this work, the boundaries for the main issues impacting this sector are presented and discussed. Examples and possible analytical frameworks are presented in a question and answer format. Relevant key topics and related boundaries are discussed: What are algae and how do microalgae differ from macroalgae? Why are algae and specifically microalgae relevant? Is algae cultivation an aquaculture process? Can algae and specifically microalgae be classified as vegetables and their production be classified as agriculture or are they an industrial process? How is algaculture compared with other agricultural sectors? What are organic algae? Can microalgae be grown in wastewater and how can they be used? What are toxic algae? What are the bottlenecks for microalgae culture scale-up? How does the microalgae biodiversity contribute to their development? We conclude that microalgae are developing as a novel agricultural enterprise that can provide major benefits to a sustainable circular economy and environment but require appropriate regulations and support from governments and businesses, recognising its unique attributes and potential.

Keywords: algae; microalgae; aquaculture; biomass; bottlenecks; regulatory; innovation; bioeconomy

check for updates

Citation: Vieira, V.V.; Cadoret, J.-P.; Acien, F.G.; Benemann, J. Clarification of Most Relevant Concepts Related to the Microalgae Production Sector. *Processes* **2022**, *10*, 175. https://doi.org/10.3390/pr10010175

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03

THE MOST RELEVANT CONCEPT BOUNDARIES

01. WHAT ARE ALGAE?

> what is the difference between macro and microalgae?

The difference between macro and microalgae is that the latter are unicellular or small colonial or filamentous species, are generally microscopic (only visible with a microscope), whereas macroalgae are multicellular and can be up to 60 meter in length.
Macroalgae or seaweed do not have vascular tissues, as higher plants, and therefore can grow much fast.
Microalgae as single cell organisms can on average duplicate everyday.

> are algae aquatic organisms?

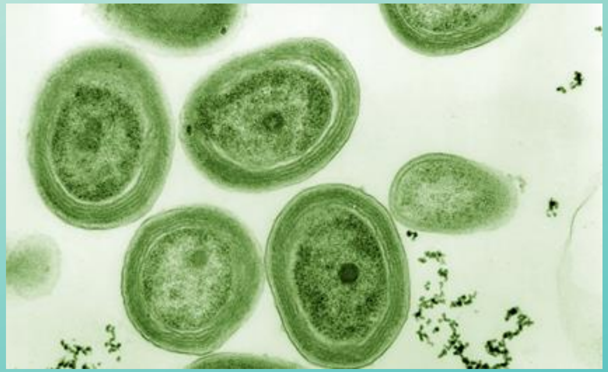
Yes. All algae are aquatic organisms, even if some some algae can survive for a long time in cysts, as some soil algae - and spores from macroalgae. These cysts and spores of microalgae and seaweed respectively can survive for long periods of time in extreme conditions as dry environments and low temperature (hundreds of years and negative temperatures on ice or desert soils).

The first boundary (1st)
Algae is a **common name** for a wide range of aquatic organisms. **Not** a taxonomic group (as cyanobacteria).

Prochlorococcus (chloroxybacteria), **which is the most abundant photosynthetic organism in the oceans**, dominates the deep chlorophyll maximum (DCM). That organism is one of the smallest picophytoplankters in the ocean with volume of only 0.11–0.38 μm^3 (0.6–0.9 µm). It is smaller than the ubiquous *Synechococcus*, 0.52 μm^3 (1 µm), and much more so than the smallest eukaryotic algae (4–10 µm).

www.ncbi.nlm.nih.gov/pmc/articles/PMC98958/

Macrocystis pyrifera, commonly known as **giant kelp**



Electron micrograph of a cultured strain of *Prochlorococcus*.
Images from: http://jgi.doe.gov

What are algae? EABA Position Paper
Alison G. Smith, Mario R. Tredici, Sammy Boussiba, Vítor Verdelho, Jean-Paul Cadoret, Matthew P. Davey, Maria Huete-Ortega, Francisco Gabriel Acien, Ulrike Schmid-Staiger, Herminia Rodriguez, John Benemann, Stefan Leu, Rodolfi, Natascia Biondi, Lisandra Meinerz (2019 revised in 2021)
www.what-are-algae.com (2015-2019)

02. WHY ALGAE ARE IMPORTANT?

> phytoplankton are algae?

Yes. Phytoplankton are microalgae and the foundation of the aquatic food web, the primary producers, feeding everything from microscopic, animal-like zooplankton to multi-ton whales. The two main classes of phytoplankton are dinoflagellates and diatoms. Dinoflagellates use a whip-like tail, or flagella, to move through the water and their bodies are covered with complex shells. Diatoms also have shells, but they are made of a different substance and their structure is rigid and made of interlocking parts. Diatoms do not rely on flagella to move through the water and instead rely on ocean currents to travel through the water.

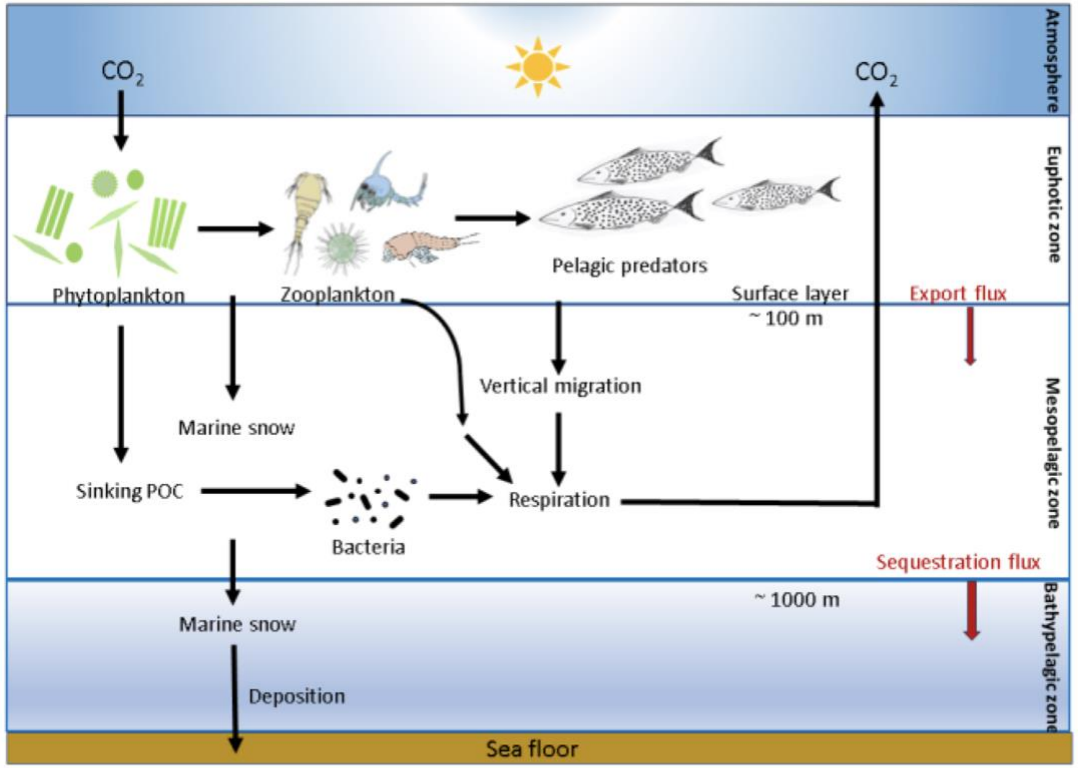
> what is the role of algae in oxygen production?

More than 50% of all oxygen on earth is recycled by algae. The surface layer of the ocean is teeming with photosynthetic plankton. Though they're invisible to the naked eye, they produce more oxygen than the largest redwoods. Beyond plankton the macroalgae also have a relevant contribution as the Great Atlantic Sargassum Belt.

https://oceanservice.noaa.gov/facts/ocean-oxygen.html

> what is the algae compliance with the Sustainability Development Goals?

Algae are the only group of organisms that in different levels comply with all the 17 UN Development Goals. Some of them have a complete adherence and in some of them have a marginal impact. There is a global social awareness that algae are very relevant for the planet and one of the reasons for that is the relevant impact in many sustainability development areas.



Adapted from: www.mdpi.com/2071-1050/10/3/869/htm

The second boundary (2nd)

Algae are primary producers, in the **first level of the food chain**.

ROLE OF ALGAE IN THE SUSTAINABLE DEVELOPMENT GOALS

Unlike higher plants, where we use only parts of the plant and energy is wasted to produce a large potions, the whole plant,

with algae **all the biomass is usable !**

- **No waste of biomass**
- **No waste of energy**
- **Less water use**

Adapted from: https://blogs.helsinki.fi/potentalgae/2020/07/28/role-of-algae-in-sustainability/ an d http://www.algonauts.org/algae2030 [assessed in 2020Aug28]

03. ALGAE CULTIVATION IS AQUACULTURE?

> what is aquaculture?

Adapted from: www.fao.org/3/x6941e/x6941e04.htm

Aquaculture or farming in water is the aquatic equivalent of agriculture or farming on land. Defined broadly, agriculture includes farming both animals (animal husbandry) and plants (agronomy, horticulture and forestry in part). Similarly, aquaculture covers the farming of both animals (including crustaceans, finfish and molluscs) and plants (including seaweeds and freshwater macrophytes). While agriculture is predominantly based on use of freshwater, aquaculture occurs in both inland (freshwater) and coastal (brackishwater, seawater) areas.

FAO (1988) introduced a definition of aquaculture which reduces its confusion with capture fisheries:

> Aquaculture is the farming of aquatic organisms, including fish, molluscs, crustaceans and aquatic plants. Farming implies some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated. For statistical purposes, aquatic organisms which are harvested by an individual or corporate body which has owned them throughout their rearing period contribute to aquaculture, while aquatic organisms which are exploitable by the public as a common property resources, with or without appropriate licences, are the harvest of fisheries.

The above definition is significant as it introduces a social criterion (ownership of the stock throughout the rearing period) to qualify the production technology aspects.

> algae production is an aquaculture process?

Yes. Algae cultivation can be considered as an aquaculture activity because it takes place in an aquatic environment. Algae cultivation based organisms are therefore aquaculture products.

No. When algae, are harvested from the environment, that harvest is not an aquaculture product, either microalgae bloom of seaweed collected from the ocean, even if with the appropriate licences.

The third boundary (3rd)

Algaculture requires active human effort in maintaining or increasing the number of organisms involved (with **ownership of the stock** along the cultivation). **Algae cultivation always happens in an aquatic environment** even if some are able survive and duplicate in environments as soils.

04. ALGAE ARE PLANTS AND THEREFORE VEGETABLES?

> algae are considered plants?

Yes. In aquatic ecology microalgae are often called phytoplankton, from the greek words "phyton" (plant) and "planktos" (wanderer or drifter), referring to microscopic photosynthetic organisms that form part of the plankton community. Seaweeds are marine plants also known as algae. They are found in a marine environment and have specialized parts that allow for photosynthesis. In the Merriman-Webster Dictionary alga are defined as: a plant or plantlike organism of any of several phyla, divisions, or classes of chiefly aquatic usually chlorophyll-containing nonvascular organisms of polyphyletic origin that usually include the green, yellow-green, brown, and red algae in the eukariontes and especially formerly the cyanobacteria in the prokaryontes.

No. Some algae are not strictly plants, even if they are photosynthetic – but they are usually considered plantlike organisms.

> why are algae considered plant-like?

The main reason is that they contain chloroplasts and produce food through photosynthesis.
However, they lack many other structures of true (higher) plants.
For example, algae do not have roots, stems, or leaves.

For the purposes of **external trade** algae have been assigned a customs code number
(Regulation (EEC) No. 2658/87) under Chap. 12 "*oil seeds and oleaginous fruits; miscellaneous grains, seeds and fruit; industrial or medicinal plants; straw and fodder*".
In other words, for these purposes algae are considered "plants"

> are Algae Plants and Therefore Vegetables?

Vegetables are plants that are consumed by humans or other animals as food. The original meaning of vegetable refers to all edible plant matter, including flowers, fruits, stems, leaves, roots and seeds. Algae are plants, based on the common usage of the term and their inclusion into the field of botany.

The green algae or chlorophytes originated from an endosymbiotic event in which an ancestral non-photosynthetic microbe acquired a cyanobacterium (blue-green alga) are the ancestors of all higher and lower plants. The red algae resulted as well from such an initial endosymbiosis. Other types of algae, such as brown algae and diatoms, dinoflagellates, eustigmatophytes and euglenoids, resulted from additional endosymbiosis events of a red or green alga with other eukaryotic host cells. The common term algae include all the species that carry out oxygenic photosynthesis, from prokaryotes (the cyanobacteria) to several kingdoms of the eukaryotes. www.ncbi.nlm.nih.gov/pmc/articles/PMC2817223/

The fourth boundary (4^{th})

Most **algae are plants**, and therefore, they or **their edible parts are vegetables**

O5. ALGAE CULTURE IS AGRICULTURE?

> why algae cultivation is agriculture?

Algae production can be considered as agriculture, defined as the art and science of growing plants and raising animals, for food, feeds and many other economic activities.

Algae Agriculture Triumphs in Farm Bill Compromise

December 12, 2018

In a historic day for the algae industry, the U.S. Senate Tuesday approved a Farm Bill compromise that dramatically expands federal support for algae agriculture. The bill sets U.S. farm policy through 2023. It is expected to pass the House of Representatives as soon as today and receive President Trump's signature before Christmas.

Among the bill's more than 800 pages is a suite of provisions placing algae among the nation's top priorities for new crop deployment and providing support for the development of algae and related technologies in nutrient management, soil health, carbon recycling and other farm and rural applications.

2018 FARM BILL HOUSE & SENATE CONFERENCE REPORT

https://algaebiomass.org/blog/10424/algae-agriculture-triumphs-farm-bill-compromise

> are algae a crop?

Yes. Algae are a crop with a diverse number of species being cultured. Crops can be classified into six categories based on their applications in foods, feeds, fibers, oils, ornamentals and industry. Algae fit in all categories and already are crops, with one-tenth of thousands of tons of microalgae being cultivated in large pond systems and millions of tons of seaweeds farmed in near-shore environments.

> Is algae biomass different from the other crops?

No. Algae biomass is not substantially different from other crops; its biochemical composition and nutritional properties are analogous to those of other crops, although some species contain unique components, such as long-chain omega-3 fatty acids, not found in conventional crops. From the production/technological perspective, algae farming faces similar problems to those encountered in agriculture and aquaculture. Further, algaculture is not understood by most decision-makers, investors and other stakeholders, due to a lack of knowledge and background in this merging of agriculture with aquaculture.

The fifth boundary (5th)

Algae cultivation-based products are crops. **Stakeholders lack specific knowledge of the requirements for their production**.

06. WHAT IS MARINE AGRONOMY?

Santelices B. (1999) A conceptual framework for marine agronomy. In: Kain J.M., Brown M.T., Lahaye M. (eds) Sixteenth International Seaweed Symposium. Developments in Hydrobiology, vol 137. Springer, Dordrecht.
https://doi.org/10.1007/978-94-011-4449-0_3

Bernabé Santelices González
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> how is marine agronomy defined?

Marine agronomy referres to the science and technology of producing and using marine algae and marine aquatic plants for food, fuel, fiber and ocean restoration.

> what are the main marine agronomy production

The main marine production crops are aquaculture macroalgae (seaweed) and the halophile plant salicornia / sarcornia.

Most seaweeds produced in Asia, are a result of marine agronomy, also classified as algaculture in the ocean.

Often this cultivation activity is combined with fish and /or shellfish production with benefit from available organic matter.

Seaweed production in Europe is still emerging but with a very high growth.

A conceptual framework for marine agronomy

B. Santelices

Conference paper

Part of the Developments in Hydrobiology book series (DIHY,volume 137)

Abstract

Between the late 1960s and the early 1980s, several generations of phycologists in Hawaii and the Philippines, associated with M. S. Doty, contributed to developing a new approach, and to advance concepts in marine agronomy. This study reviews the approach and the main concepts contributed. Integrating these contributions with others, a basic conceptual framework for marine agronomy is presented.

The sixth boundary (6th)

Marine aquaculture **local permissions are required for seaweed cultivation** in the oceans.

07. WHAT IS THE ALGAE INDUSTRY?

The algae industry **produces** and **harvests** algal biomass and then **transforms** it into products, using both mechanical and chemical operations.

> are algal pastes and sun dried seaweed from natural harvest industrial products?

No. Solar dried seaweed and microalgae paste from harvesting microalgae blooms are not industrial products (as other agriculture products) because there is no transformation process involved, just dehydration that could happen naturally.

> is algal biomass cultivated in ponds, photobioreactors or fermenters an industrial product?

Yes. The final stages that transform algae into an algae biomass product requires a specific processing and therefore are industrial products. Microalgae production is analogous to bacteria and yeast production at an industrial scale, with industrial processes ranging from closed dark fermentations to indoor autotrophic production and large-scale outdoor ponds.

> is the production of algae extracts an industrial process?

Yes. The production of an extract usually requires a disruption of the biomass and the use of a chemical or mechanical extraction process and is, therefore, an industrial process.

As the seventh boundary, an algal industrial process requires the production of the algal biomass or the transformation of algae harvested from natural environments into a product different from the whole biomass.

The seventh boundary (7th)

An **algal industrial process** requires the production of the algal biomass or the **transformation of algae harvested** from natural environments into **a product different from the whole biomass**.

ALGAE PRODUCTION

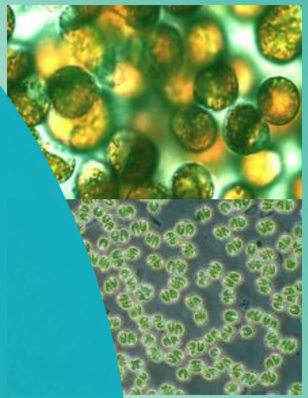
MACROALGAE

- Cultivation in the ocean
- Cultivation in ponds
- Harvesting from nature

> Multicellular
> Composition
10-25% protein
30-50% carbohydrates
0.5-5% lipids

MICROALGAE

- Cultivation in open systems
- Cultivation in photobioreactors
- Cultivation in fermentors



> Unicellular
> Composition
30-70% protein
10-30% carbohydrates
10-50% lipids
Rich in ω−3 fatty acids

René Wijffels (2019)

08. ALGACULTURE X AQUACULTURE X AGRICULTURE

Algaculture is complex, as it combines the <u>knowledge of biology and engineering from both agriculture and aquaculture</u>
and is a relatively new sector when compared with agriculture and aquaculture,

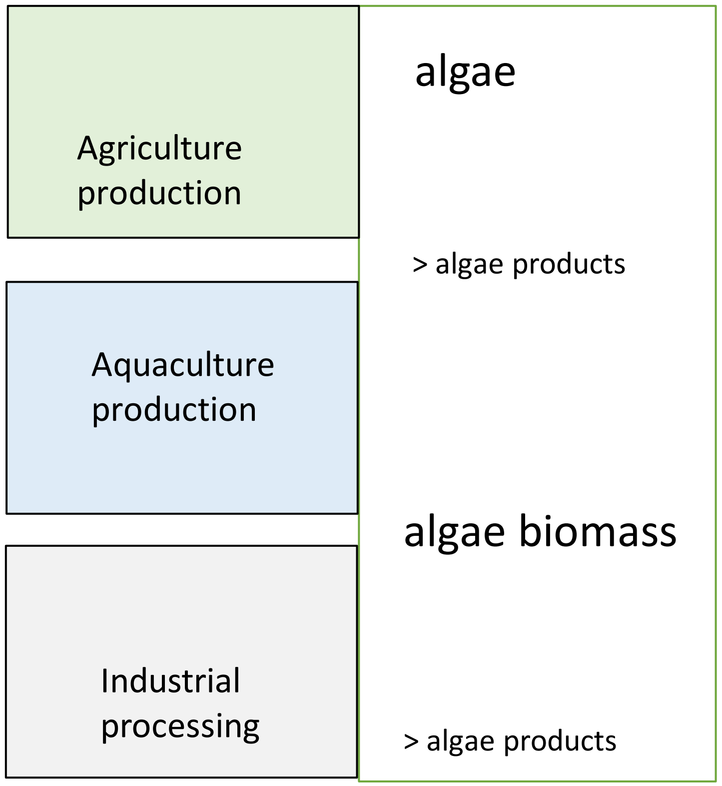
> what is the algaculture relation with aquaculture and agriculture?
Yes. Algaculture combines parts form aquaculture and from agriculture. Can be compared with agriculture crops and aquaculture products.
Algaculture is somewehre between agriculture (plants) and aquaculture (water-based cultivation).

> what is the comparative Google index (2022)?

for agriculture	is 870 million;
for aquaculture, it	is 38 million, and
for algaculture, it	is only 413.000.

There is a long way to go…

ALGACULTURE



The eigth boundary (8th):
Algaculture is **not yet a globally established and recognized** sector

09. WHAT IS ALGAE BIOMASS?

> What is the difference between algae and algae biomass?

The term '**algae**' (macro and microalgae) referes to the aquatic organisms when they are in the media where they grow and duplicate, either soil or water. When we have algae in nature as phytoplankton in the surface of any all waterbodies in the planet or seaweed that float in the oceans they are named as 'algae'.

The term "**algae biomass**" is used, when there is cultivation, harvesting, stabilization or other processing that results in an algae product. In the case of either seaweed or microalgae, because they grow in the water, a drying process is usually required. Microalgae also require specific harvesting technologies because of their microscopic size. The drying of microalgae is industrially carried out, mainly using spray-dryers, and it is performed to reduce the water content to 5% or below.

For macroalgae, sun or air drying is typically used. Other stabilization methods, such as ensiling, are also possible. These processes produce stable algal biomass that then can be converted into foods, feeds and other products.

1 Paste
- Aquaculture
- Fertilizers

2 Dried
- Food & Feed
- Aquaculture
- Ceuticals
- Fertilizers

3 Extracts
- Ceuticals
- Fertilizers

> Algae biomass results from harvested and dried algae that was in grown in a culture media suspension?

Yes. Water must be removed. Microalgae with 20% water is still a paste. Solid form requires les than 5% water. The same for seaweed.

The nineth boundary (9^{th})

the **harvesting and stabilization** of algal biomass is the first step to producing useful products.

10. WHAT ARE ORGANIC ALGAE?

Organic refers to products that meet certain regulatory requirements such as cultivation without synthetic fertilizers pesticides and other chemicals, the use of genetically modified organisms (GMOs) or wastewaters. Regulations are set in the USA by the US Department of Agriculture under Organics Food Production Act and in Europe under a similar legal and regulatory framework, with both US and EU organic regulations generally mutually compatible to have an “organic” certification. The final product needs to meet the requirements of **EU Regulation 2018/848** on organic production and the labelling of organic products. Euroleaf is the EU logo that identifies packaged organic food products. Organic regulations designed around soil-based systems do not transfer well into algaculture or aquaculture. In addition, organic seaweed regulation cannot be used for microalgae. The main difference is that in organic agriculture organic fertilizers are applied in the soil which are not in direct contact with the crops (e.g., corn and fruits). Finding suitable organic fertilizers for algaculture is a challenge.

> Does organic microalgae cultivation require a “pasteurized” organic carbon source?

No. There are no specific requirements for the use of pasteurized or sterilized ingredients for the organic production of algae. However, good practices must be followed to avoid the potential contamination of the final products.

> Are seaweeds always organic products?

No. Specific regulations define the inputs and productions modes to achieve organic production status.

unlike higher plants, where we use only parts and energy is wasted to produce large potions of biomass, **with algae all the biomass is usable !**

New logo selected for all EU organic products

February 08, 2010

On February 8, 2010, the European Commission officially announced the winner of the EU organic logo competition. Over the past two months, some 130'000 people have voted online to choose the new organic symbol from three finalists.

The winning design is from a student from Germany, who gained 63 percent of the overall vote for his 'Euro-leaf' logo.

From 1st July 2010, the organic logo of the EU will be obligatory on all pre-packaged organic products that have been produced in any of the EU Member States and meet the necessary standards. It will be optional for imported products. Other private, regional or national logos will be allowed to appear alongside the EU label. The organic farming regulation will be amended in the coming weeks to introduce the new logo into one of the annexes.

The tenth boundary (10th)

Organic algae require **specific** aquaculture-based **regulations**.

11. ALGAE GROWN IN WASTEWATER CAN BE CONSIDERED AS USEFUL BIOMASS ?

> can algae grown in wastewarter be considered algal biomass?

Yes. Wastewaters, either industrial or urban (and including from agriculture, animal farming and also aquaculture), contain nutrients, such as nitrates, phosphates, micro- elements and organic substrates. The biomass grown in such substrates under sunlight is a mix of mainly algae and bacteria, with fungi and other organisms present. That resulting biomass can only be considered in the production of products that do not directly enter the human food chain, such as biofuels, biofertilizers and bioplastics. Only if safety and quality are assured, such as in the treatment of some food processing, agricultural or aquacultural wastes, could wastewater grown biomass be considered in the production of animal feeds. However, in general, in wastewater treatment processes, the resulting algal-bacterial product is not greatly different from the bacterial biomass produced in, for example, the activated sludge from conventional wastewater treatment.

> can algae produced from wastewater be applied directly or indirectly for foods or feeds?

No. Existing regulations prevent the use of materials, algal or not, recovered from or related to wastewaters for human uses. This is a prevention measure to ensure the health of the population. It can be noted that “toilet to tap” systems are becoming increasingly necessary to deal with the increasing water shortages, suggesting a future pathway to the integration of wastewater treatment into the circular economy.

> can algae produced from wastewater be in animal feeds, including aquaculture?

No, except in some cases. Wastewater contains useful nutrients for animal farming either urban and industrial. To prevent potential health problems, it is forbidden to use algae biomass produced on urban wastewater in animal feeds. However, manure is accepted as a raw material for some aquaculture applications, although strict regulations exist regarding the certification of the safety of material to be used, including chemical/biochemical composition, microbiological contamination, heavy metals and other toxic compounds contents.

The eleventh boundary (11th)

Wastewaters might have contamination that limit the potential applications - when using wastewaters to produce algae there are regulatory and technical issues, **limiting the application** of produced biomass **to mainly biofuels, biofertilizers and bioplastics**.

12. WHAT ARE TOXIC ALGAE?

> what Are Toxic Algae and Harmful Algal Blooms?

Some species of algae produce toxins to compete with other algae or deter grazers and other predators. Often toxic algae bloom in a natural environment and, even if not toxic, can be harmful to the ecosystems by depleting oxygen when the bloom decays, resulting in "dead zones" with fish kills, noxious odors and foul taste of water supplies.

Although the vast majority of algae, including bloom formers, are not toxic, some harmful algal blooms are associated with algae-produced toxins. Harmful algal blooms can last from a few days to many months..

> what is the origin of Harmful Algal Blooms?

They are mostly caused by eutrophication—an overabundance of nutrients, mainly fixed nitrogen (nitrates, ammonia, etc.) and phosphates in the wa- ter, released from human settlements and agriculture. High water temperature and low circulation are contributing factors Harmful, sometimes toxic, algae blooms are caused by a few species of cyanobacteria, dinoflagellates and diatoms. Toxic algae can now be identified with multi-probe RNA chips and microarrays which are becoming
a near-standard tool for toxin detection in algae blooms

Often when people think of a HAB they think of the "scum formers," like *Microcystis aeruginosa*.

The twerveth boundary (12th)

Toxic microalgae and harmful **algal blooms have** significant **economic impacts**.

13. MICROALGAE ARE UBIQUOUS?

> how Is Microalgae Biodiversity Ubiquous?

Algae are ubiquitous in marine, freshwater and terrestrial habitats, providing a broad biochemical diversity. The numbers of different algal microalgae species are not easily estimated, and over ten thousand have been described, with some hundreds thousand mating types estimated only for some species of diatoms. Possibly, a million or more species may exist, depending on what definition of species is adopted.

Grains of dust are composed of plant debris, insect parts, silica, chemical residues, molds, fungi and bacteria and their metabolites, including endotoxins. Approximately 40% of its particles are less than 5 µm in mean diameter and represent a respirable piece. 60% have a larger size and **can have attached a wide range of micoorganisms**, virus and chemicals.

Adapted from: Agricultural Health and Safety
M.J. Perry, in International Encyclopedia of Public Health, 2008
Microbes and Their Toxins

The different species of algae cover all water bodies and most land areas on the planet, including extreme environments from ice (such as *Chlamydomonas nivalis* and relatives) to hot springs (such as *Mastigocladus laminosus* that survives up to 64 ◦C) and hypersaline environments (such as *Dunaliella salina*). It was shown that in the species of *Dunaliella salina*, the same strains exist in different locations across the world [23]. *Lobosphaera incisa* (previously known as *Parietochloris incisa*) isolated from Mount Tateyama, Japan is genetically identical to the same species isolated in a water lake from a mine in the Czech Republic.

The **European Algae Biomass Association has catalogued 75 microalgae culture collections worldwide**, and each of them has between 500 and 1000 different strains. However, it is estimated by the culture collection curators that 20% to 30% of the registered species are wrongly classified; and more than half the species are common to most collections even if isolated in a different location. The emergence of DNA barcoding and other molecular biology techniques will bring new light to the algae taxonomy, and therefore, we will see changes of names at both the species and genus levels. More than 70,000 different algae species are known, and they **will undergo a genetic-based reorganization over the next 10 years.**

The thirteenth boundary (13th)

algae species, especially microalgae, **are biodiverse and ubiquitous** with the same species present in different geographies. Similar ecological niches worldwide show the same microalgae strains.

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ENVIRONMENTAL MICROBIOLOGY

Cyanobacteria and Algae in Clouds and Rain in the Area of puy de Dôme, Central France

Kevin P. Dillon,[a]* Florence Correa,[b] Celine Judon,[b] Martine Sancelme,[b] Donna E. Fennell,[a] Anne-Marie Delort,[b] Pierre Amato[b]

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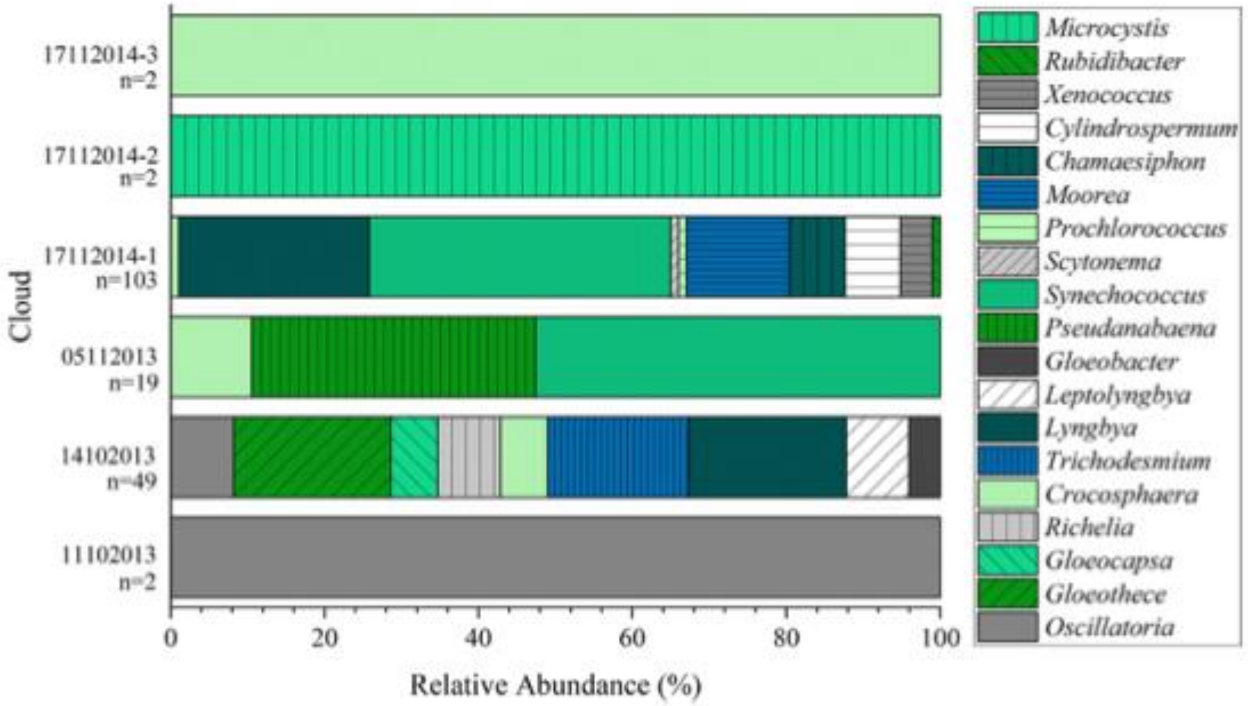
[b]Université Clermont Auvergne, CNRS, SIGMA Clermont, ICCF, Clermont-Ferrand, France

ABSTRACT The atmosphere contains diverse living microbes, of which the heterotrophic community has been the best studied. Microbes with other trophic modes, such as photoautotrophy, have received much less attention. In this study, culture-independent and dependent methods were used to examine the presence and diversity of oxygenic photoautotrophic microbes in clouds and rain collected at or around puy de Dôme Mountain, central France. Cloud water was collected from the summit of puy de Dôme (1,465 m above sea level [a.s.l.]) for cultivation and metagenomic analysis. Cyanobacteria, diatoms, green algae, and other oxygenic photoautotrophs were found to be recurrent members of clouds, while green algae affiliated with the Chlorellaceae were successfully cultured from three different clouds. Additionally, rain samples were collected below the mountain from Opme meteorological station (680 m a.s.l.). The abundance of chlorophyll *a*-containing cells and the diversity of cyanobacteria and green algae in rain were assessed by flow cytometry and amplicon sequencing. The corresponding downward flux of chlorophyll *a*-containing organisms to the ground, entering surface ecosystems with rain, varied with time and was estimated to be between ~1 and >300 cells cm^{-2} day^{-1} during the sampling period. Besides abundant pollen from Pinales and Rosales, cyanobacteria of the *Chroococcidiopsidales* and green algae of the Trebouxiales were dominant in rain samples. Certain members of these taxa are known to be ubiquitous and stress tolerant and could use the atmosphere for dispersal. Overall, our results indicate that the atmosphere carries diverse, viable oxygenic photoautotrophic microbes and acts as a dispersal vector for this microbial guild.

IMPORTANCE Information regarding the diversity and abundance of oxygenic photoautotrophs in the atmosphere is limited. More information from diverse locations is needed. These airborne organisms could have important impacts upon atmospheric processes and on the ecosystems they enter after deposition. Oxygenic photoautotrophic microbes are integral to ecosystem functioning, and some have the potential to affect human health. A better understanding of the diversity and the movements of these aeolian dispersed organisms is needed to understand their ecology, as well as how they could affect ecosystems and human health.

FIG 2 Relative abundance of bacterial genera associated with detected photosynthetic genes in cloud water. The total number of reads of functional genes related
to photosynthesis (n) in each cloud metagenome and their associated taxonomy at the genus level were based upon the UniProtKB database. All clouds were marine in origin except 11102013 which was continental in origin.



Adapted from: Dillon KP, Correa F, Judon C, Sancelme M, Fennell DE, Delort A-M, Amato P. **2021.** Cyanobacteria and algae in clouds and rain in the area of puy de Dôme, central France. Appl Environ Microbiol 87:e01850-20. https:// doi.org/10.1128/AEM.01850-20.

04

LIMITING BOTTLENECKS

14. THE ALGAE PRODUCTION SCALE-UP BOTTTLENECKS ?

> what Are the Major top 10 Bottlenecks for the Algaculture Scale-Up?

The **LOGISTICS** and locations for the large-scale deployment of algal production technologies and infrastructures is an immediate issue.

The **CONTAMINATIONS** are related to crop protection on an ever-present challenge in algaculture.

The **MARKET** demand is often the limiting factor for scale-up, thus achieving economics of scale.

The **VALUE CHAIN** is related to the lack of established products that can support the market demand.

A **PEOPLE** bottleneck is due to the lack of experienced professionals able to manage such production facilities.

The **INVESTABILITY** is related to the combination of risk and returns on investment.

The **PRODUCT** and **REGULATORY** is based on **novel food approval** and the development and standardization of the final products.

The **BUSINESS MODEL** is the way to achieve the scale-up.

BIOPROCESSING is the necessary transformations between the production of biomass and the final products.

Finally, **POLITICAL** drives the incentives and reduces the barriers to algae businesses, within a wider economic, social and environmental framework.

Regulatory is transversal to most bottlenecks: Novel Foods, Organic Algae, Labelling, Production permits…

The Bottlenecks	What?	For Macroalgae (Land Off-Shore)	For Microalgae (Earth Lined Ponds)
01. Logistics	Agriculture and aquaculture combined	Harsh marine environments	Complex infrastructures
02. Contaminations	Crop protection and control	Difficult to control and predators	Wide-range, microscopic and unknown
03. Market demand	Lack of market knowledge and valuation	The market is still very specific.	The production cost limits the market.
04. Value chain	Complex and non-focused	Long and non-specialized	Long and non-specialized
05. People	Lack of trained multi-specialists	Lack of seedling knowledge	Lack of experienced managers
06. Investability	Reduced investment attractiveness	Long return on investment (*)	Very long return on investment
07. Produtech	Final product formulation complexity	Processing-required products	Non-evident, high-value and small-scale
08. Business model	Profitability at the small scale, before at the large scale	Relevant value only in complex business models	Relevant value only in complex business models
09. Bioprocessing	Processing is required in the value chain.	Long processing from farm to fork	Long processing, from farm to fork
10. Political incentives	Framework before sustainability	Global strategic impact of the Integrated multitrophic aquaculture	Advanced crop with low CO_2 emission

(*) Unless for a very large scale.

Table 2. Most relevant bottlenecks for both macro- and microalgae.

> can algae, either macro- or microalgae, have industrial Property protection, like patents?

No and **Yes**. It is not possible to patent living organisms already existing on the planet. However, it is possible to obtain patents for strains bred or genetically modified to yield novel phenotypes. In the US, it is possible to apply for a "plant patent" for an asexually reproduced and distinctive new plant variety. It is also possible to patent and has IP protection for GMOs and related processes.

It is also possible to have patents about the production and processing of natural living organisms for specific applications.

The Nagoya protocol also provides geographical recognition, and in some cases, benefits can be provided for the location of origin.

The Material Transfer Agreement (MTA) is a contract that governs the transfer of tangible research materials between two and defines the rights of the provider and the recipient for the materials and any derivatives. (www.wipo.int/tk/en/databases/ contracts/texts/bio.html; accessed on 25 January 2021).

The knowledge about the boundaries is a bottleneck!

Understanding the most relevant **concept boundaries** in the algae biomass sector can help to **overcome the limiting bottlenecks.**

The fourteen boundary (14th)

Scale-up is a relevant bottleneck for the algae biomass sector and is centered in **knowledge management about the bottlenecks**.

CONCLUSIONS

1. There is a complex context

It is difficult to straightforwardly answer all questions raised above, **as the "reality" is complex**.
However, the understanding of boundaries can help to separate "yes" and "no".

Algae are highly diverse in size, from *Ostreococcus tauri*, a picoplankton that is **less than one micron**, to the gigantic Pacific kelp, *Macrocystis pyrifera*, which can grow **up to 60 meters**. Microalgae are highly diverse in their habitats, from freshwater to hypersaline and high-temperature environments, for example, and can grow in autotrophic, heterotrophic or mixotrophic modes. Seaweeds, by contrast, only grow in ocean habitats with narrow salinity and temperature requirements.

Algae have a wide range of application potential in largely different fields including the following:

(i) **human nutrition** and health (pharma, cosmetic, nutraceuticals and foods);
(ii) foods and **feed** production (aquaculture, animal feeding and agriculture);
(iii) **materials** and energy (chemical commodities, bioplastics and biofuels); and
(iv) **bioremediation** (CO2 capture from flue gases, soil regeneration and wastewater treatment).

All these applications and production frameworks not only provide a high potential for algae production, but also entail complex and extensive regulatory frameworks. The above discussions suggest that the boundaries and the **bottlenecks** for innovation in algaculture **can be overcome**, suggesting major advances in this field.

Innovation bottlenecks exist, from the lack of knowledge from basic processes to regulatory issues and that hinders the development and scale-up of new products and processes.

The innovation potential of the algae biomass sector is due to algae being compatible with agriculture and aquaculture and its related industries and services.

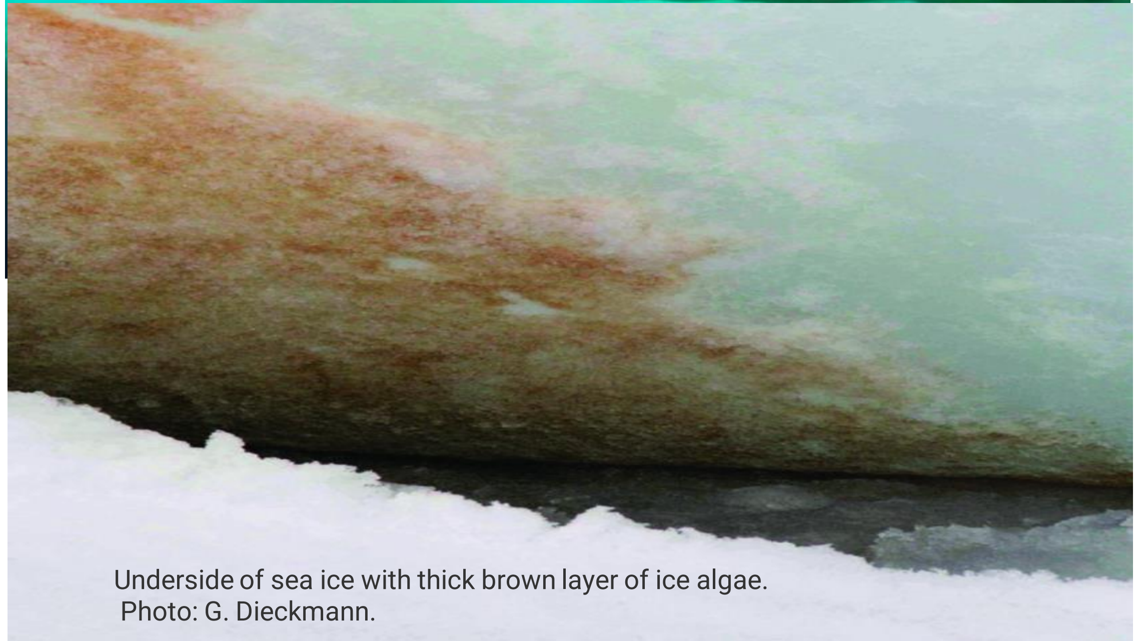
3. How to unlock the existing bottlenecks?

The proposed roadmap for the future

EUROPEAN ALGAE BIOMASS ASSOCIATION

Top 10 most relevant growth factors for the sector	Related impacts
Public awareness about algae biomass	**VERY HIGH** Can generate demand and a consumer driven production
Novel Food approval for new product development	**VERY HIGH** Can generate new products and promote a larger trade portfolio
Unknown approval and regulatory status of many species	**HIGH** The EU Food catalog is outdated and regulatory issues are not clear
Production licencing	**HIGH** Relevant for all algae biomass production, specially for seaweed cultivation.
Technology botlenecks	**HIGH** There are technology related constrains but there are also solutions
Carbon credits for the algae biomass sector	**HIGH** The current carbon credits can provide impact in the sector
Standardization related with Algae Biomass	**MEDIUM** Provide a common framework and allows a more precise exchange
Research, Development and Innovation	**MEDIUM** Generates innovation and promotes more qualified jobs for the industry
Taxes and related trade complexity	**MEDIUM** Import-Export is complex for European products
Unequal and unfair regulations for imported algae	**MEDIUM** Imported algae are not subject to the same constrains as European algae

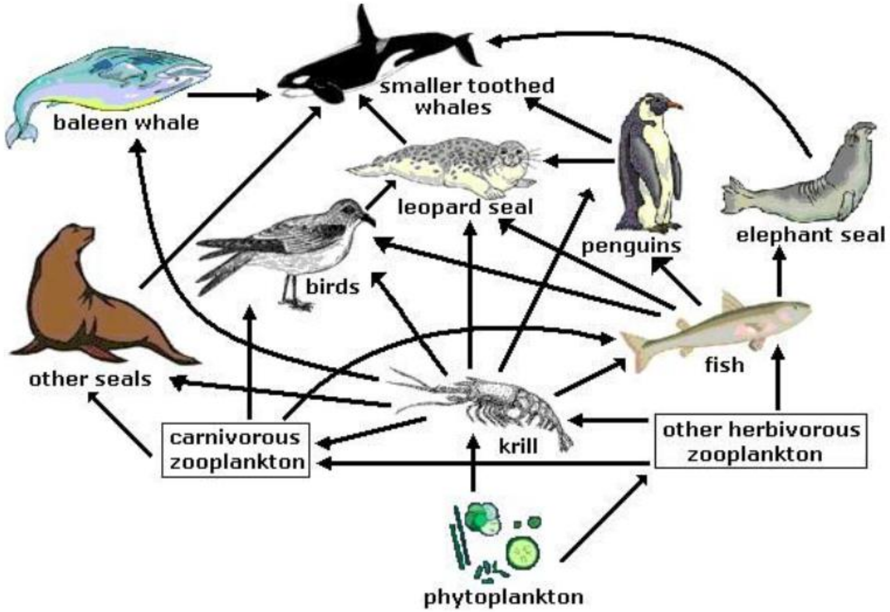
ICE ALGAE

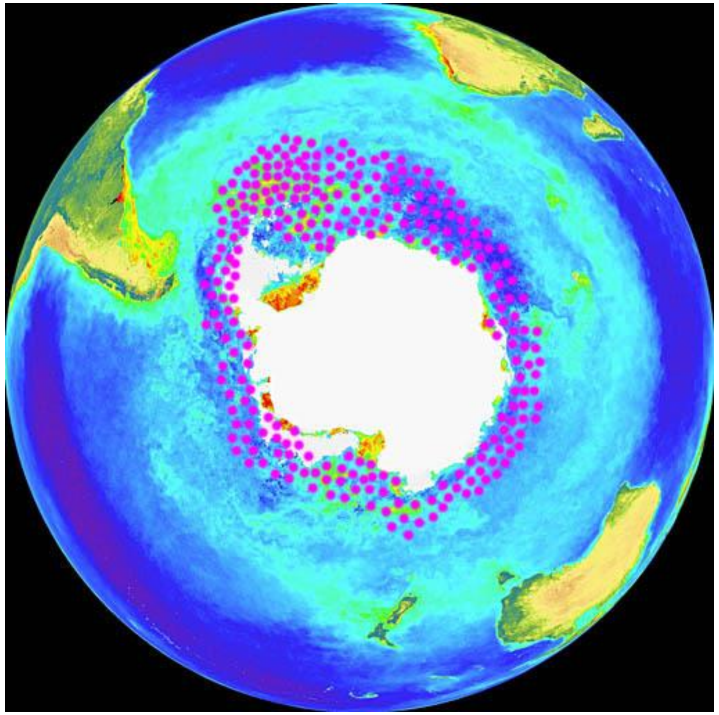


Underside of sea ice with thick brown layer of ice algae.
Photo: G. Dieckmann.

ALGAE THE SOURCE OF OMEGA 3

•source: http://www.ecoscope.com/icecave2.htm





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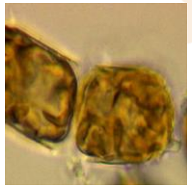
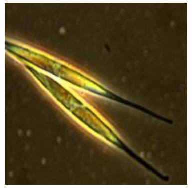
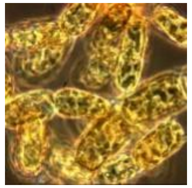
- Excellent **amino-acids** balance
- Highly **digestible** and **hypoallergenic**
- Best quality **unsaturated fatty-acids**
- **Clean** and **sustainable**

- High level of **fatty acids**
- High **productivity** / m^2
- High level of **control of quality**
- European **relocation**







- Low **GHG** emission
- Incredible **biodiversity**
- **No competition** with agro-land
- Low **water** consumption

SUSTAINABLE DEVELOPMENT GOALS

2 ZERO HUNGER | 3 GOOD HEALTH AND WELL-BEING | 12 RESPONSIBLE CONSUMPTION AND PRODUCTION | 13 CLIMATE ACTION | 14 LIFE BELOW WATER

ALGAMA TODAY

An expert Team in Food and Biotechnology dedicated to harnessing the potential of algae in the food industry

25 PATENTS ACROSS 31 COUNTRIES	11.5 M€ RAISED
30 PEOPLE	PARIS HEADQUARTERS
70% R&D EMPLOYEES	OFFICES IN NYC (USA) AND AVIGNON (SOUTH OF FRANCE)
4 ACTIVE SPIN-OFF	3 PRODUCTS ALREADY LAUNCHED

Algae Technologies

Algae Ingredients

Consumer Products

2 European Grants
1 National Grant
2 Regional Grants

SUSTAINABLE DEVELOPMENT GOALS
2 ZERO HUNGER
3 GOOD HEALTH AND WELL-BEING
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION
14 LIFE BELOW WATER

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SUCCESSFUL BUSINESS CASE

Development of the first vegan mayonnaise brand available in supermarkets

The Good Spoon : Algama's Spin-off commercializing the mayonnaise

TAMALGA™ Dressing

INGREDIENT
Egg-replacer

ALGAMA

THE GOOD SPOON™

PRODUCT CONCEPT
THE GOOD SPOON

the GOOD SPOON

- *60% less fat and calories*
- *Plant-Based*
- *Non-GMO*
- *No preservatives*
- *No cholesterol*
- *Soy-free*
- *Gluten-free*
- *4 Flavors on the market*

Auchan MONOPRIX amazon
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EUROPEAN ALGAE
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10 YEARS

The European Algae Biomass Association

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EUROPEAN ALGAE
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10 YEARS

EABA – European Algae Biomass Association
Viale Belfiore, 10 – 50144 Florence, Italy

Established in Florence on june 2009, EABA is the European association representing both research and industry in the field of algal technologies.

www.eaba-association.org
www.algaeworkshops.org
www.algaeurope.org
www.what-are-algae.com

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EUROPEAN ALGAE BIOMASS ASSOCIATION

BENEFIT OF BECOMING A MEMBER

01 Influence the future of the sector with **specific positions** and contributions

02 Opportunities to participate on **EABA committees** and EABA policy initiatives

03 Access **unique network** to disseminate, scientific, industrial and commercial news

04 **Visibility** through the EABA of relevant news and advances by your organization

05 Access to EABA's members-only **reports**, presentations, publications

06 Inputs and participation in the development of well **technical standards**

07 **Networking with members** to develop joint projects, proposals,...

08 Opportunity to participate in **on-going EABA educational activities**

09 Obtaining to **regular updates** on developments via member alerts and newsletter

10 **Reduced fees for EABA activities** and events, and those promoted by affiliated partners

Europe has a long tradition in algae knowledge development and innovation with European companies in the forefront of practical applications of algae for novel foods and feeds, biofuels and chemicals, specialty bioproducts and environmental services.

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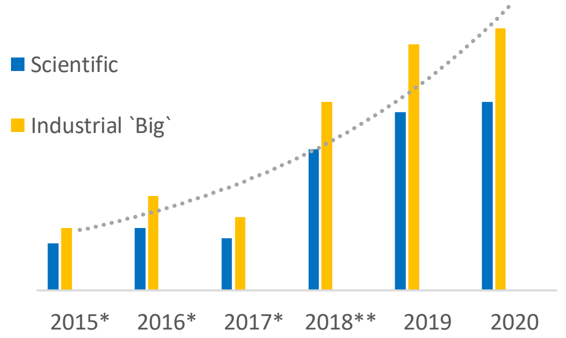

EABA Full Members History 2015-2020 (Dec 31, 2020)

EUROPEAN ALGAE
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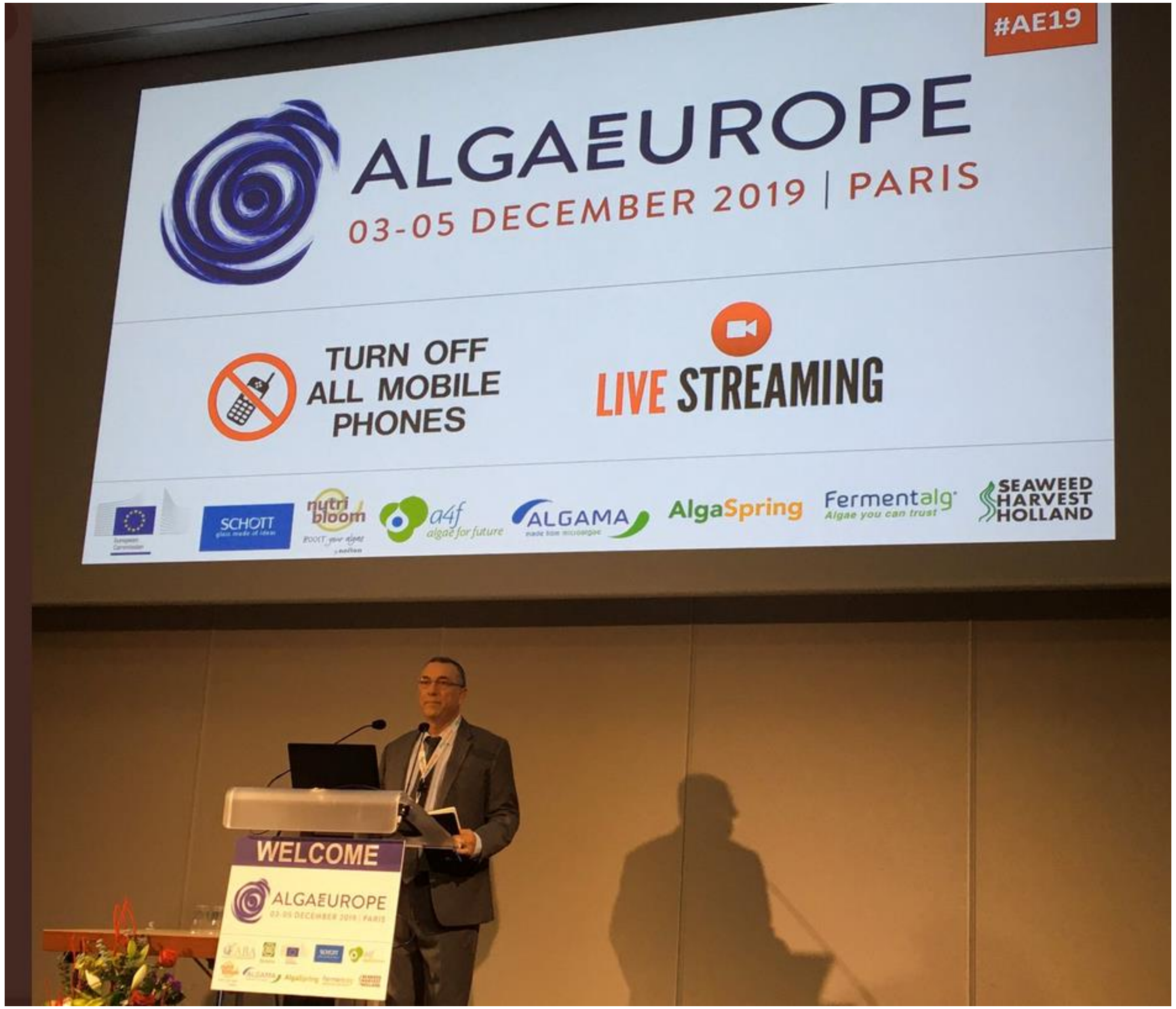
10 YEARS

AN ANNUAL CONFERENCE



Thank you!

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