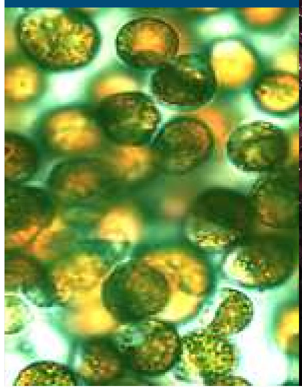
# Marine Biorefineries

Maria Barbosa, René H. Wijffels

Wageningen University and Research Center

maria.barbosa@wur.n



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# Contents

# Drivers for aquatic Biomass

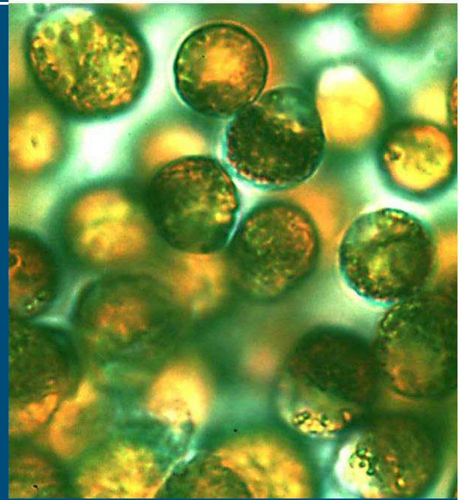
## Biobased Economy

- World population growth and increase in prosperity -> higher energy demand
- High energy prices
- Security of energy supply
- Climate change due to greenhouse gasses
- Rural development

## Specific aquatic biomass

- Increased competition for land for the production of food, chemicals and energy
- Limitations of land for agriculture
- Impacts of global climate change on agricultural productivity

# Microalgae and Seaweeds



- No competition for arable land
- High areal productivities
- Production of a wide range of biobased products + energy
- Knowledge on cultivation and processing is still at its infancy

# What can be produced?

## Microalgae vs seaweed - biomass composition

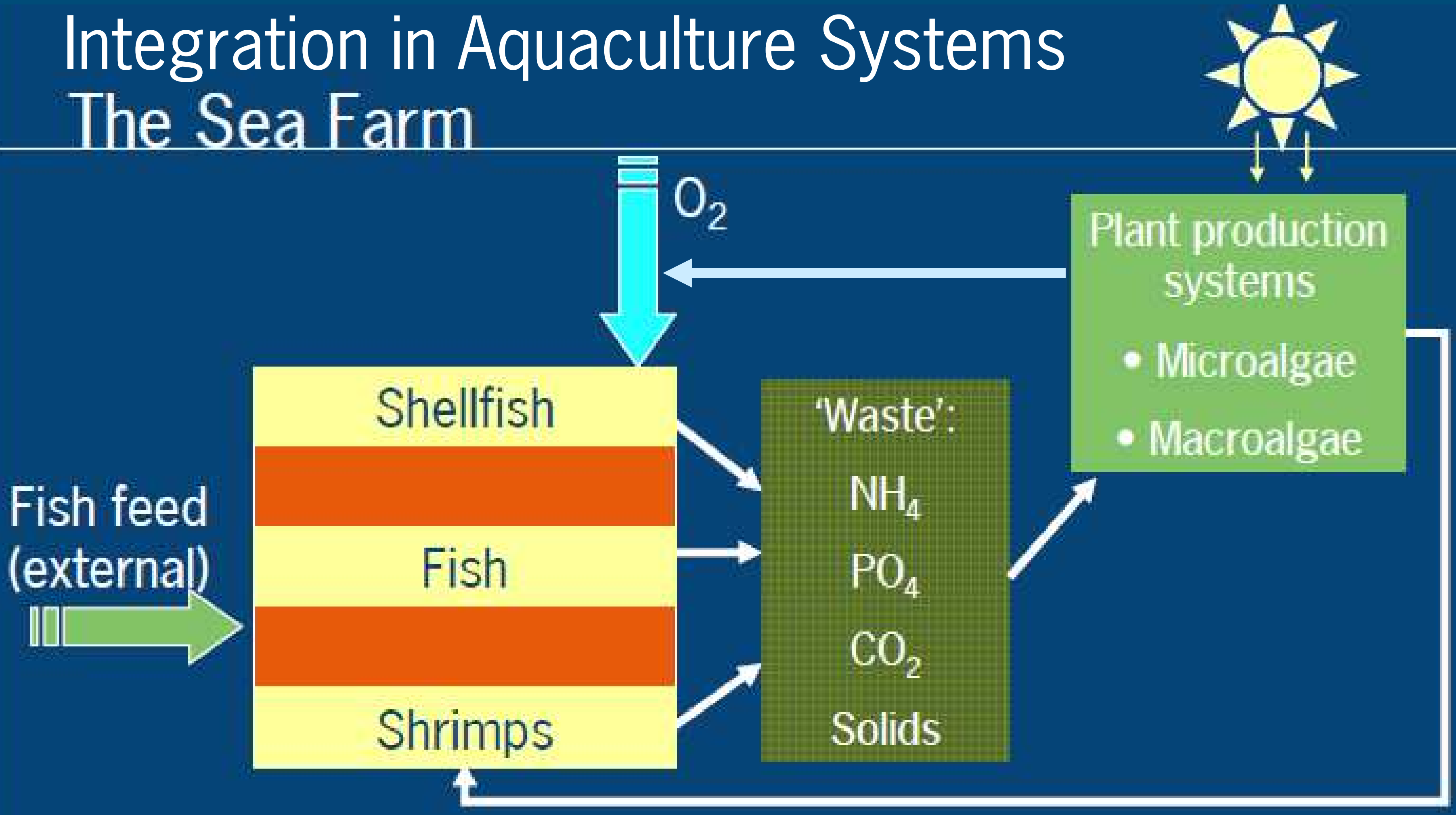
| | |
|---|---|
| Microalgae | Protein<br>Lipids or hydrocarbons |

| | |
|---|---|
| Seaweeds | Carbohydrates |

# What can be produced?

- Biofuels
- Industrial biochemicals (biopolymers, lipids, …)
- Pharmaceuticals
- Ingredients for food/feed
- ‘Sink’ for $CO_2$
- Integration with other processes
  - Biogas installation
  - Waste water treatment
  - Aquaculture systems (fish /shellfish, shrimps)

# Integration in Aquaculture Systems
## The Sea Farm



# Integrate Processes

**(Waste) Water**

## Waste streams

**N and P**

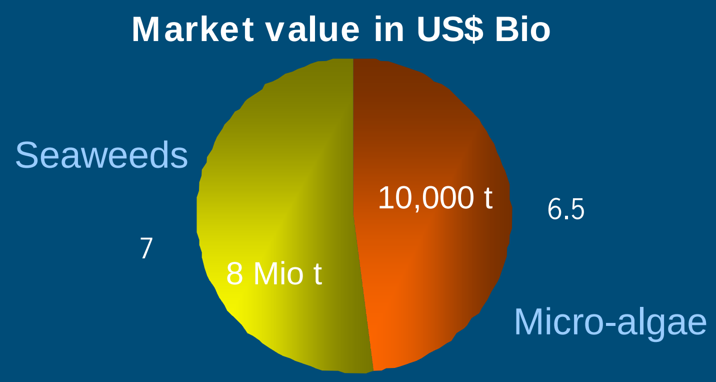
- municipal and animal wastewaters
- byproducts from chemical companies
- effluents from fermentations

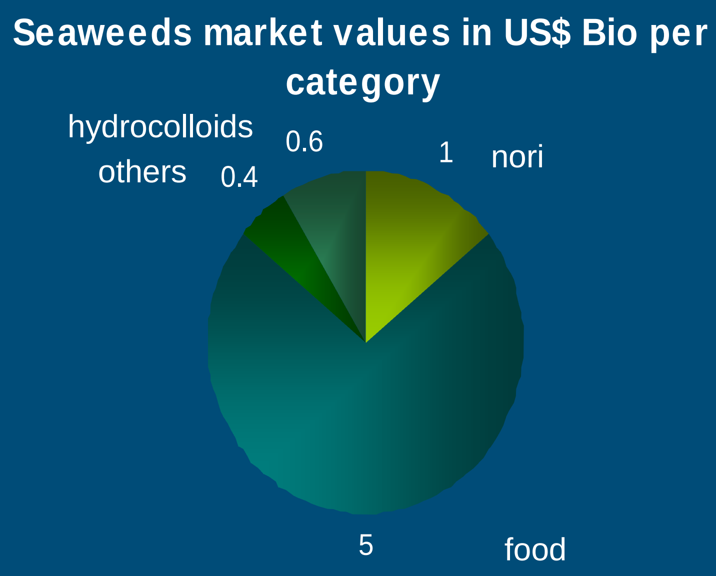
**$CO_2$**

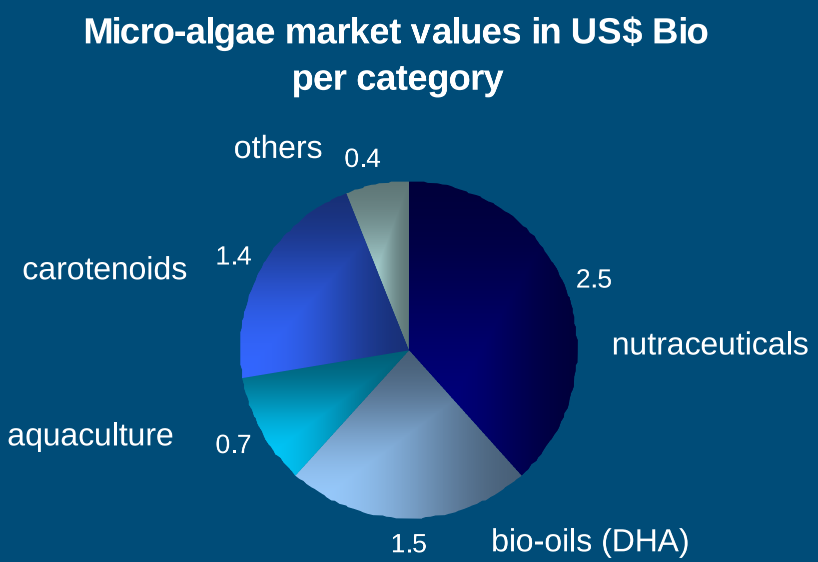
- power plants
- fermentation processes (e.g biogas installations)

**Algae Production**

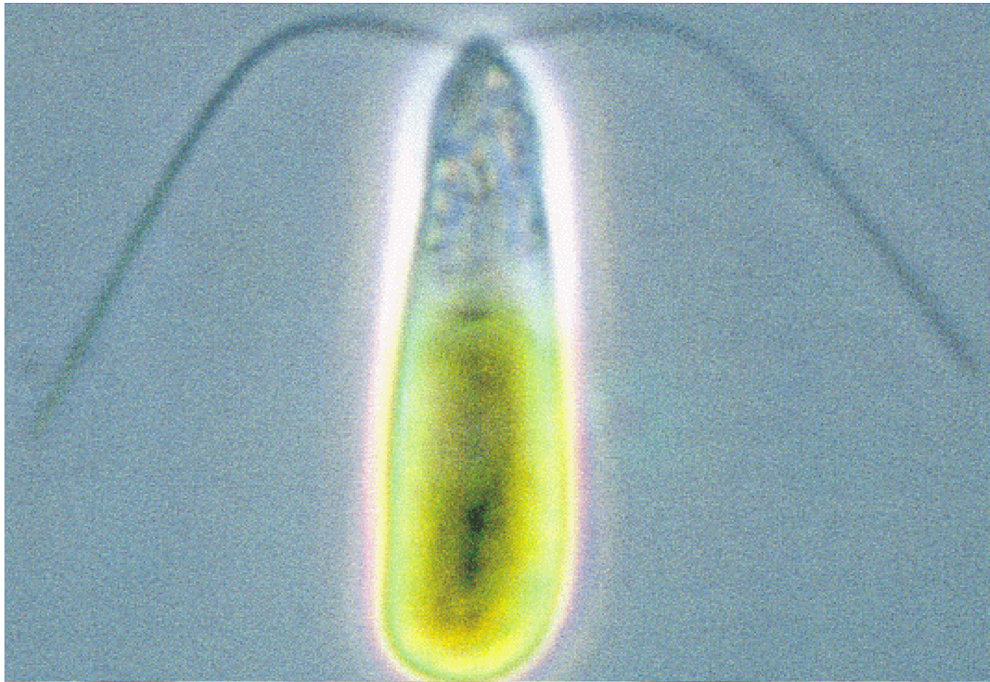
# Algal production, products and market values



| Applications | Genus |
| --- | --- |
| **Aquaculture** | |
| • Feed | *Isochrysis* |
| • Colorants | *Heamatococcus* |
| **Pharma- nutraceuticals & cosmetic** | |
| • Vitamins | *Chlorella*, *Anthrospira* |
| • Tocopherols | |
| • Bio-oils (DHA, EPA, ARA) | *Thalassiossira, Phaeodactylum,Macrocystis*, *Lessonia* |
| • Drugs and toxins | *Lyngbya*, *Porphyridium* |
| • Care | *Chlorella*, *Anthrospira*, *Muriellopsis* |
| • Carotenoids, xanthins, phycobilins | *Dunaliella* |
| **Bioremediation** | |
| • Organic pollutants | *Chlorella*, *Ankistrodesmus*, *Scendesmus* |
| • Heavy metals | *Sargassum* |
| **$CO_2$ sequestration & mitigation** | |
| • Exhaust treatment | *Chlorococcum*, *Chlorella* |
| **Energy** | |
| • Biomass | *Spirulina*, *Chlorella*, *Dunaliella*, *Nostoc*, *Aphanizomenon* |
| • Bio-Fuels | *Botryococcus*, *Phaeodactylum* |
| • Bio-Gas | |
|     • Bio-methane | *Macrocystis, Gracilaria, Sargassum, Laminaria* |
|     • Bio-hydrogen | *Chlamydomonas* |
| **Materials** | |
| • Food colorants | *Dunaliella*, *Heamotococcus* |
| • Industrial pigments | |
| • Silica | *Diatoms spp.* |
| • Polymers (hydrocolloids) | *Euchema, Kappachycus, Laminaria, Ulva* |
| **Research** | *Diatoms spp.* |
| **Human food** | |
| • Nori | *Porphyra* |
| • Specialized and others | *Odontella* |



# *Microalgae*

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# Microalgae

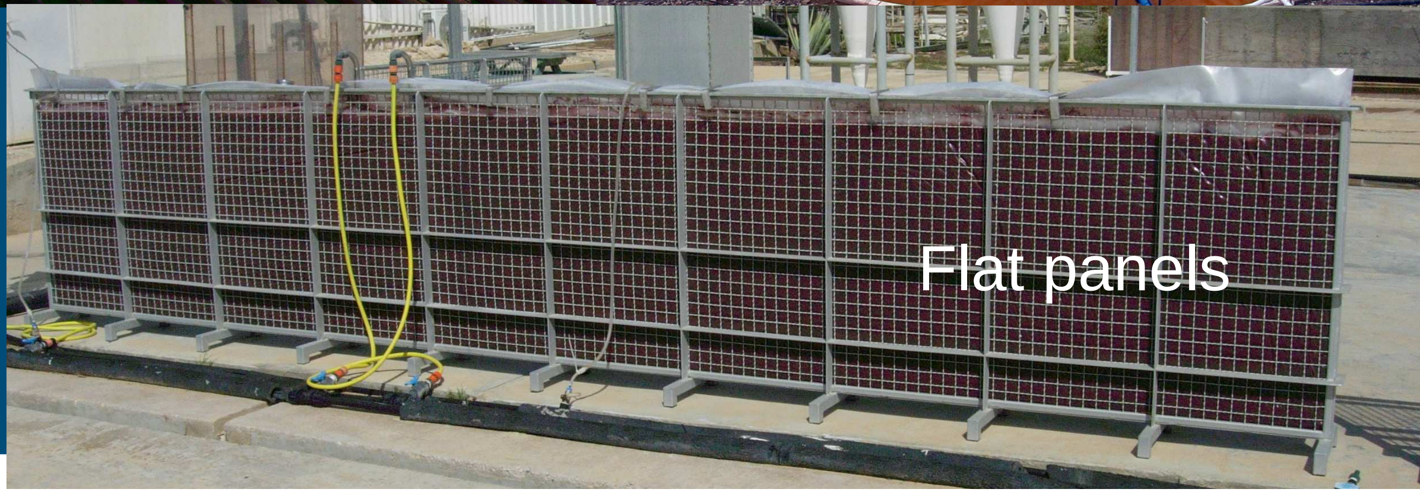
- Does not compete for land suitable for agriculture irrigation or consumption by humans or animals -> Food security
- High areal productivity
- Great variety in species -> variety in products!
- Offer possibility to steer metabolism to production of specific compounds
- Ability to accumulate large amount of oils
- $CO_2$ mitigation
- Recycling nutrients

# Microalgae: Importance of a biorefinery approach

- Varied and high quality composition of biomass
- Economic need to optimise valorization of the biomass by extraction of multiple products in addition to e.g fuels

# Feedstock - Economic need: 2007 Delta Feasibility Study



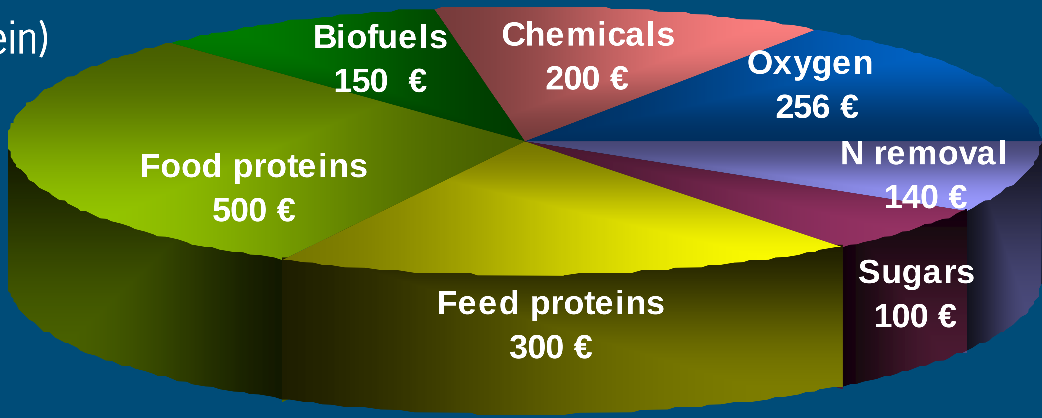


# Economic need

- At 1 ha scale today: 10 €/kg
- At 100 ha scale today: 4 €/kg
- What will be possible: 0.40 €/kg
- Still too expensive for biodiesel alonebvg

# Bulk chemicals and biofuels in 1,000 kg microalgae

- 400 kg lipids
  - 100 kg as feedstock chemical industry (2 €/kg lipids)
  - 300 kg as transport fuel (0.50 €/kg lipids)
- 500 kg proteins
  - 100 kg for food (5 €/kg protein)
  - 400 kg for feed (0.75 €/kg protein)
- 100 kg polysaccharides
  - 1 €/kg polysaccharides
- 70 kg of N removed
  - 2 €/kg nitrogen
- 1,600 kg oxygen produced
  - 0.16 €/kg oxygen
- Production costs: 0.40 €/kg biomass
- Value: 1.65 €/kg biomass

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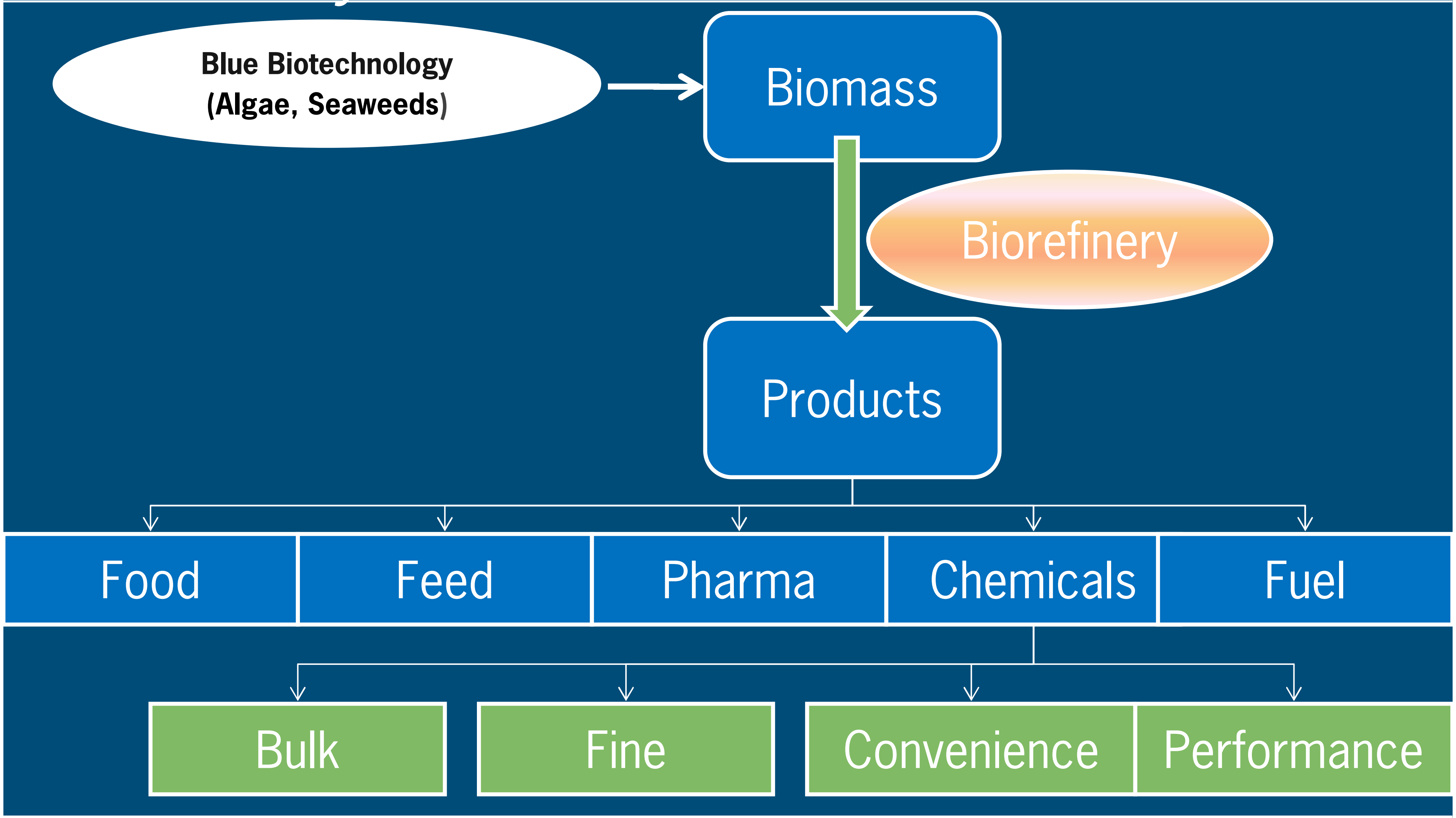
# Biorefinery



# To replace all transport fuels in Europe

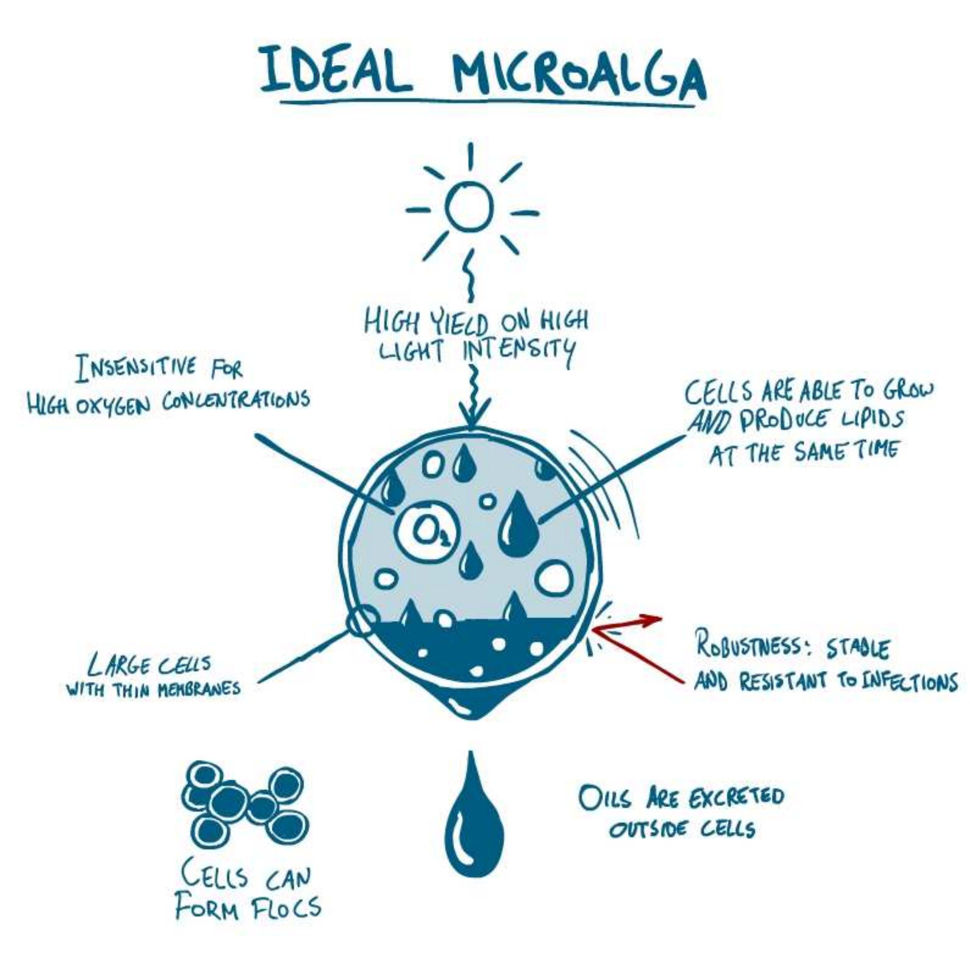
- 400 million $m^3$ lipids needed
- 9.25 million ha surface area
- Equivalent to surface area of Portugal
- 400 million tons of proteins produced
- 20 times the amount of soy protein imported in Europe

# Complexity of biorefinery

- Business model in which different end users need to collaborate
- Market volumes must fit
- Highest value is obtained if functionality of molecules is maintained
- Biomass production and biorefinery depend on each other

# No optimization on a single parameter

- High biomass productivity
- High productivity in required molecules (proteins, saturated neutral, lipids, unsaturated fatty acids)
- Insensitive to high oxygen concentrations
- Possibility to grow under selective conditions
- Easy to harvest
- Mild extraction



# First project: protein isolation from algae

**1** Mild and effective **protein isolation** from microalgae cells

**2** **Characterization** of isolated proteins

**3** **Fractionation** of isolated proteins

**4** Determination of **techno-functional properties** of individual protein classes

**5** **Optimization** of isolation and fractionation procedures

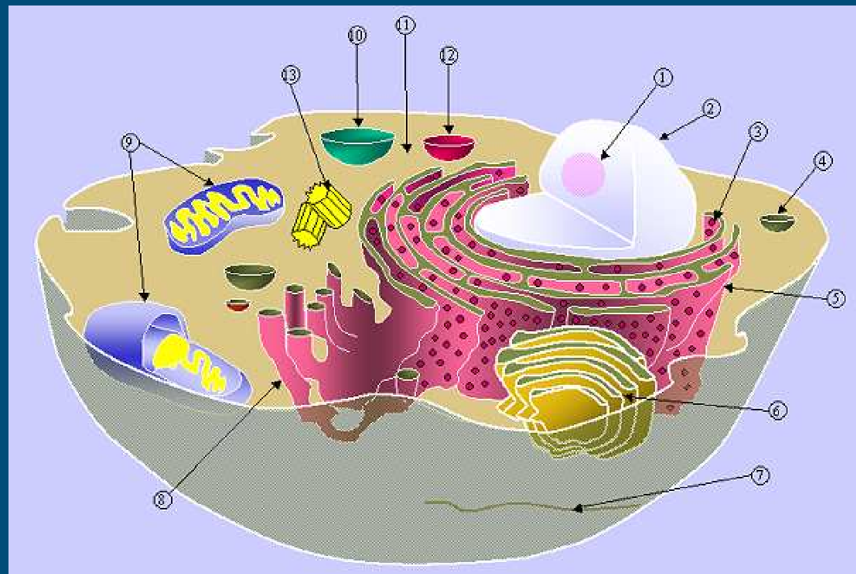
- **Cell disintegration under mild conditions ✓**
- **Removal of chlorophyll ✓**
- **Up scaling**

***Tetraselmis suecica*** **as model organism**

# How can we make a more structure based approach for biorefinery?

- To fractionate all components
- Maintain their functionality
- At low energy input

# Localization of components in different organelles in the cell




Molecular and Technological knowledge both needed

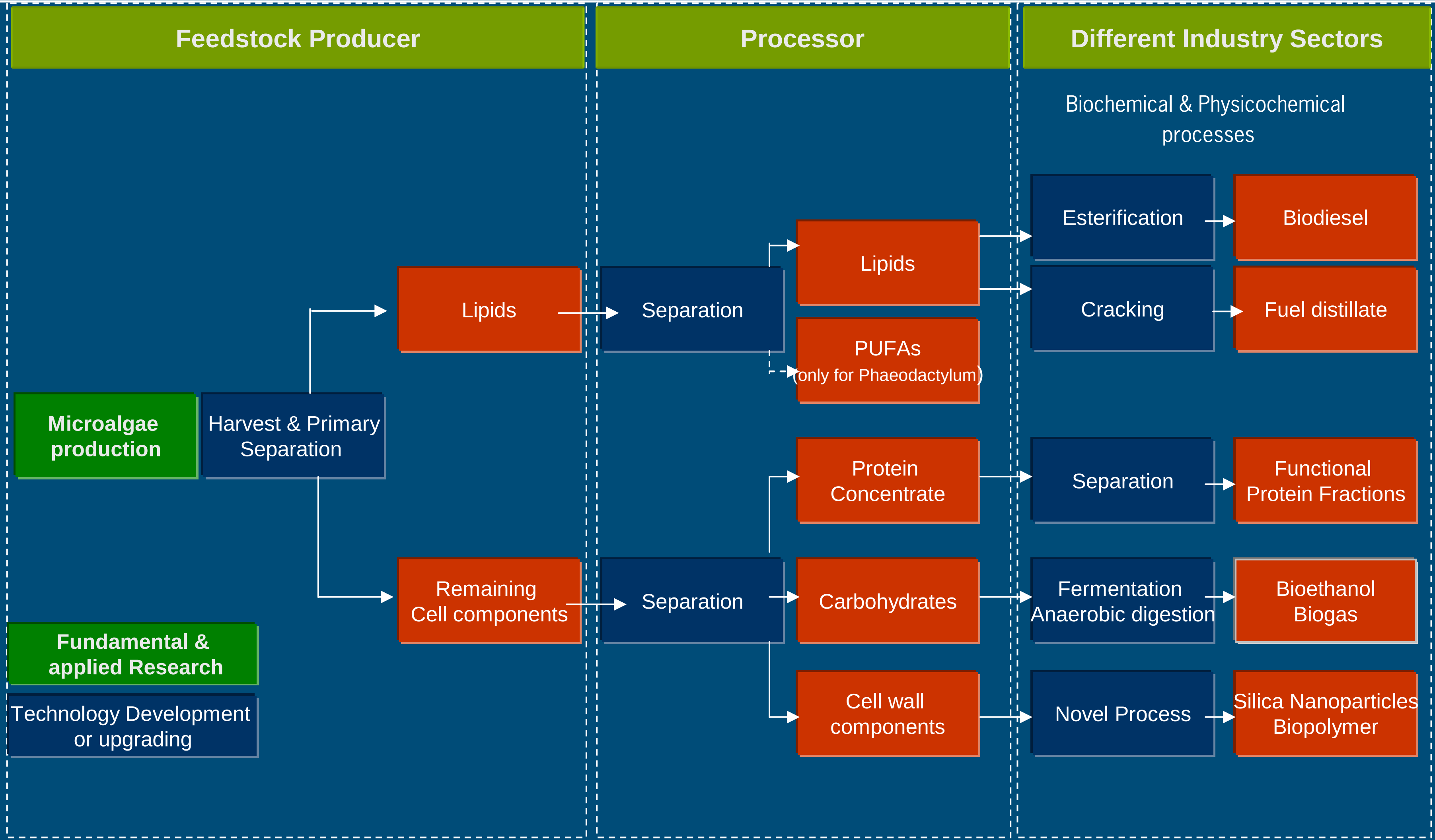
# Mild biorefinery approach for Algae

- Identify different components (proteins, lipids, carbohydrates, etc.) in organelles (labeling, localization studies) of the micro-algae
- Perform selective cell disruption technologies to identify and recover components from cytoplasma, eventually inhibitors need to be added to protect high valuable components from processing
- Separate/isolate organelles with most high valuable products (Rubisco from pyrenoids) and perform mild disentanglement for product isolation of these organelles
- Isolate the more hydrophobic lipids from the more hydrophilic proteins and carbohydrates
- Recover/isolate proteins and carbohydrates as valuable components
- Further processing towards fragments, building blocks and minerals

# Present

- One process for one product

# Chain Approach: from feedstock to end products

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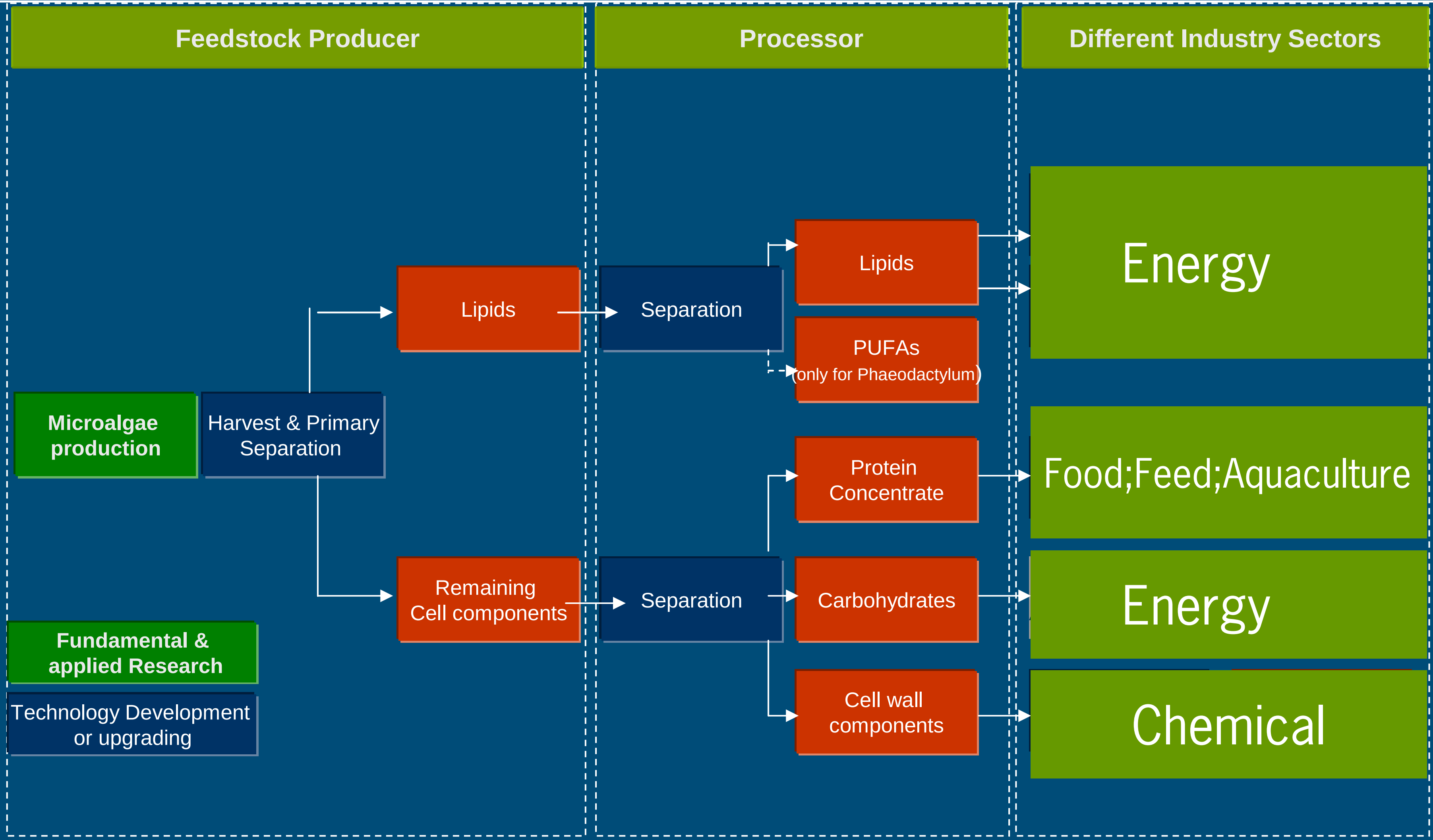
# Chain Approach: from feedstock to end products

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# Specific developments required for a microalgae biorefinery

- Development of mild and efficient cell disruption, extraction and fractionation technologies
- Effective technologies for separation of carbohydrates, proteins  and lipids
- Lipid /oil  refining technologies
- Improvement of energy consumption and environmental performance, decrease of capital costs
- Integrate knowledge & facilities for oil, food and fine chemical industry
- Biomass provision (quantity and quality)

# Challenges in the entire chain

- High CAPEX, high running costs and energy consumption for cultivation, harvesting and product separation
- Large-scale cultivation of microalgae
- Current process technology does not allow the production of multiple products
- Lack of trained personnel
- Product development to commercial applications
  - Regulatory approval for use of algae in feed/food is lacking
  - Broad consumer acceptance of algae and seaweeds in food
  - The full range of potential products, best combinations and their market values is unclear

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# MANY SCATTERED ACTIVITIES

Different locations

Different designs

Different measurements

How to compare systems?

How to learn from this process?

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# AlgaePARC

## Algae **P**roduction **A**nd **R**esearch **C**entre

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# Algae PARC: Objectives

- Build up an international , open and independent centre for applied research
- Translate research towards applications
- Acquire Information for design of full scale plants
- Develop competitive technology (economic viability and positive energy balance)
- Cradle to Cradle: Closing material loops - $CO_2$, N, P
- Defined Research Programme (5 years) & Contract research
- Production of algal biomass for bulk chemicals, food and feed ingredients and biofuels


Seaweeds

# Seaweeds: Present and Future

| Present | | Future |
|---|---|---|
| Biomass | Chemicals & Energy | |
| Direct consumption | Polysaccharides (alginate, agar carrageenan) | Chemical buillding blocks replace oil derivatives |
| Fertilizer (maerl) | High value compounds (nutraceuticals, cosmetic, personal care) | Anaerobic digestion (methane<br>Fermentation<br>(ethanol, butanol, citric acid, butyraldeyde, glycerol, lactic acid…) |
| $CO_2$ fixation | | |

# Seaweeds: Importance of a biorefinery approach

- High quality composition of biomass

Very low levels of lignin

<u>Dry Matter:</u>
Proteins 15%
Lipids 1%
Carbohydrates 58%
Ashes 14%
Fibers 12%

- Economic need to optimise valorization of the biomass by extraction of multiple products in addition to e.g fuels

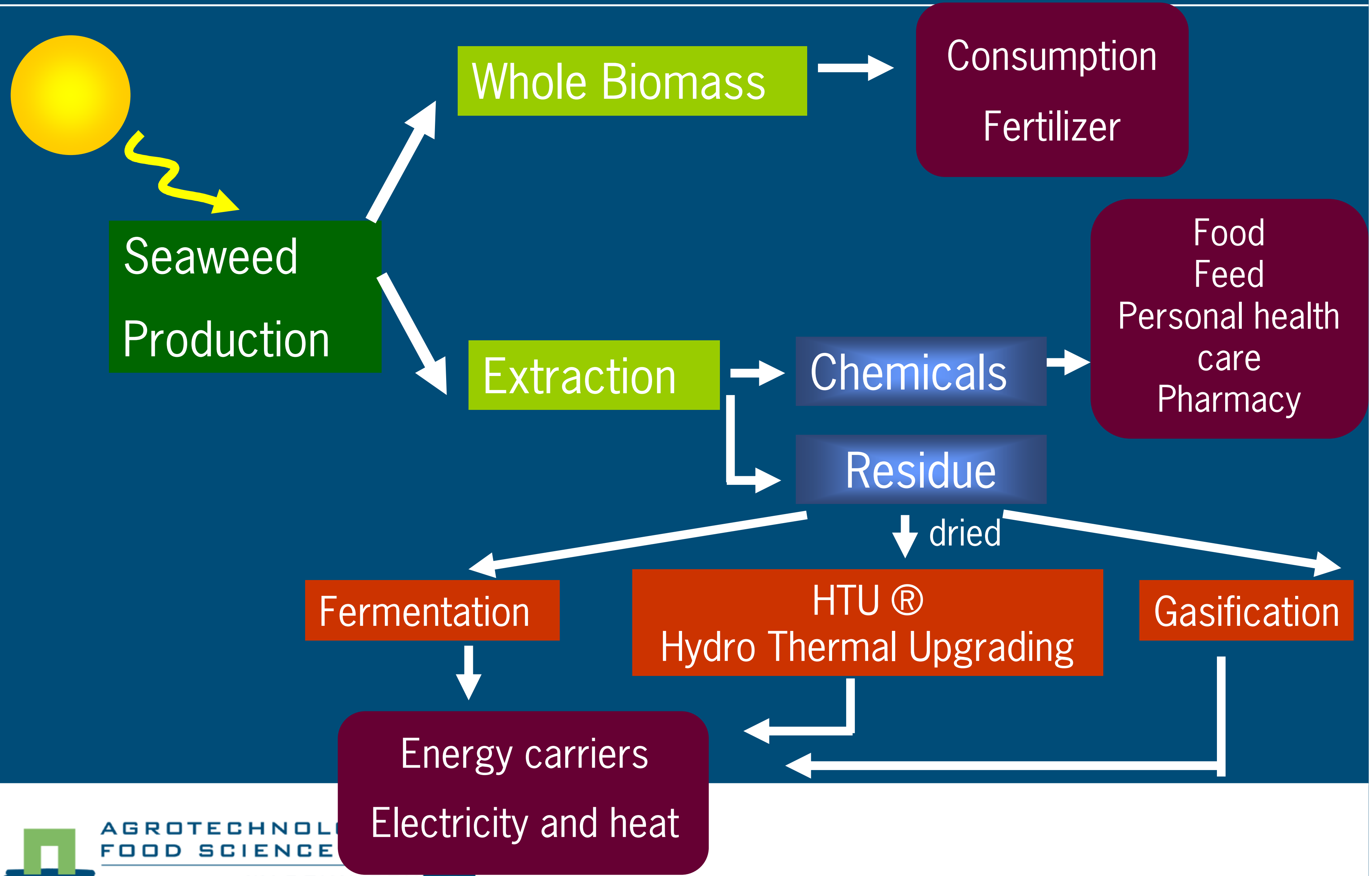
# Current seaweed production

- In several European countries (Ireland, Norway , France, Spain) production processes are based on harvesting (manual and mechanical) natural populations for human consumption and hydrocolloid production

- There is currently no seaweed production in the North sea

- Asia – cultivated

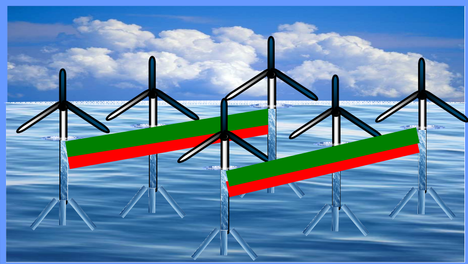
# Process, Products and Energy



# Improving economics

***Cultivation System***

- Multilayer system



***Strains***

- Local strains

e.g. North Sea strains- Palmaria (red), Ulva (green), Laminaria (brown)

- Selective breeding programmes

***Cultivation***

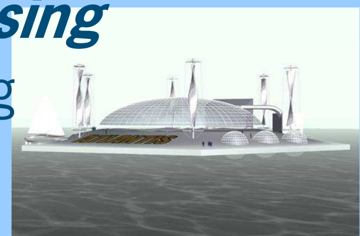
***Processing***

***Substrate availability***

- Light Intensity
- Feeding System

***Operating, Harvesting Transport, processing***

- Automatic harvesting
- Dewatering at sea
- Processing



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# Challenges

## Harvesting , pre treatment and extraction

- Dewatering without loss of valuable ingredients (offshore)
- Pre-treatment – extraction of secondary high value metabolites without losing much energy and biomass
- Improvement of existing technologies for extraction of hydrocolloids, with respect to costs, energy use and environmental performance

# Challenges

## New applications (in biofuels)

- Development of technology for new applications. In order to produce biofuels in the form of either methane or ethanol from seaweeds it will be necessary to:
  - Optimise the pre-treatment to improve the performance of a substrate for AD.
  - Overcome toxicity caused by high levels of phenols, heavy metals, sulphides, salts, and volatile acid compounds found in seaweeds, which can inhibit methanisation.
- Screen for bacteria that can be used in both methanisation and bioethanol production.
- Incorporate latest AD technology from terrestrial biomass digestion and design digestor's specifically for seaweeds

# Challenges

## Integration and Implementation

- Selection , up-scaling and process integration
- Ecological impact
- Public acceptance
- Development of new markets

# Conclusions

- Marine biomass has the potential to offer a wide range of biobased products and energy.
- Economic feasibility requires a biorefinery approach
- Technology still needs to be developed or further upgraded to produce a wide variety of products in the same process (both for feedstock cultivation and processing)
- Market development and public acceptance are important issues that need to be dealt with

www.algae.wur.nl

# Thank you for your attention!

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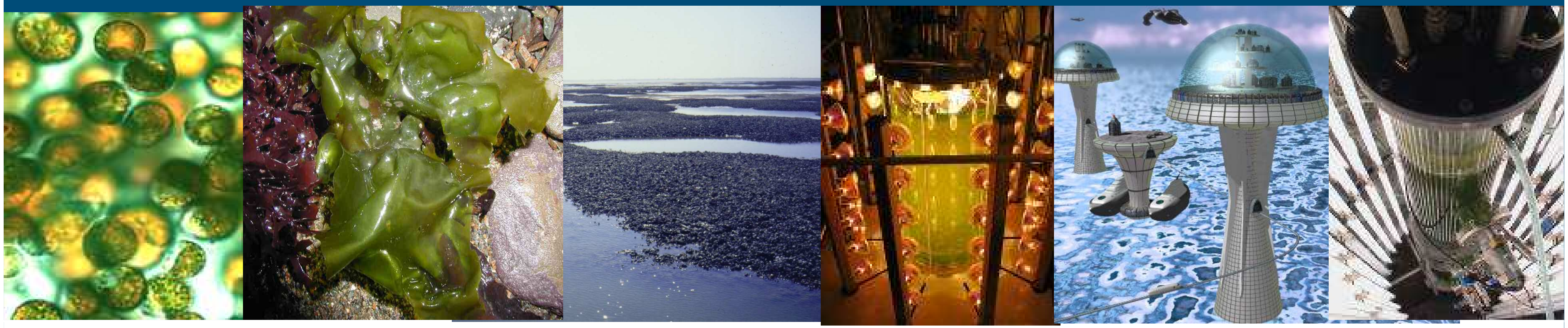

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