Demonstration of Innovative Functional food production systems based on more sustainable value chains of marine and freshwater raw materials for conscientious EU consumers

NOVAFOODIES

2.0 Processing techniques of marine and algae products in the context of sustainability

2.1 Integration of sustainability in processing of aquaculture products

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This project has received funding from the European Union under Grant Agreement N° 101084180.

Main objective

- Learn innovative processing techniques of algal biomass and products and understand their ecological background

Learning outcomes

- Understand relevant sustainability aspects when processing algal biomass and products
- Describe processing techniques that emphasize sustainable approaches
- Learn best practice examples of the described techniques

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Agenda

- Algae processing
- Processing techniques
  - Algae drying
  - Biorefineries
  - Algae fermentation
  - Hydrothermal Liquefaction for microalgae
  - Ultrasound-assisted extraction
  - Algae-based packaging material
- Group exercise – “Company factsheets”

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Algae processing

Cultivation

- Harvesting (macro algae)
- Photobioreactors
- Open ponds
- Semi Open ponds
- Land-based or sea-based Aquaculture
- IMTA

Harvesting

- Microalgae (flocculation, centrifugation, filtration, sedimentation
- Macroalgae (manual or mechanical, rinsing)

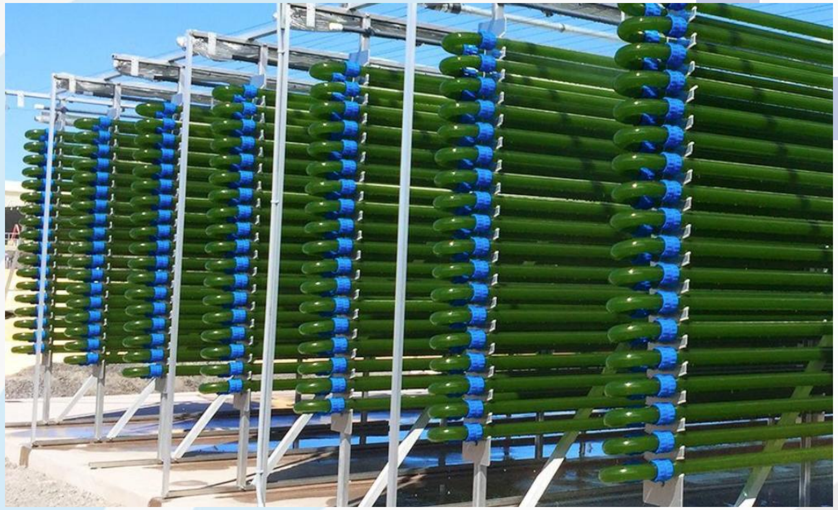
https://www.aquaculturescience.org/browse-by-species/seaweed/

Dewatering & Drying

- Centrifugation or pressing
- Different drying techniques

Further procedures depending on end use

- Cell disruption (e.g. PEF, UAE, etc.)
- Extraction of valuable compounds
- Purification and refining



https://freshbydesign.com.au/aquaponic-aquaculture-products/algae-systems/varicon-aqua-algal-photobioreactors-2/

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Sustainable processing techniques of algae

Algae Drying:
- Preservation of biomass and active ingredients.
- Usage of renewable energy simple and cost effective

Biorefinery processes:
- High-tech facilities to produce value-added chemical compounds or energy.
- Transformation of biomass, increasing resource utilization.

Fermentation:
- Converts algae biomass using microbial activity.
- Process also produces renewable energy, waste biomass valorization possible.

Hydrothermal Liquefaction:
- Converts wet biomass to bio-crude oil.
- No drying needed, reduces energy consumption, lowers emissions.

Ultrasound-Assisted Extraction:
- Uses ultrasonic waves for compound extraction.
- Reduces chemical solvents, lowers energy use.

Algae-Polymer Blending:
- Uses algae and other bio-resources to create fossil-free plastics.
- Reduced emissions in comparison to conventional plastics.

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Algae drying

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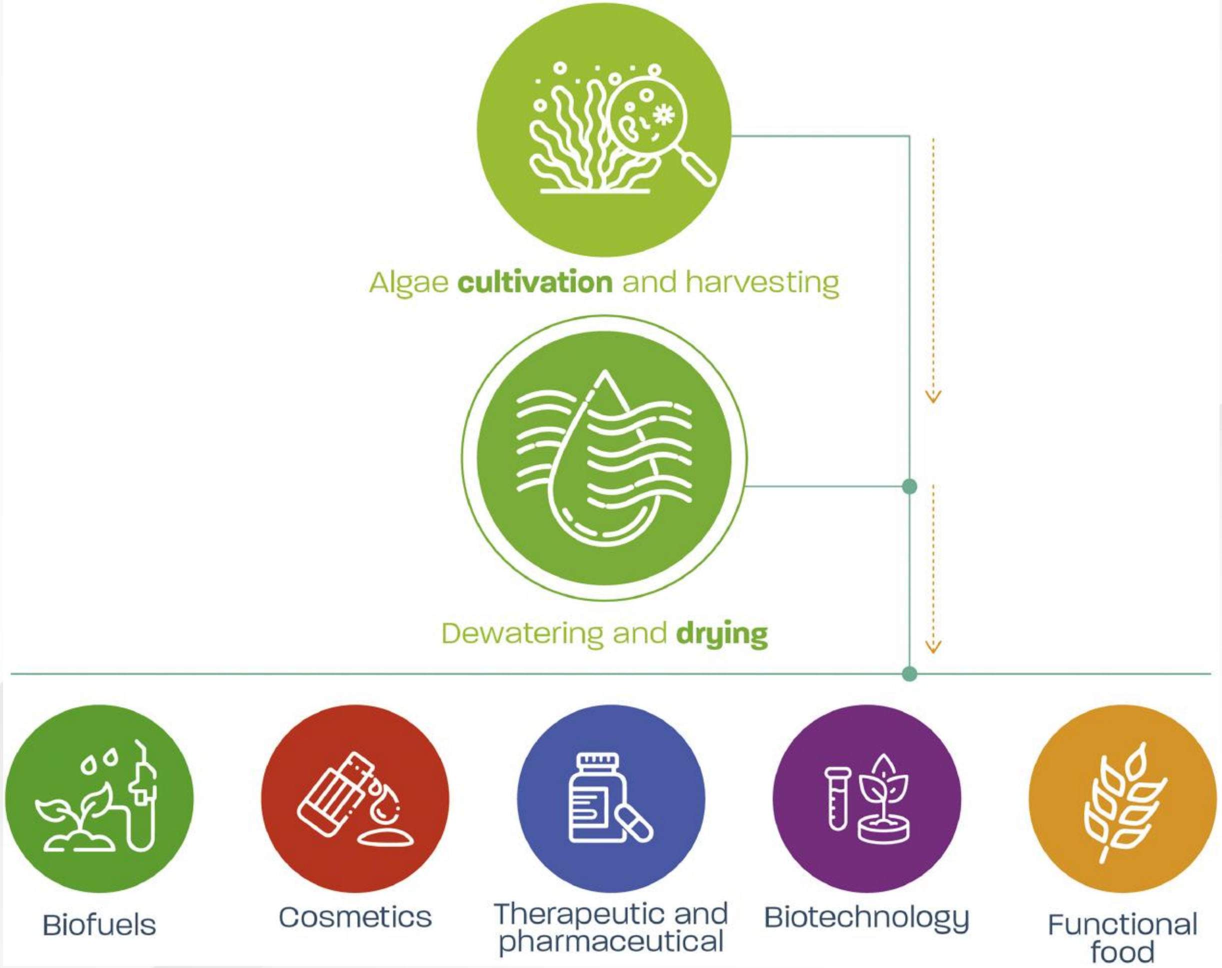
Algae drying process

- Preserve quality of algae with suitable methods
- Due to less water content:
  - Higher stability and longer shelf life (easier transport and storage)
  - Higher stability and preservation of bioactive compounds
- Dried microalgae allow further processing into powders, extracts or other formulations for use in food, cosmetics or biotechnological activities



(Hernández et al., 2024)

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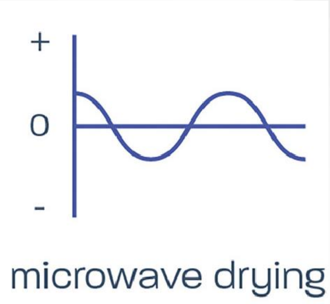
Different drying techniques



(Hernández et al., 2024)

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Microwave-assisted drying – Sevilla, Spain

- Idener Research & Development AIE
- Combination with with vacuum (microalgae) and adsorption drying (macroalgae)
- *In the video on the left microalgae drying is shown.*

Key facts

System	Processed species	Video
Microwave -assisted drying	*Chlorella vulgaris* *Schizochytrium* S31	idener.ai

Left: microwave oven for microalgae drying
Right: microwave oven for macroalgae drying
Idener.ai

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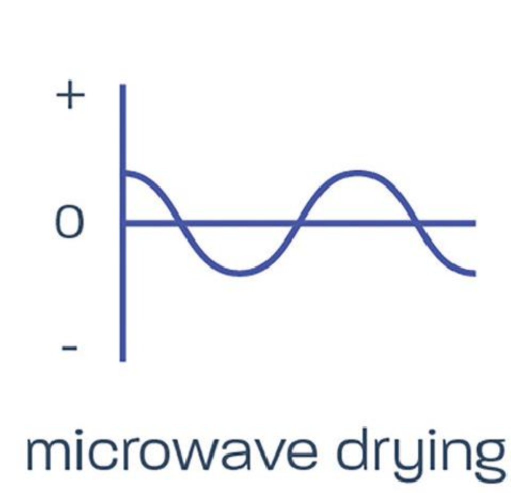
Why microwave-assisted drying?

- Acceleration of the dehydration procedure (shorter drying duration)
- Reduction of heat exposure
- Uniform and volumetric heating
- No use of chemicals or additional substances
- Conservation of bioactive compounds
- Maintaining nutritional value
- Enhancing lipid extraction efficiency
- Energy conservation and increased efficacy compared to other traditional techniques



(Hernández et al., 2024)

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Biorefinery processes

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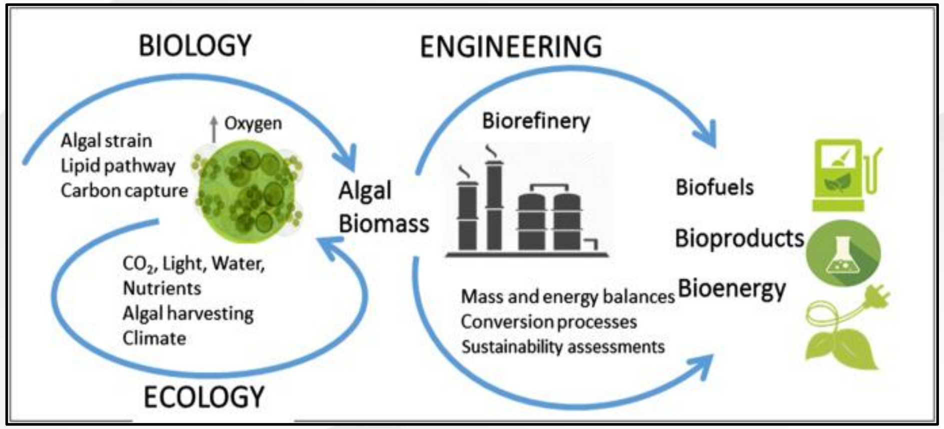
Algae Biorefineries

- Sustainable transformation of biomass into biofuels or energy along with high-value co-products, minimising waste and increasing revenue

- Algae is processed through:
  - Harvesting and drying (centrifuge, sedimentation, flocculation, etc.)
  - Extraction (solid shear, bead milling, cavitation and collapse, pulse electric field, chemical hydrolysis, etc.)
  - Conversion (gasification, pyrolysis, thermal liquefaction, anaerobic digestion, alcoholic fermentation, transesterification, etc.



Allen et al. (2018)

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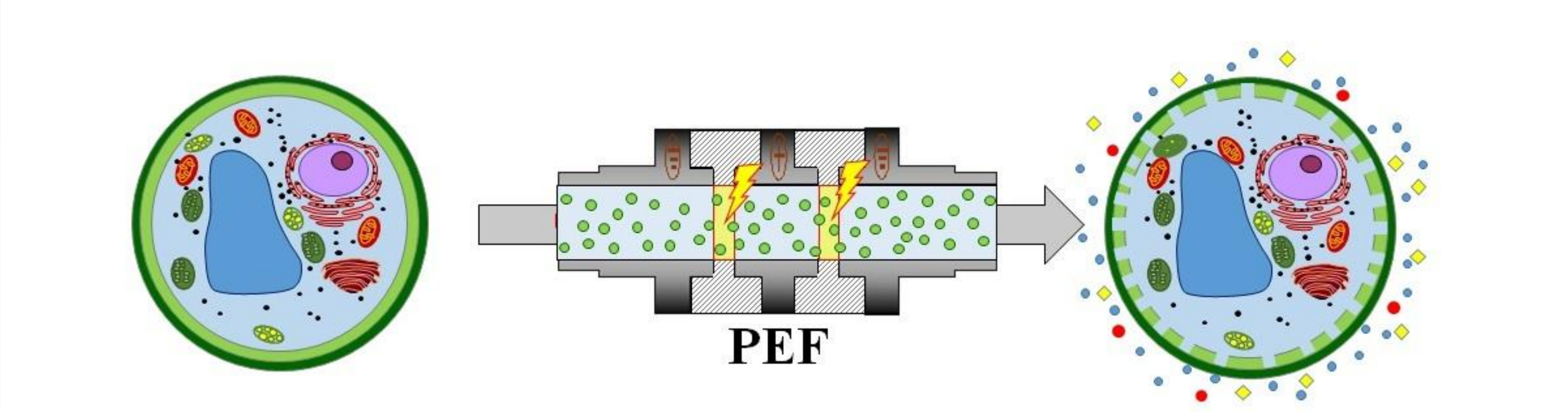
Example: Biorefinery Extraction - Pulse Electric Field (PEF)

- Wet microalgae biomass is exposed to short bursts of high-voltage electric fields, creating pores in the cell membranes. This enhances the release of intracellular products such as proteins, pigments, and carbohydrates, without extensive cell debris or thermal degradation.
- PEF is clean and energy efficient (little heating, no need for drying or solvents).
- PEF systems are becoming more efficient and cost-effective, scaled-up application is expected for the future.



Carullo et al. (2022)

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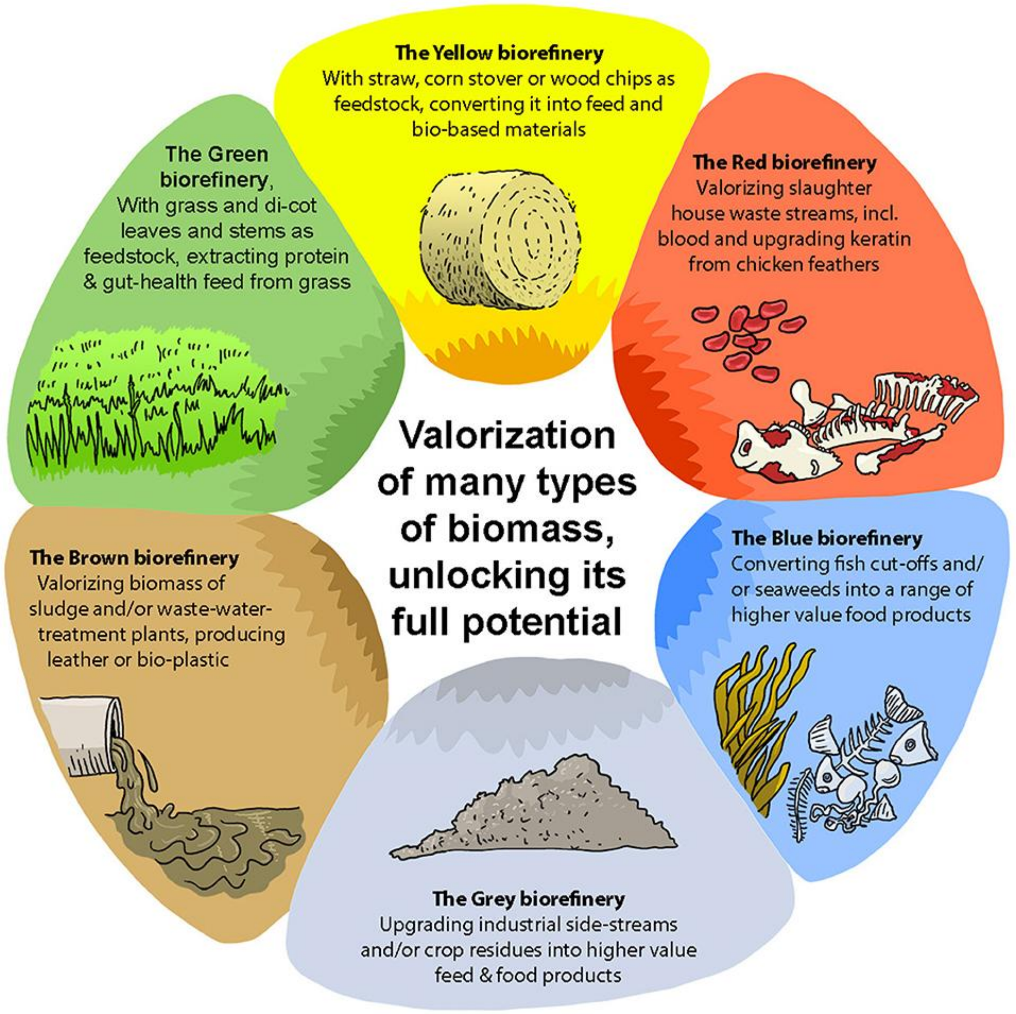
(Algae) Biorefineries

- For now:
  Production of biofuels not economically viable, extraction of co-products is necessary
- Regardless which way algae is processed, factors such as process efficiency or energy input need to be weighed carefully.
- High-value co-products must be generated to improve the economics of microalgae biorefineries.



Lange (2022)

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Biorefinery processes – Benefits and Challenges

Benefits

- Cultivation of seaweed itself contributes to a lower total environmental impact (CO2 sequestration)
- Reduced strain on fertile and arable land and high growth rate
- Extraction of a large variety of chemical building blocks (fats, carbohydrates, proteins, etc.)
- Wastewater treatment (suitable for non-food products)

Challenges

- Intense energy consumption (electricity for drying, fermentation, hydrolysis)
  → high production cost
- Technologically very complex
- Market competition (fossil fuels)
- Seaweed farms are still dependent on fossil fuels for maintenance and harvest
- Offshore farms are plagued by high maintenance costs and demanding working conditions

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Algae fermentation

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Fermentation – Bacterial-based process to increase nutritional value

- Through bacterial-based **enzymatic** decomposition
  - Bacteria grow on algae, which serves as energy and carbon source
- Fermentation method → Bioreactor

- To improve

→ digestibility and nutritional value of algae *(Ulvan, laminarin, starch, …)*
- protein digestibility → through raised hydrolysis yields
- polysaccharide decomposition → degraded cell-wall
- for human and animals (e.g. fish)

→ easier extraction and modification of compounds

… for further use in human nutrition or aquafeeds

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Hydrothermal Liquefaction for Microalgae

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Hydrothermal Liquefaction for Microalgae I

- **Hydrothermal Liquefaction** (HTL) is a thermochemical process that converts wet biomass under high pressure (10 and 25 MPa) and moderate temperature (250°C and 375°C).
- Algae serves as feedstock for the production of liquid **hydrocarbon fuel precursors** (bio-crude) or gaseous products.
- Main sustainability benefits: **drying step** can be skipped

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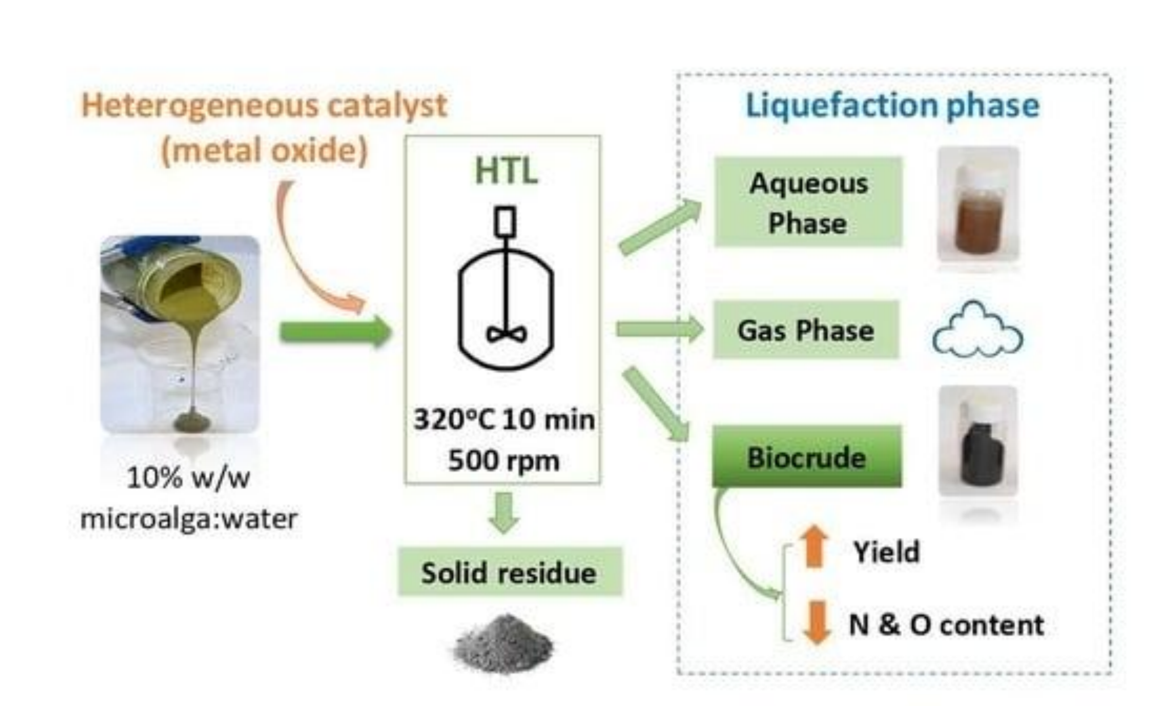
Hydrothermal Liquefaction for Microalgae II

- Co-solvents (such as isopropyl alcohol) or catalysts (metal oxides) can increase the yield
- However, this also alters the emission profile of the process
- HTL is particularly promising for wastewater algae, since food uses are not possible with this method



(Sánchez-Bayo et al., 2019)

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Ultrasound-Assisted Extraction

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Ultrasound-Assisted Extraction overview

- Ultrasound-Assisted Extraction (UAE) is a technique that uses ultrasonic waves (between 20 kHz and 2 MHz) to disrupt cell walls and enhance the extraction of valuable compounds from microalgae.
- It improves extraction efficiency and the yield of intracellular products such as lipids, proteins, and pigments from microalgae.
- Ultrasonic waves generate cavitation bubbles in the solvent, which collapse and create localized high-pressure and high-temperature conditions. This disrupts cell walls and facilitates the release of intracellular compounds.
- Ultrasound can also be applied in cultivation, improving cell growth rate.

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Algae based packaging material

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Algae based packaging material overview

- There are multiple research-groups and companies working on algae and seaweed-based packaging materials, such as biodegradable plastic, for more sustainable alternatives.

- Advantages
  - Reducing environmental impact; lower carbon footprint than fossil sources
  - Contingent biodegradability (conventional plastic is not biodegradable)
  - Fast-growing resource, growing in sea- and freshwater
  - Is inert and algae contain valuable sources of fibers and minerals, which makes it attractive for edible packaging

- Disadvantages and challenges (problems with processing, costs, ..)
  - Higher costs
  - Durability; less durable than petroleum-based plastic
  - Degradability depends on specific formula → not always home compostable

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Macroalgae-based packaging boxes - Bremerhaven, Germany

- Alfred Wegner Institute and pulp-tec
- Addition of starch and chalk (binding and filling)
- Pellets can be used to improve packaging matrix
- Moisture content is relevant
- Seaweed mixed with pulp
- No extraction step required!


Dried *Ulva*


Ground *Ulva*


Finely ground *Ulva*


Ulva pellets


Packaging prototype

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Group exercise – company factsheets

Find an algae producer (EU or worldwide) online and become familiar with the business.

- Form groups of 4 to 5 participants.
- Together, prepare a short factsheet about the producer. You can answer the following questions in your factsheet:
  - What algae are used?
  - What type of algae cultivation is used?
  - What products are produced?
  - What stage is the business in?
  - Are there any special claims for sustainability?

- Afterwards: One person per group gives a short summary of the factsheet

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Time for your presentations!

You could also answer any of these questions:

- In your opinion, how could the production become more sustainable?
- Is the business case viable?
- Is there anything that you found particularly interesting?

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Literature

- Allen, J., Unlu, S., Demirel, Y., Black, P., & Riekhof, W. (2018). Integration of biology, ecology and engineering for sustainable algal-based biofuel and bioproduct biorefinery. Bioresources and Bioprocessing, 5(1). https://doi.org/10.1186/s40643-018-0233-5
- Carullo, D., Abera, B. D., Scognamiglio, M., Donsì, F., Ferrari, G., & Pataro, G. (2022). Application of Pulsed Electric Fields and High-Pressure Homogenization in Biorefinery Cascade of C. vulgaris Microalgae. Foods, 11(3), 471. https://doi.org/10.3390/foods11030471
- Chandra, R., Iqbal, H. M., Vishal, G., Lee, H., & Nagra, S. (2019). Algal biorefinery: A sustainable approach to valorize algal-based biomass towards multiple product recovery. Bioresource Technology, 278, 346–359. https://doi.org/10.1016/j.biortech.2019.01.104
- Han, Y., Hoekman, S. K., Cui, Z., Jena, U., & Das, P. (2019). Hydrothermal liquefaction of marine microalgae biomass using co-solvents. Algal Research, 38, 101421. https://doi.org/10.1016/j.algal.2019.101421
- Hernández A, González-Moya M., Márquez A., Acevedo L. (2024). Review microalgae drying: A comprehensive exploration from conventional air drying to microwave drying methods. Future Foods, 10(2024). https://doi.org/10.1016/j.fufo.2024.100420
- Imran, M., Poduval, P. B., & Ghadi, S. C. (2016). Bacterial degradation of algal polysaccharides in marine ecosystem. In Springer eBooks (pp. 189–203). https://doi.org/10.1007/978-981-10-1044-6_12
- Lange, L. (2022). Business models, including higher value products for the new circular, Resource-Efficient biobased industry. *Frontiers in Sustainability*, *3*. https://doi.org/10.3389/frsus.2022.789435
- Naaz, F., Samuchiwal, S., Dalvi, V., Bhattacharya, A., Pant, K. K., & Malik, A. (2023). Hydrothermal liquefaction could be a sustainable approach for valorization of wastewater grown algal biomass into cleaner fuel. *Energy Conversion and Management*, *283*, 116887. https://doi.org/10.1016/j.enconman.2023.116887
- Pantis A., Nikoloudakis C., Tsoutsos T. (2024). A Critical Review of Macroalgae Exploitation Pathways Implemented under the Scope of Life Cycle Assessment. ChemEngineering, 8, 74. https://doi.org/10.3390/chemengineering8040074
- *Reisky et al. (2019), A marine bacterial enzymatic cascade degrades the algal polysaccharide ulvan. https://www.nature.com/articles/s41589-019-0311-9*
- Sánchez-Bayo, A., Rodríguez, R., Morales, V., Nasirian, N., Bautista, L. F., & Vicente, G. (2019). Hydrothermal liquefaction of microalga using metal oxide catalyst. *Processes*, *8*(1), 15. https://doi.org/10.3390/pr8010015
- Santhoshkumar P., Yoha K.S., Moses J.A. (2023). Drying of Seaweed: Approaches, challenges and research needs. Trends in Food Science & Technology, 138, 153-163. https://doi.org/10.1016/j.tifs.2023.06.008
- Tabernero, A., González-Garcinuño, Á., & Del Valle, E. M. (2024). Ultrasound-assisted steps for producing biodiesel from microalgae. *Current Research in Biotechnology*, *8*, 100251. https://doi.org/10.1016/j.crbiot.2024.100251
- Wang, H., & Zhu, B. (2024). Directed preparation of algal oligosaccharides with specific structures by algal polysaccharide degrading enzymes. International Journal of Biological Macromolecules, 277, 134093. https://doi.org/10.1016/j.ijbiomac.2024.134093

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Further reading

- Araújo R, Vázquez Calderón F, Sánchez López J, Azevedo IC, Bruhn A, Fluch S, Garcia Tasende M, Ghaderiardakani F, Ilmjärv T, Laurans M, Mac Monagail M, Mangini S, Peteiro C, Rebours C, Stefansson T and Ullmann J (2021) Current Status of the Algae Production Industry in Europe: An Emerging Sector of the Blue Bioeconomy. *Front. Mar. Sci.* 7:626389. doi: 10.3389/fmars.2020.626389 https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2020.626389/full
- Kuech, A., Breuer, M., Popescu, I., 2023, Research for PECH Committee – The future of the EU algae sector, European Parliament, Policy Department for Structural and Cohesion Policies, Brussels https://www.europarl.europa.eu/RegData/etudes/STUD/2023/733114/IPOL_STU(2023)733114_EN.pdf

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Thank you very much for your attention!

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