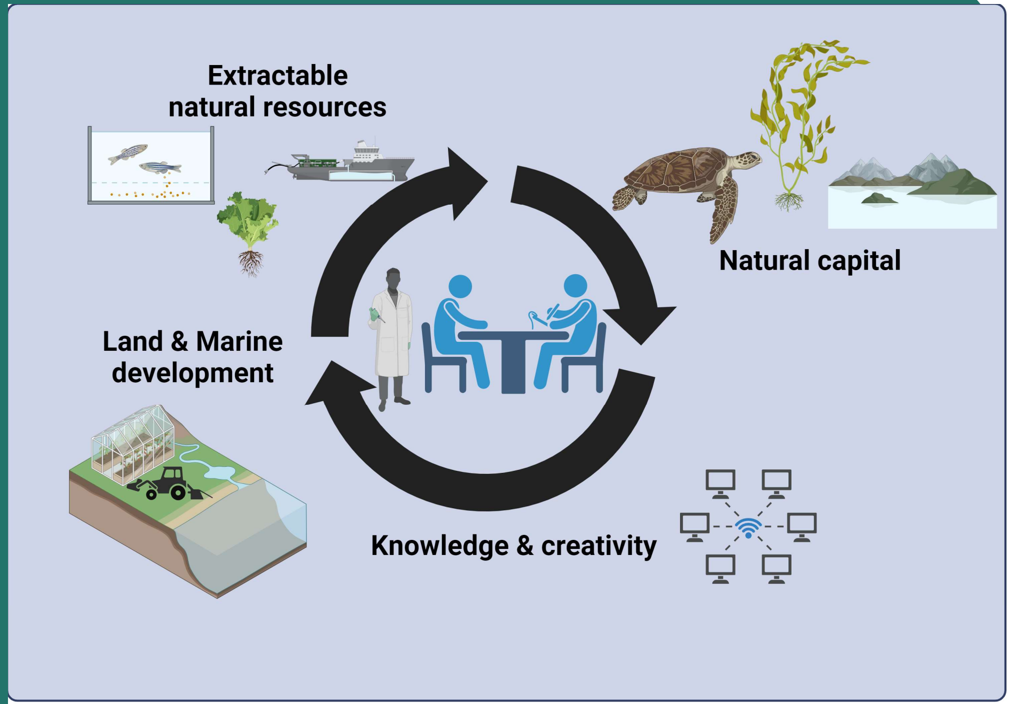



# Role of Marine Biopolymers in Circular Bioeconomy


*Dr. Anna Trubetskaya*


*July 12th, 2024*

# Career

*Research interests:* nanocellulose, thin films, bioactives, green chemistry, circular processes & manufacturing, sustainable pharmaceuticals

A total **79** articles since 2016 were published: First Author papers: **52**; Corresponding Author: Q1=**39**; Google Scholar Stats: **1770** Citations; H-index: **25**

2022 **-** Assoc. Professor, *Nord University,* Department of Biosciences, Norway
2019 **-** Adjunct Lecturer, *University of Limerick*, Ireland
2022 - Product manager, *Valmet Technologies*, Finland
2021- 2022 - PI / Research fellow**,** *Aalto University*, Finland
2019 – Visiting researcher, *MIT Chemical Engineering*, USA
2018 - 2021 - Research fellow (SFI individual award), *University of Limerick*, Ireland
2016 - 2018 - Postdoctoral researcher (Kempe award), *Umeå University*, Sweden

**MBA** (Operations management & Marketing), Warwick Business School (**2025**)
**Post**graduate certification (Climate Entrepreneuership), *Trinity College Dublin* (**2021**)
**Ph.D. (Chemical Engineering),***Technical University of Denmark* (**2016**)
❖Exchange year at TU Munich (Prof. Dr.-Ing. Hartmut Spliethoff)
**Master of Sciences in Engineering,** *University of Kassel*, Germany (**2011**)
❖ Exchange year at University of New Hampshire, USA,1-year UNH CEPS scholarship (50k USD)
**Dipl.-Ing (FH) in Biotechnology & Process Engineering,** *Hochschule Flensburg*, Germany (**2009**)
❖ Exchange year at BGB analytics (green analytical chemistry), USA (Ingo Christ & Dr. Vivian Watts)

# Nord University



- Established in 2016: University of Nordland (est. 2011), Nesna University College (est. 1994), and Nord-Trøndelag University College (est. 1994)
- Strategy: blue and green growth, innovation and entrepreneurship, and welfare, health and education
- Biosciences and Aquaculture (FBA), Business school, Education, and Health & Pharmacology

## Nord University

Aquaculture

Ecology

Animals & Veterinary sciences

Genomics

Microbiology

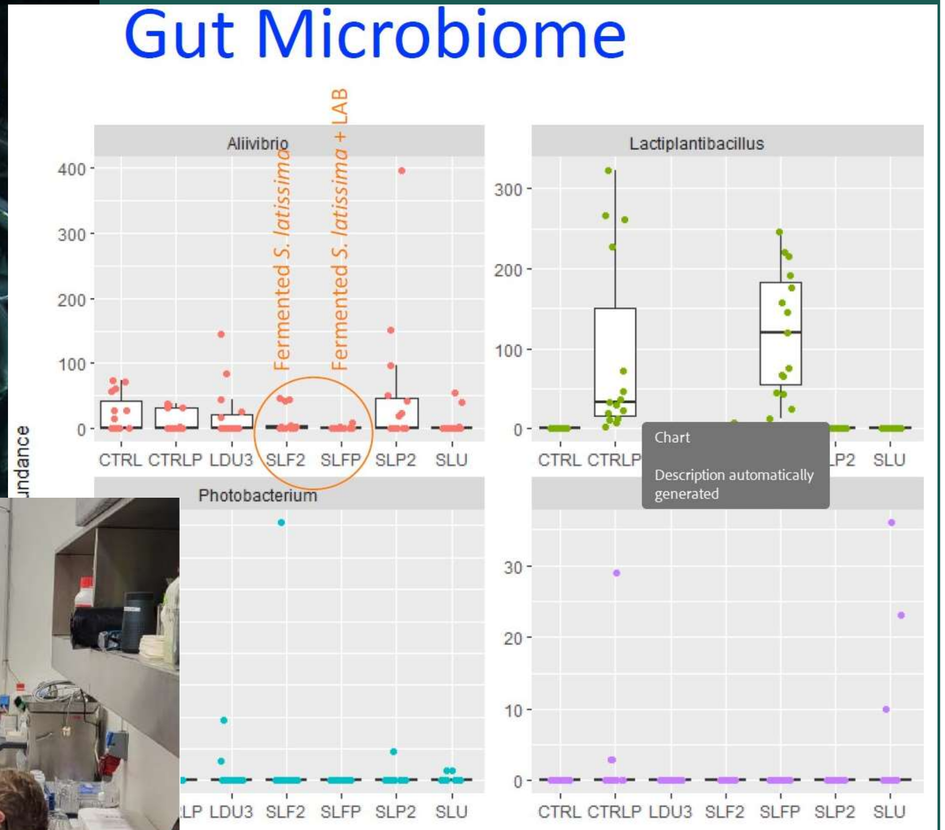
# Research stations

Mørkvedbukta

Mære agricultural school

Norwegian Institute of Bioeconomy (NIBIO) & biorefinery

# Alternative Aquafeeds





Fermented seaweed might be:

- Nutrient rich feed
- Anti-microbial agent

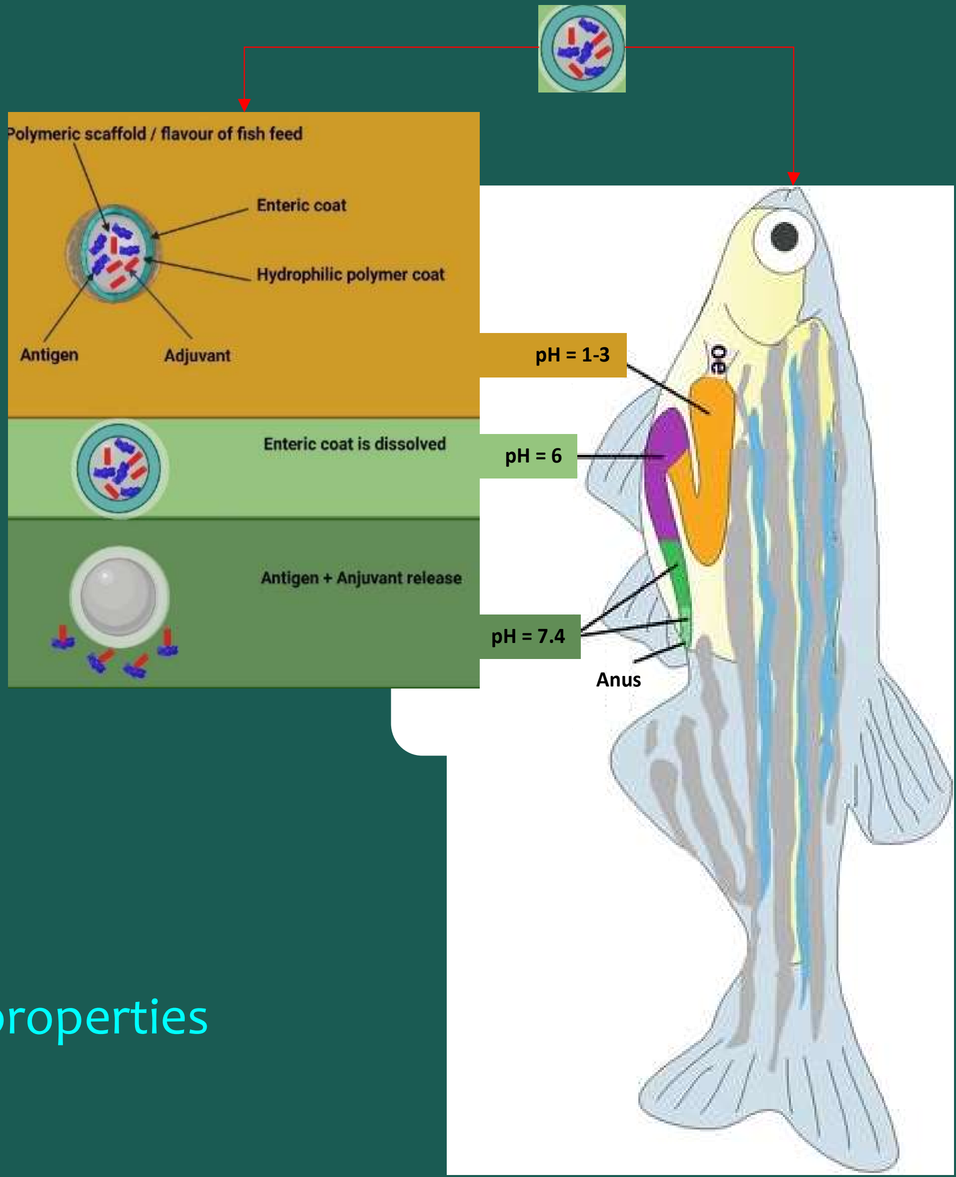
# Sustainable drug carriers in aquaculture

- Several research centers in Nordland & Trondelag districts on salmon & cod fish

- Chemical modification of methylcellulose & preparation as a drug carrier in combination with other cellulose types

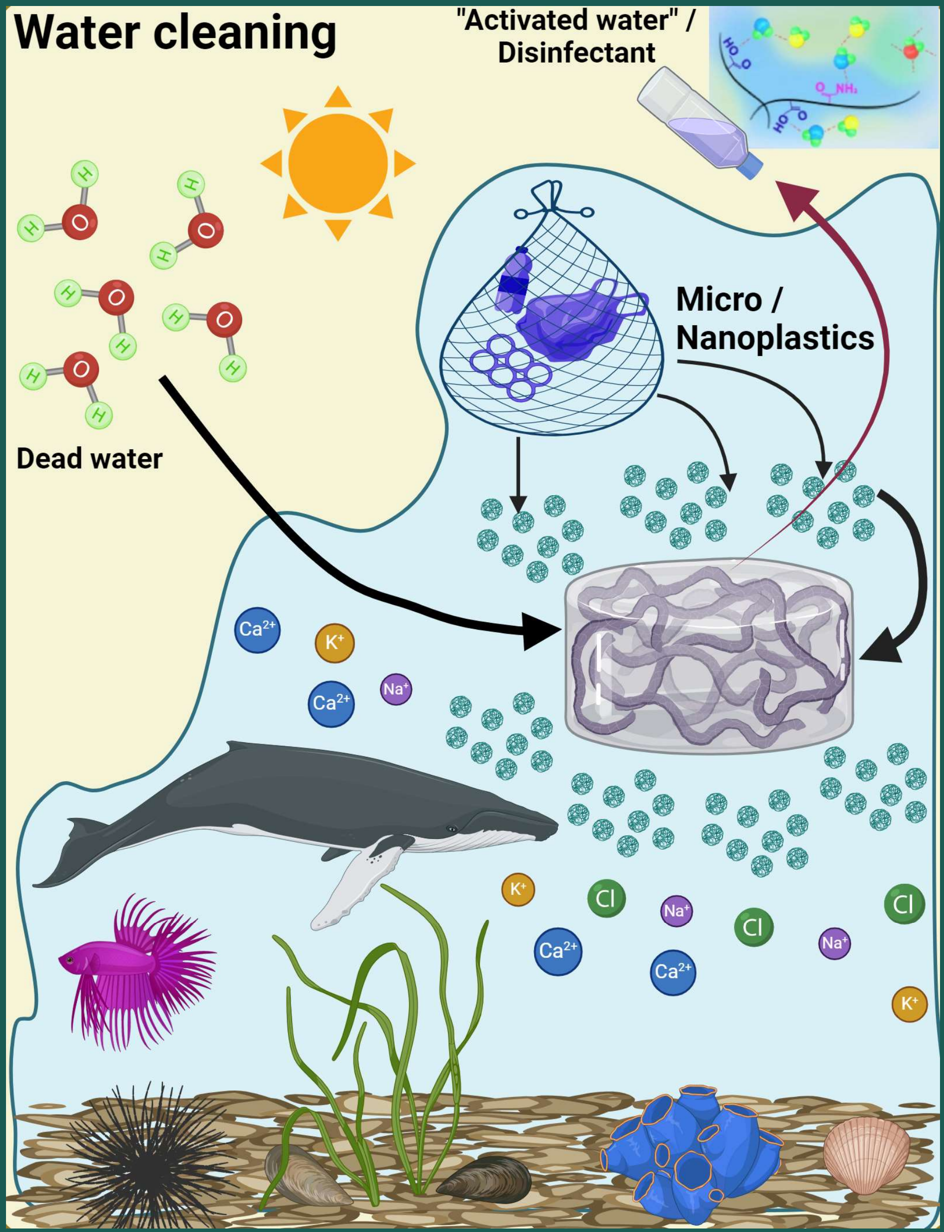
- Prevention of drug injections

- Challenging concerning the cellulose properties optimization

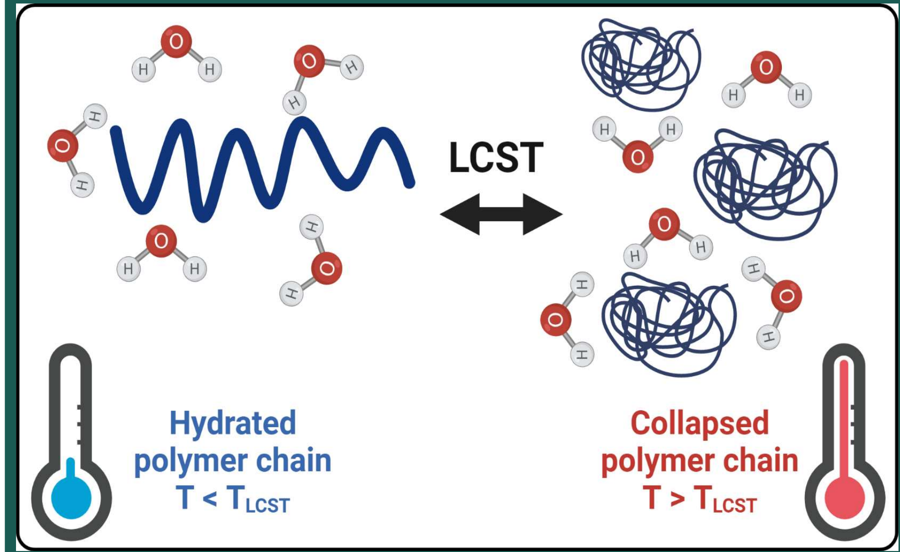


## Sustainable disinfectant

- Bio-based hydrogels using marine plant and animal-based resources
- Balancing the required water quality in aquaculture ponds
- Optimized in Nordland region, but no research has been done in South and Central Norway
- Nanoplastic / microplastic can be also removed from the ocean, but we have not started

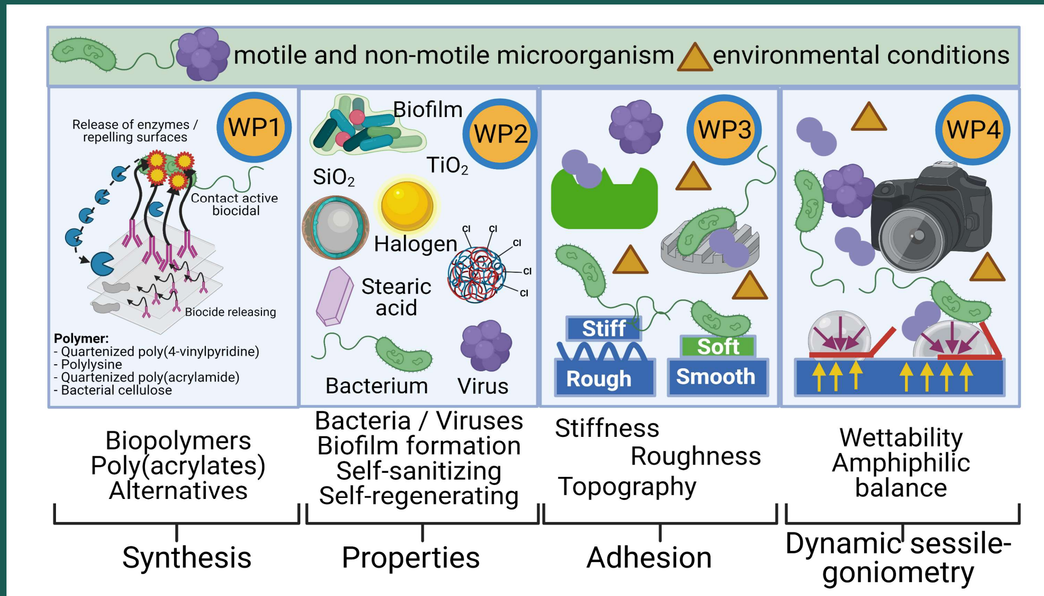


# Nanocellulose materials in biomedical sciences



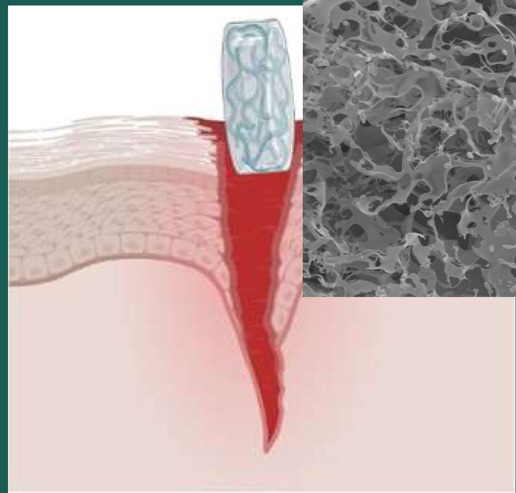

- Methylcelluloses (commercial Dow chemicals) and chemical modification to be used as a hydrogel / aerogel and further development as a part of in vivo models (neurogenesis, eye diseases)
- Chemical protocols development for the chemical structure characterization
- Can they be used in a smart way with various cells using other bio-based materials?

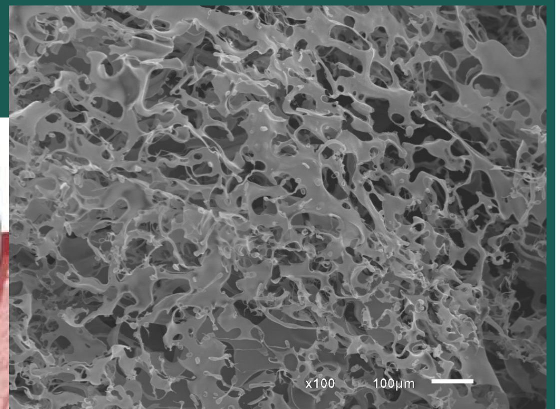
- Antibacterial coatings using nanocellulose with sufficient surface properties to regenerate on various substrates
- Characterization of properties
- Optimization for various bacteria / viruses
- The multilayer solution is the most visible way



# Bio-based patches

- Deep wounds on animal skin is not simple to treat
- There are synthetic material-based bandages (low cost & well sticking)
- Bio-based alternative patches can be considered
- Alginates & collagen are already a part of patches
- Policies & legislations





# Seaweed biopolymers in material sciences

- Cultivation of microalgae *Nannochloropsis oceanica* and *Tetraselmis sp* is mostly for the extraction of bioactive and use as animal feed at the Nord University

- *Ascophyllum nodosum & Saccharina latissimi* for nanocellulose, protein, & bioactive

- *Residual Ascophyllum nodosum* can be found on the Atlantic coast or lakes/rivers surrounding as semi-fermented material

- The residual seaweed can be further fermented/composted to be used in medicine, agriculture, and fish feed

# Manufacturing – Supply Chain Management – Industry 4.0 and AI

- Statistical Process Control
  - Multivariate capability analysis
  - Multivariate control charts
- Statistical Model Building (regression and classification)
  - Data Mining – dimensionality reduction
  - DOE – multivariate optimization

Training data

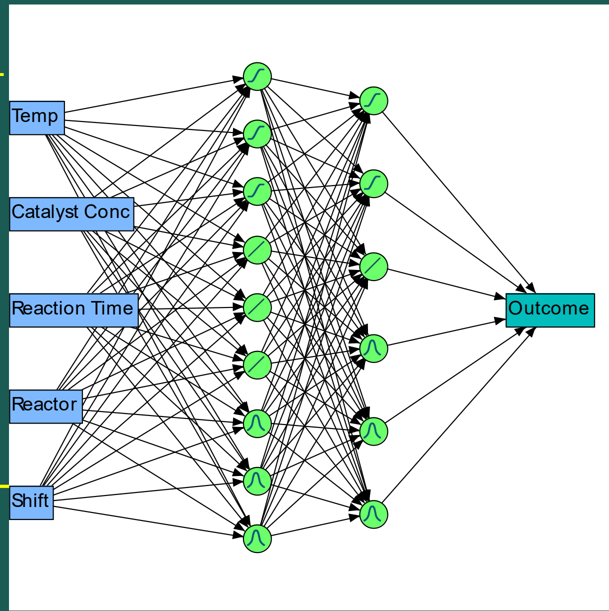
used to **train** the model

Validation data

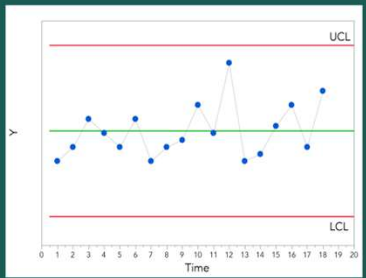
used to **select** the model

Test data

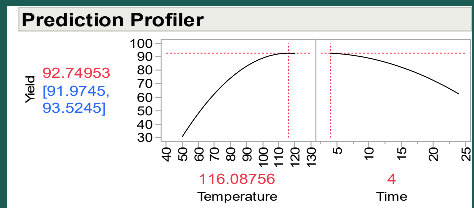
used to **evaluate** the model



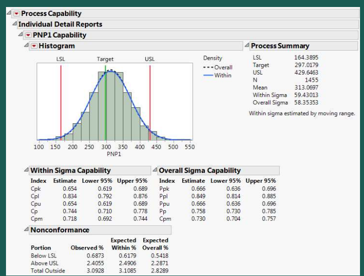

## Control charts



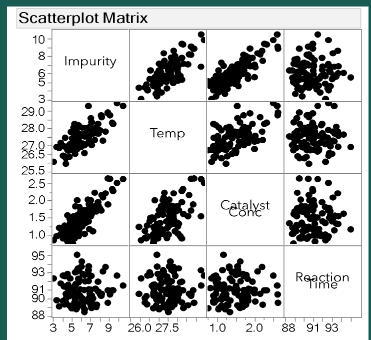

## Design of experiments



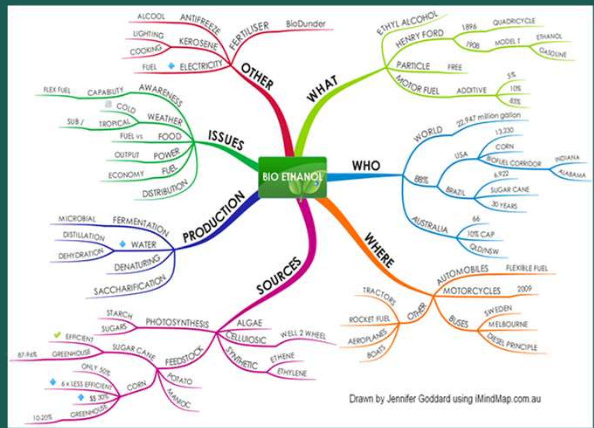

## Capability analysis




## Principle component analysis (PCA)

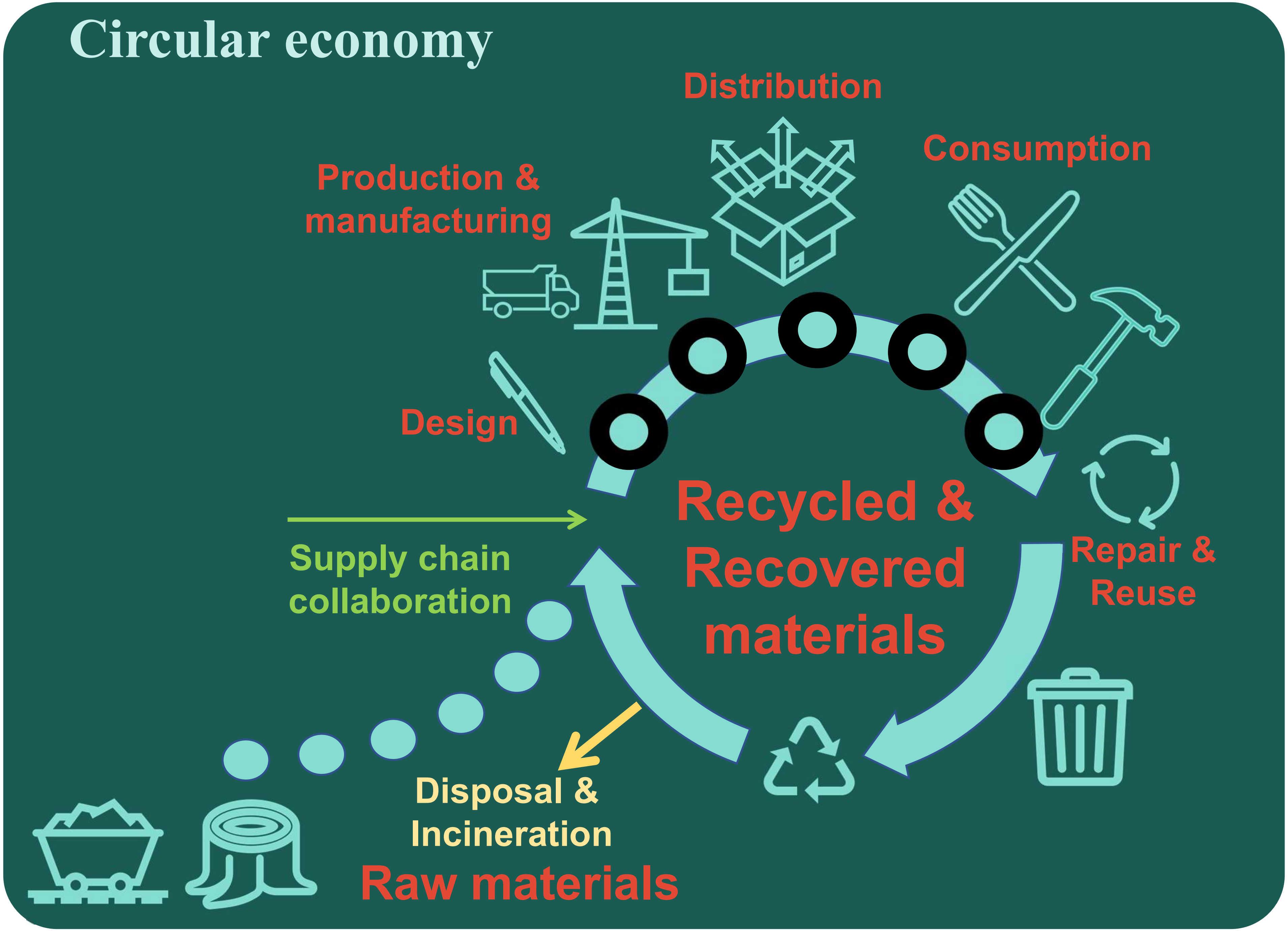


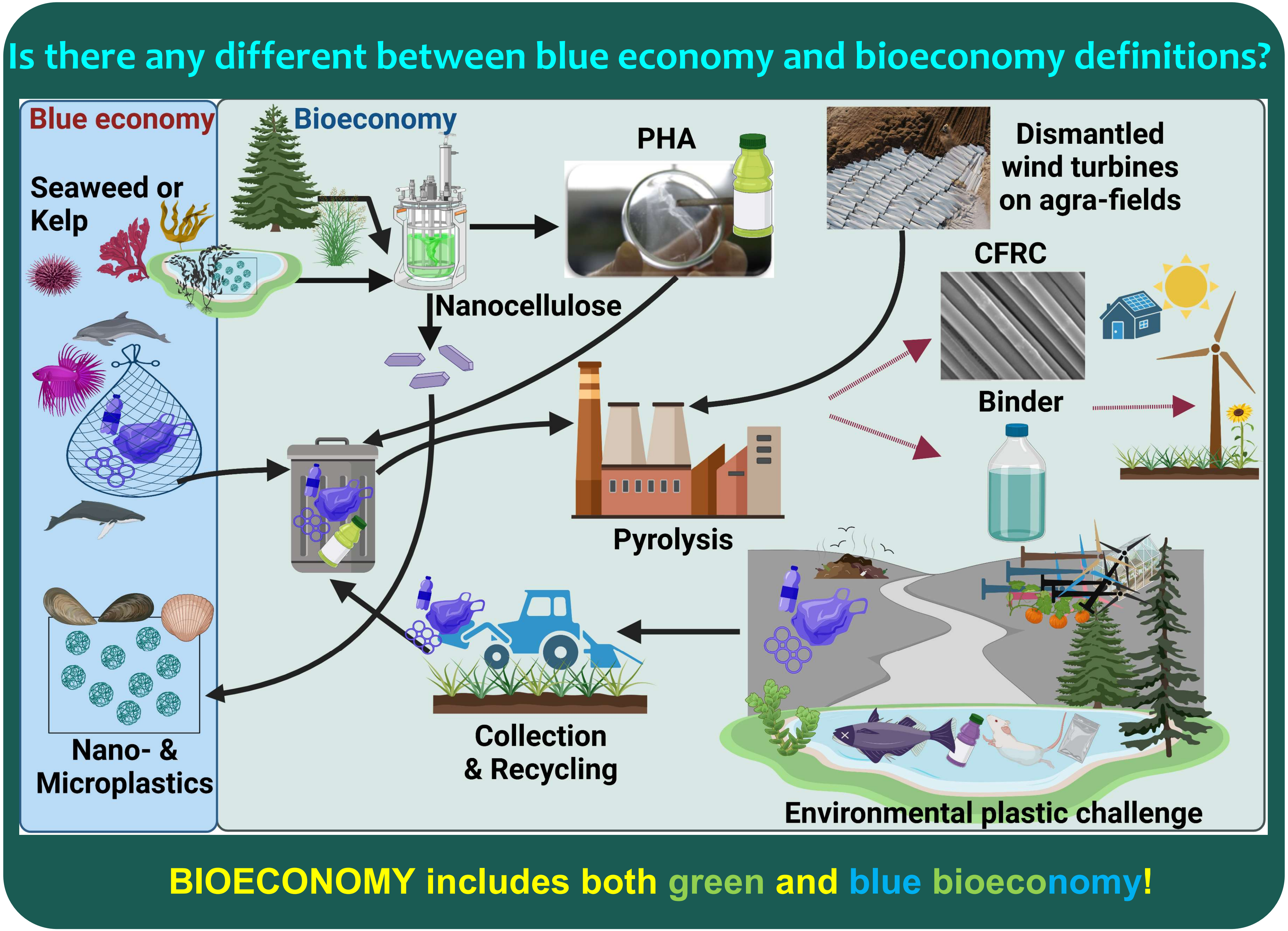

## Process map





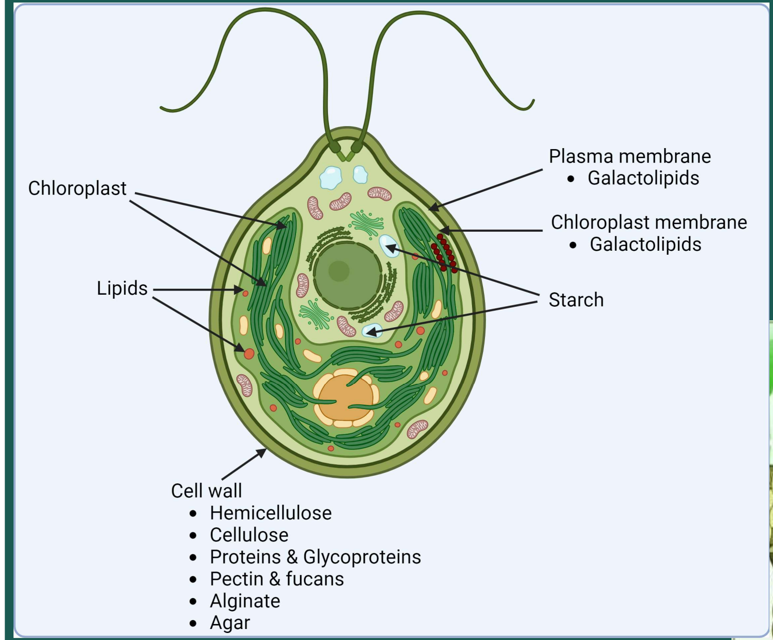
*Trubetskaya et al., (2021) A Methodology for Industrial Water Footprint Assessment Using Energy-Water-Carbon Nexus, Processes, 9(2), 393.*
*Trubetskaya et al., (2021) A methodology for assessing and monitoring risk in the industrial wastewater sector, Water Resources and Industry, 25, 100146.*


Circular economy
Distribution
Consumption
Production &
manufacturing
Design
Recycled &
Recovered
materials
Repair &
Reuse
Supply chain
collaboration
Disposal &
Incineration
Raw materials



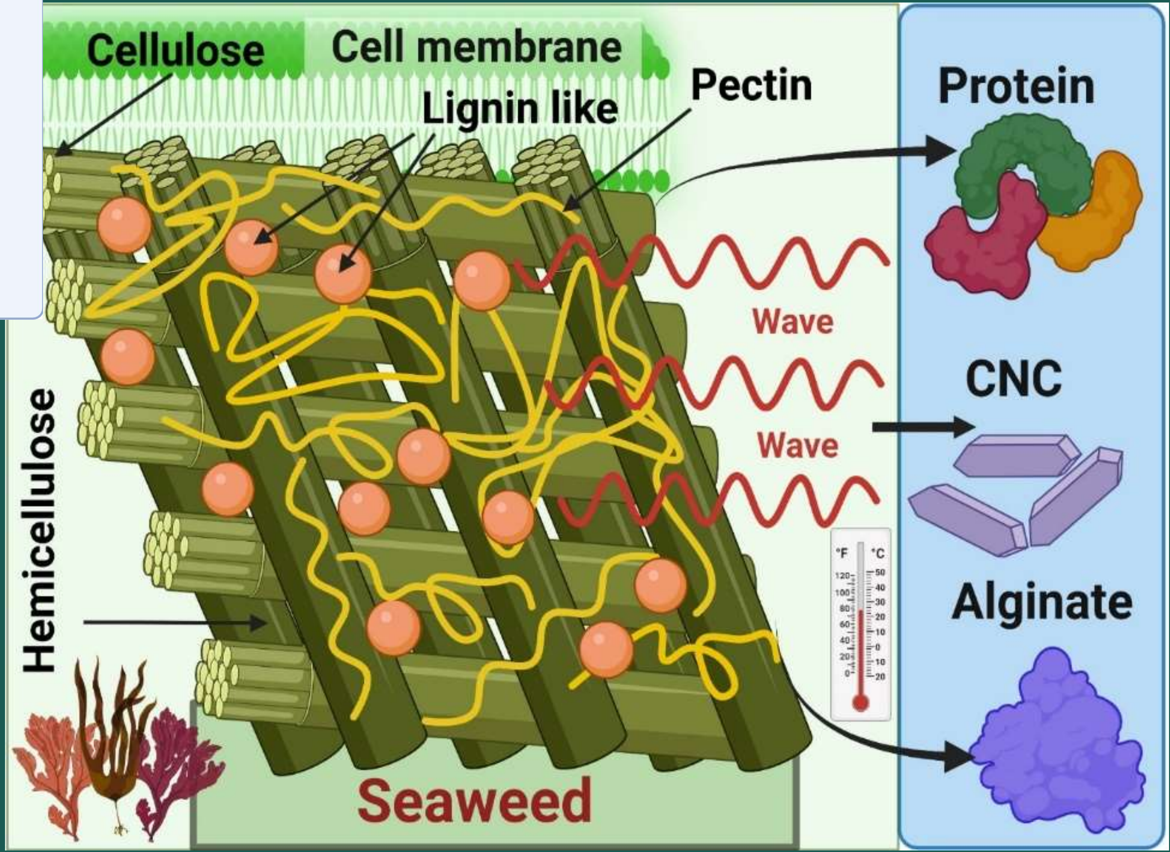

July 12th, 2024

# Marine plant biopolymers

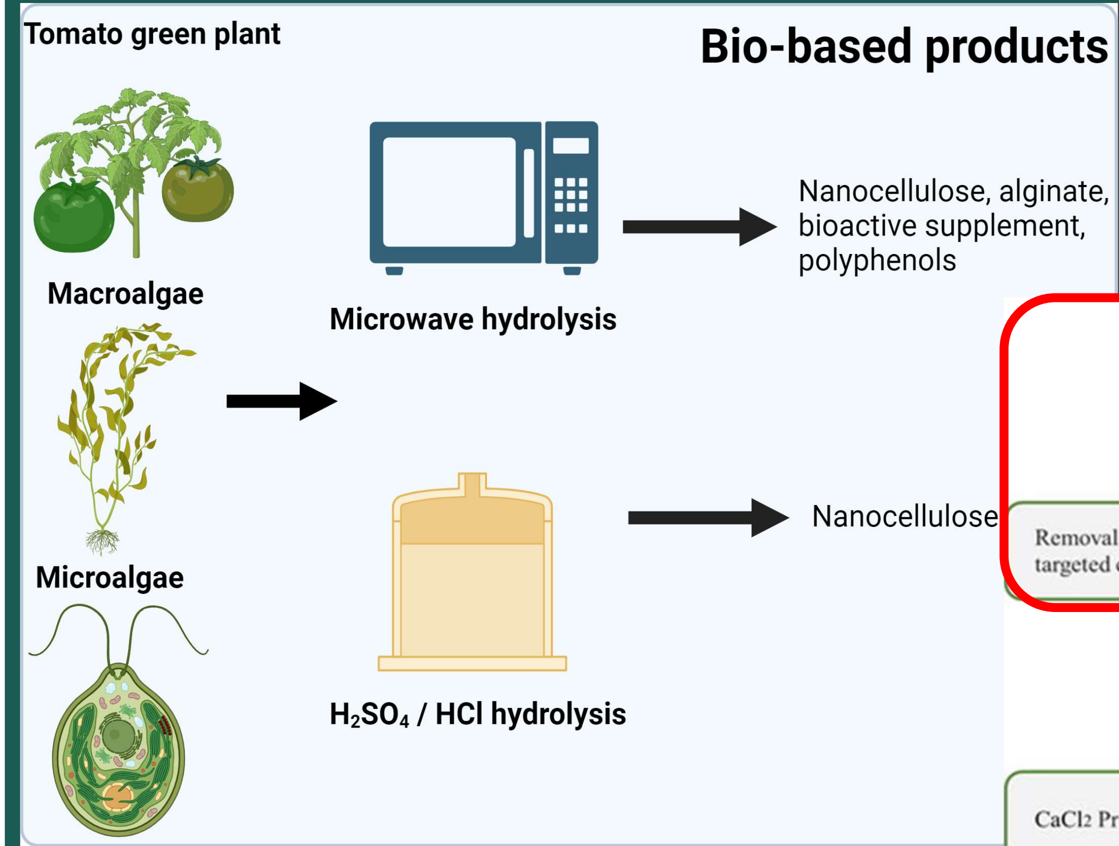



## Microalgae

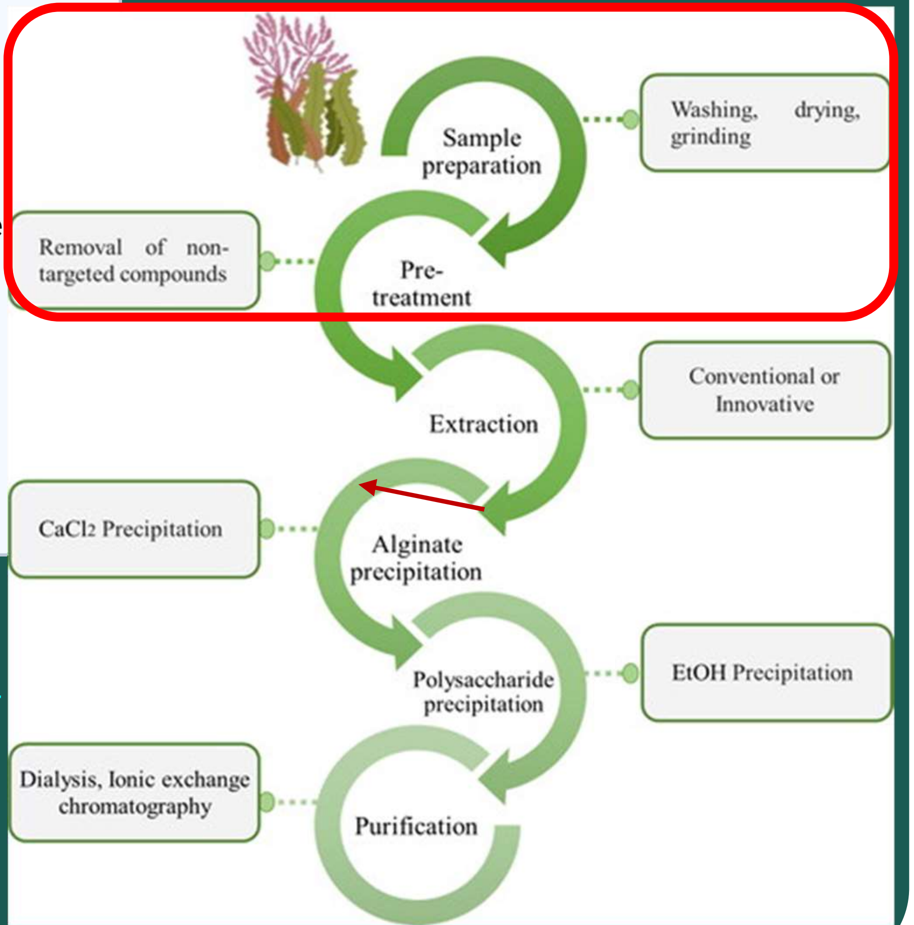

## Macroalgae



# Marine biopolymers & processing



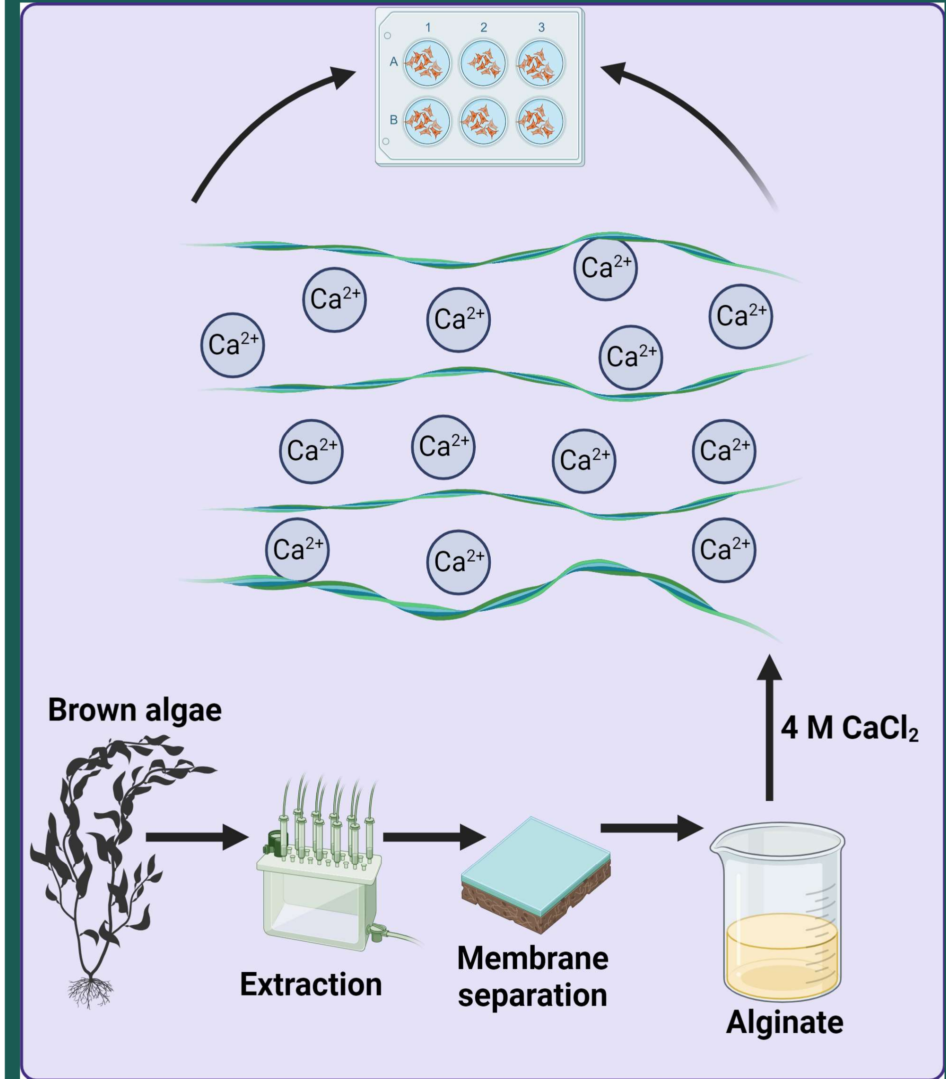

- ❖ Optimization of growth conditions
- ❖ Removal of metals from marine resources using blenching process
- ❖ Extensive washing of matrix prior alginate separation



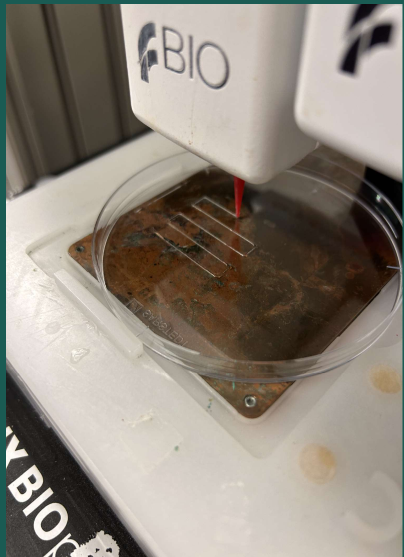

- ❖ Alginate is the most common polymer
- ❖ Monosaccharides are frequently to find, fucoidan
- ❖ Polyphenols are not intensively used yet, but "lignin-like" material is used in cosmetics & food
- ❖ Carrageenan & agar from red algae are used as thickners and stabilisers in food

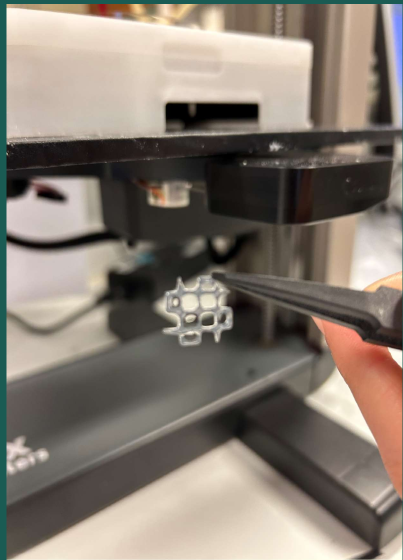
*Otero, Carpena, Garcia-Oliveira et al. (2021) Critical Reviewv in Food Science and Nutrition*, 63(13), pp. 1901-1929

# Alginates




- Biocompatible polymer for the biomedical application
- Broadly available on Atlantic coast in kelp & brown algae species
- 30-40 % dry weight
- Alginates can be used in different gel preparations
- More interest in alginate due to its printability

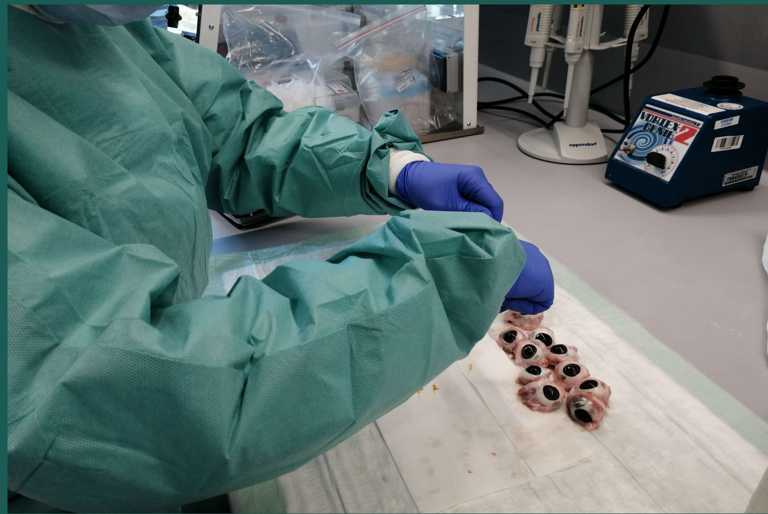


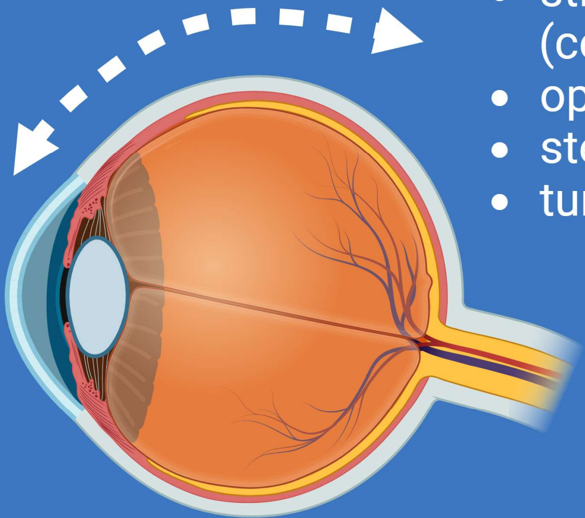



*Otero, Carpena, Garcia-Oliveira et al. (2021) Critical Reviewv in Food Science and Nutrition, 63(13), pp. 1901-1929*

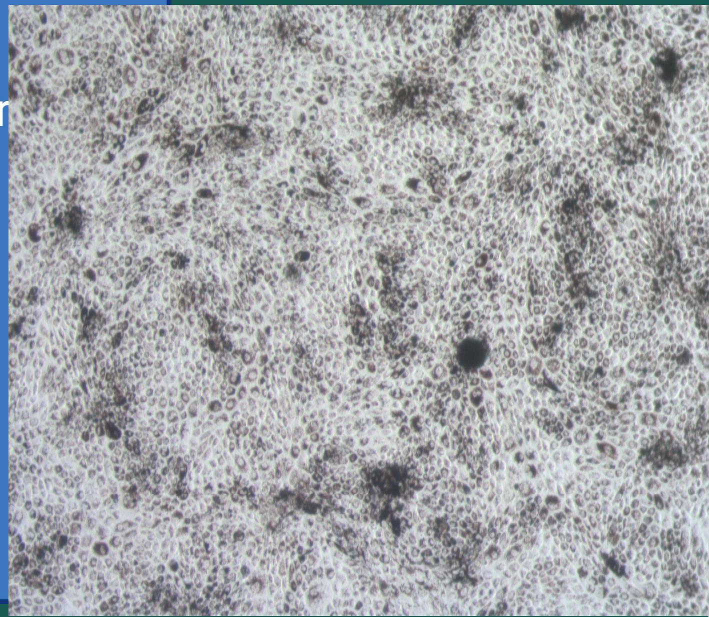
# Ophthalmological ARPE-19 & RPE retina culture cells

- Hydrogels are incubated at 37°C: **1 hour**
- Alginate is one of the compounds
- Non-transparency is a problem for the biomedical application
- The stiffness and simplicity of synthesis are attractive properties for the further research

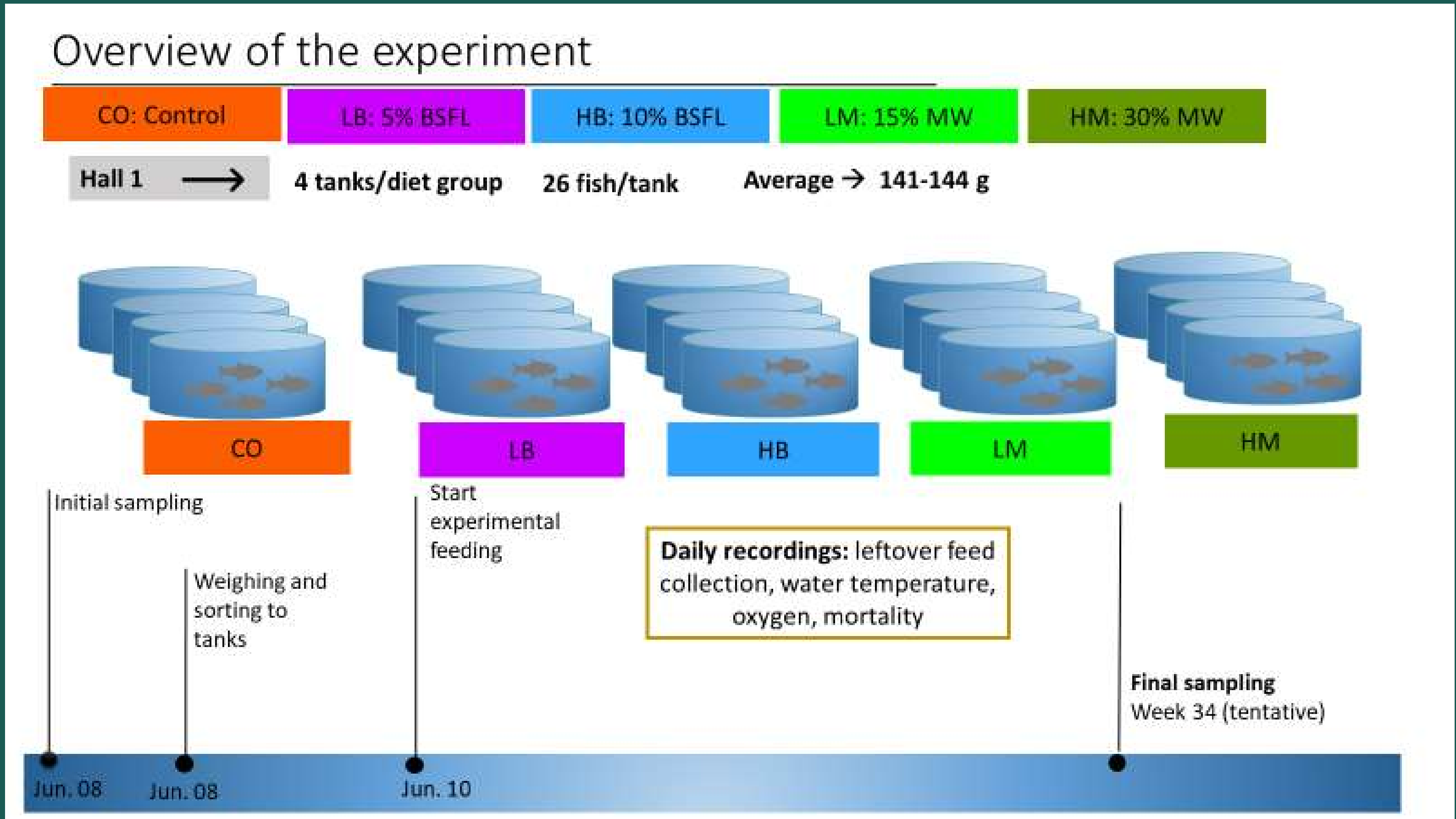




- biocompatible
- stiff gels (50-100 kPa) (cells allocate on top of hydr
- optically transparent
- sterilizable
- tunable nutrients release



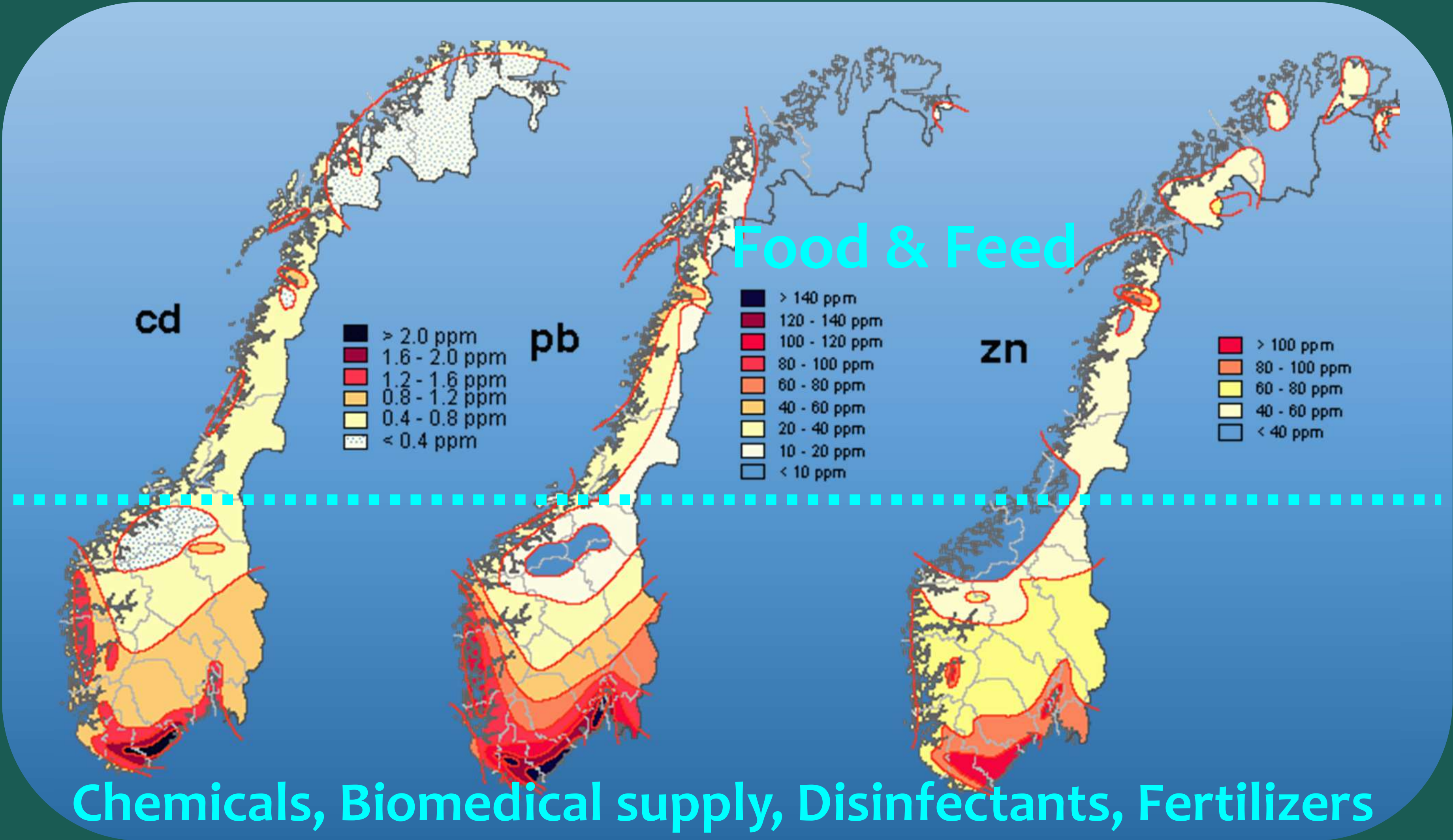
# Circular bioeconomy in aquaculture




- ❑ Atlantic coast (Bodø region)
- ❑ Fish feed is the main emissions contributor
- ❑ 4 tanks pro type of the fish feed with 26 salmon species each
- ❑ The entire cycle takes 34 weeks for the smolt to grow to the large size fish
- ❑ Five different diets using traditional protocols and replacement of 10-20% with the alternative compounds, e.g., microalgae oil, black soldier, yellow mealworm

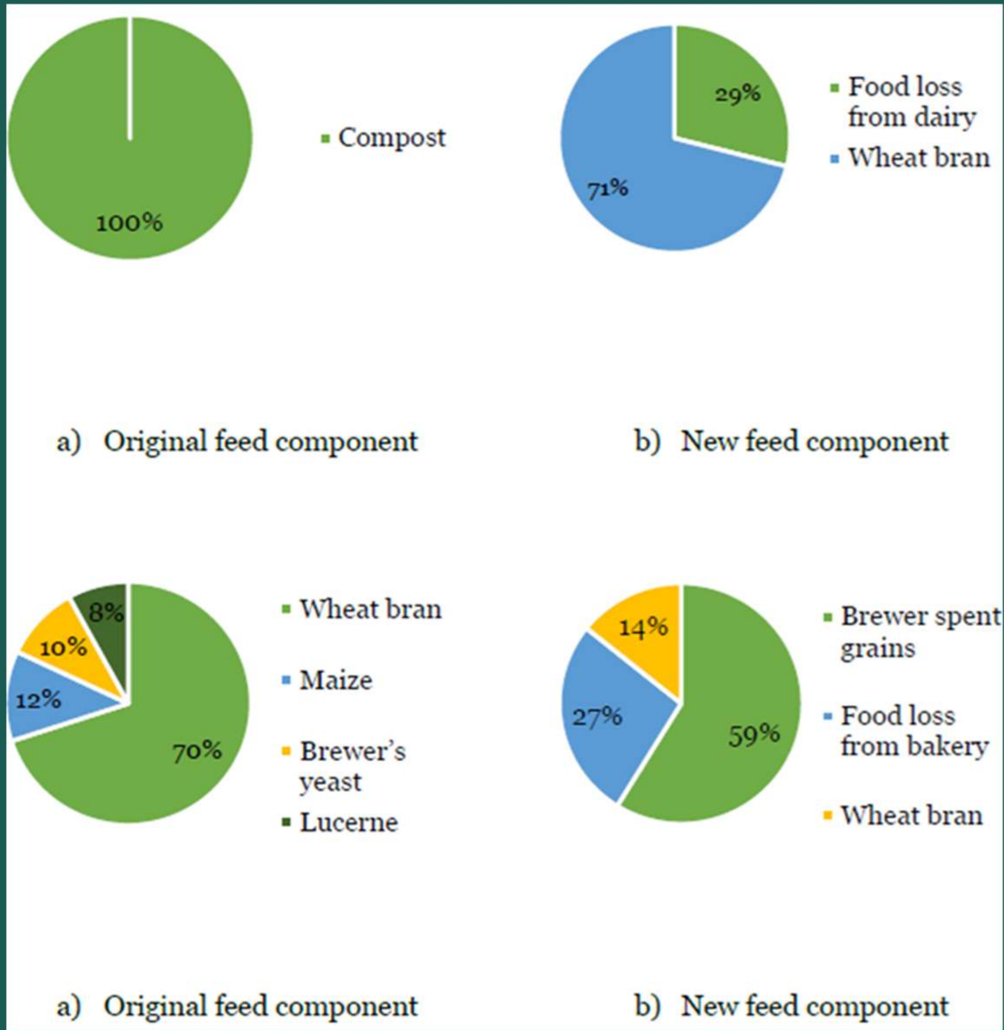
# Water contaminants in Norway

- South Norway showed high concentrations of Cd, Pb, Zn




*National geographical society in Norway, Statistics, 2020*

## Alternative fish feeds

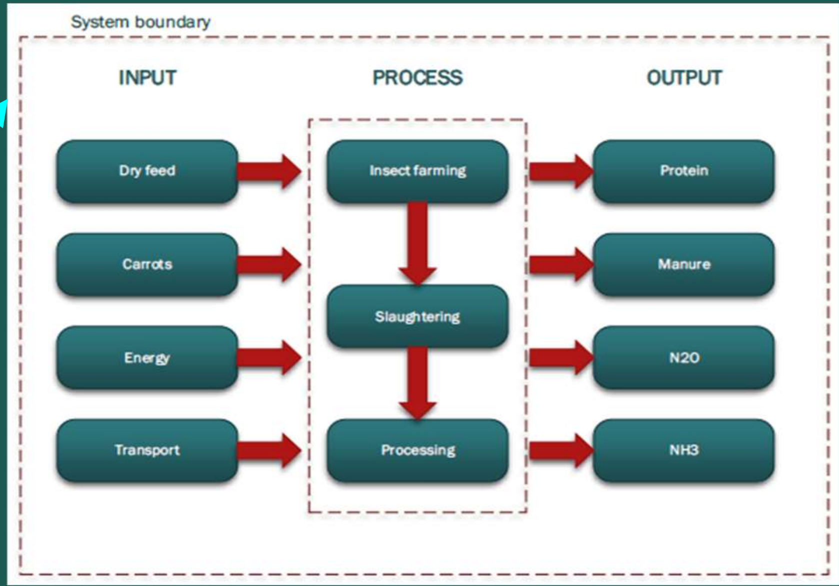



- In Circular economy, it is demanded by the government to integrate more waste, e.g., food.
- It is not always simple to say if it an alternative fish feed or the traditional one.
- There are no plans to Norway to replace 100% the traditional feeds with the alternative options.
- Even if we can follow biological outcomes, the regulations will not allow to replace the traditional feeds with the new one, e.g., consequences for the environment and human life.

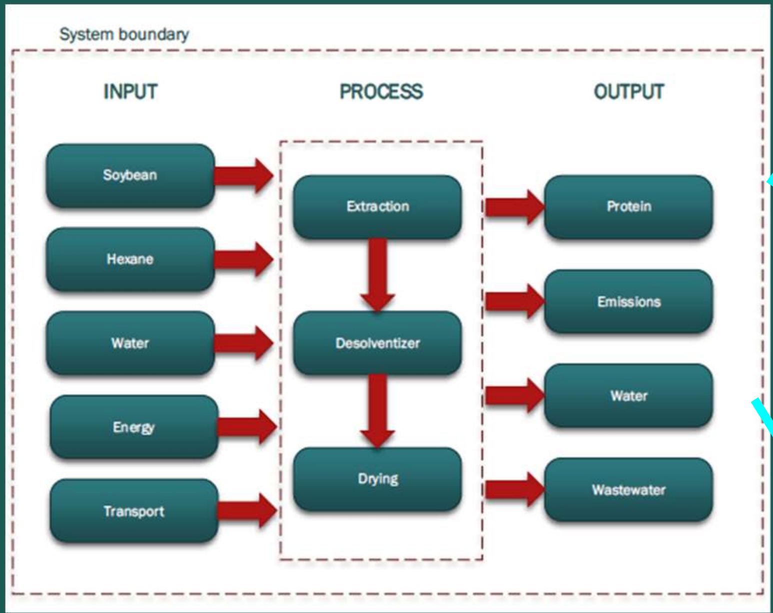
*Trubetskaya et.al Life cycle analysis of the Bodø community aquaculture, submitted 2024*

# Boundary conditions for LCA in aquaculture

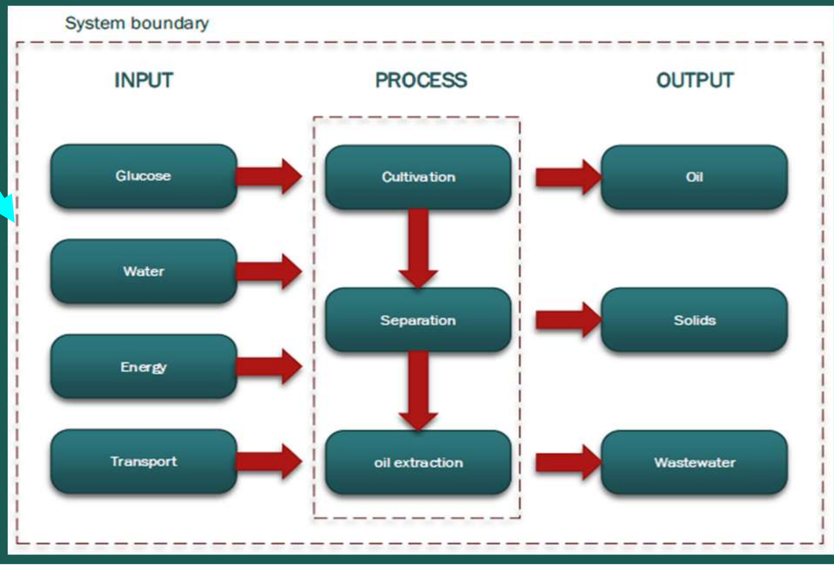
*Alternative yellow mealworm*




*Traditional soya feed*

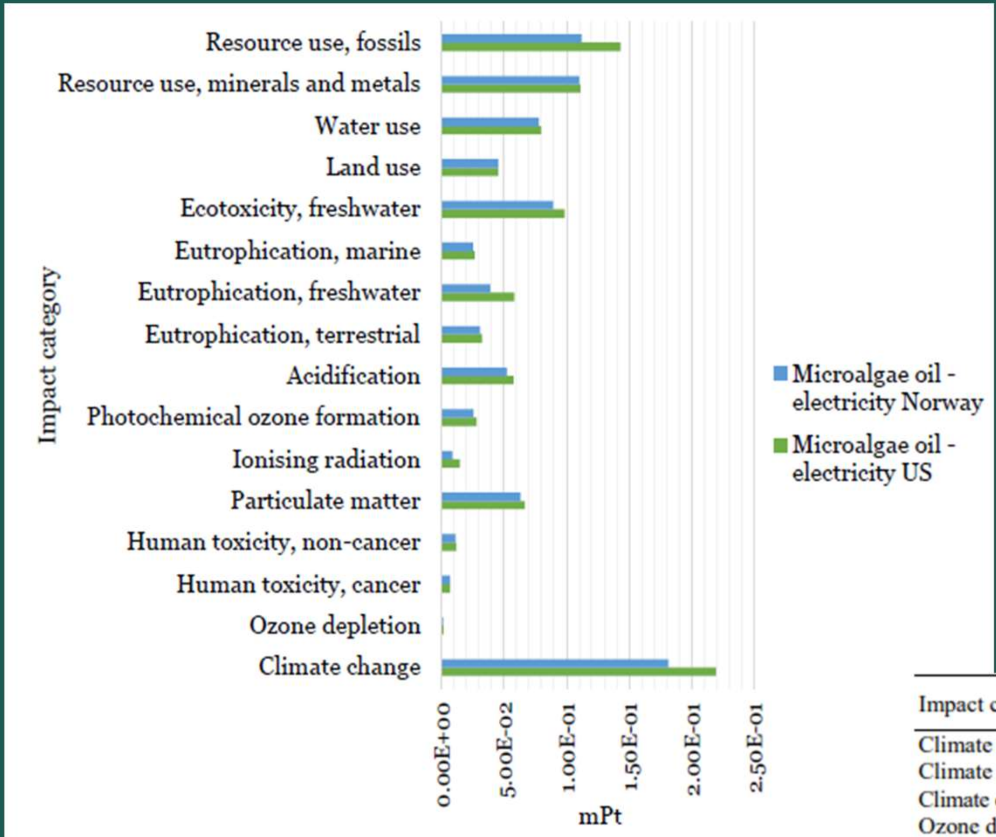


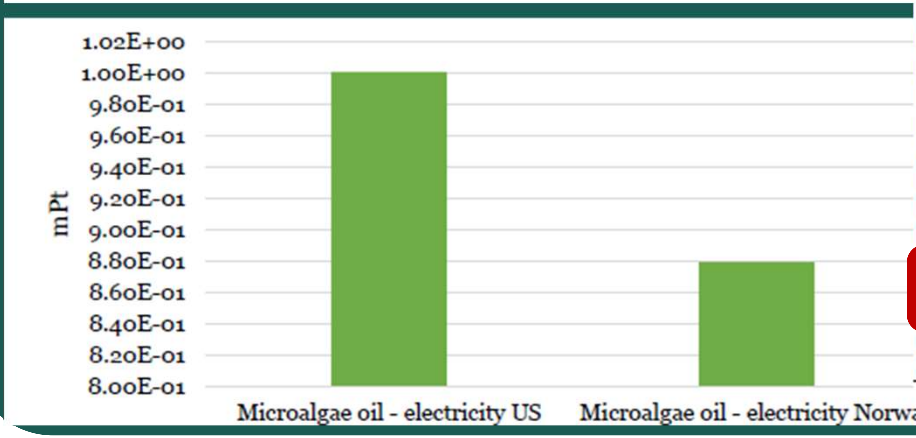

*Alternative microalgae oil*




- ❑ Exact process drawing of each feed compound manufacturing
- ❑ Drying step is very energy consuming
- ❑ Many processes are NOT circular (See microalgae oil)
- ❑ Wastewater remains a "black box"

# LCA results for microalgae oil with polyphenol addition in feed




- If production happened in Norway, the impact from used electricity is making less impact on the environment than it is when production is in the US with US electricity.
- The total single score value for Microalgae oil is 1.00E+00 mPt (millipoints), and the most significant impact is from glucose and electricity consumption.
- The most environmental impact on the water and land used for microalgae cultivation and growth.

| Impact category | Unit | Electricity the US | Electricity Norway |
|---|---|---|---|
| Climate change | kg $CO_{2\ eq}$ | 8.43E+00 | 6.97E+00 |
| Climate change - Biogenic | kg $CO_{2\ eq}$ | 3.52E-01 | 3.52E-01 |
| Climate change - Land use and LU change | kg $CO_{2\ eq}$ | 1.90E-01 | 1.90E-01 |
| Ozone depletion | kg CFC11 $_{eq}$ | 1.12E-06 | 1.04E-06 |
| Human toxicity, cancer | CTUh | 5.56E-09 | 5.27E-09 |
| Human toxicity, non-cancer | CTUh | 1.45E-07 | 1.37E-07 |
| Particulate matter | disease inc. | 4.42E-07 | 4.19E-07 |
| Ionising radiation | kBq $U^{235}_{\ eq}$ | 1.23E+00 | 7.28E-01 |
| Photochemical ozone formation | kg NMVOC $_{eq}$ | 2.37E-02 | 2.16E-02 |
| Acidification | mol H+ $_{eq}$ | 5.16E-02 | 4.70E-02 |
| Eutrophication, terrestrial | mol N $_{eq}$ | 1.54E-01 | 1.47E-01 |
| Eutrophication, freshwater | kg P $_{eq}$ | 3.34E-03 | 2.23E-03 |
| Eutrophication, marine | kg N $_{eq}$ | 1.75E-02 | 1.66E-02 |
| Ecotoxicity, freshwater | CTUe | 2.19E+02 | 1.99E+02 |
| Land use | Pt | 4.71E+02 | 4.67E+02 |
| Water use | $m^3$ depriv. | 1.07E+01 | 1.05E+01 |
| Resource use, minerals and metals | kg Sb $_{eq}$ | 9.35E-05 | 9.29E-05 |
| Resource use, fossils | MJ | 1.12E+02 | 8.74E+01 |

## Overview

- Marine biopolymers are very supported by the green-blue strategy in Norway;
- Many applications are considered, and even more to expect in the next few years;
- One of the alginate application could be in the oil drilling as a part of the cooling fluids;
- The purity of marine biopolymers remain a challenge, especially for the medical use;
- Life cycle analysis is very tricky, and very offered referred to the feed manufacturing;
- Water & wastewater are "black box", but it could be also a challenge for the multifold use of marine plants and animals due to the heavy metal concentrations;
- Pigments and supplements into the feed is under consideration and extensive research;
- Regulations and environmental legislations are important to take into LCA consideration.

## Acknowledgement

SEA EU
European University of the Seas

ACADEMY OF FINLAND

Tampere University

Nansenfondet og de dermed forbundne fond

Aalto University

The Research Council of Norway

Algaia
Your natural partner

VTT

UNICAMP

C A U
Kiel University
Christian-Albrechts-Universität zu Kiel

Dow

TU Bergakademie Freiberg
TUBAF
Die Ressourcenuniversität.
Seit 1765.

Innovation Norway

NORTH SEA FARMERS

# Thank you ☺

anna.trubetskaya@nord.no