Overview of four on-going R&D projects on seaweed biorefinery

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Outline

• Market & Products from seaweed biorefinery
• Macroalgae species in a Nordic perspective
• Overview of four on-going R&D projects on seaweed biorefinery
  • SeaRefinery
  • MacroFuels
  • MAB4
  • MacroCascade
Typical markets and prices of seaweed derived products

- **MacroCascade**
  - Agar, Pharmaceuticals, Colorants, Global market size < € 500 million

- **MAB4/SeaRefinery**
  - Hydrocolloids, Food and Feed ingredients, *etc.* Global market size ~ € 1 billion

- **MacroFuels**
  - Energy (ethanol, methane), Fertilizer, Global market size ~ € 50 billion

- **Low-Value Compounds** < €1/kg
  - High-Value Compounds > €10/kg
  - Mid-Value Compounds €1- €10/kg
Business case: Market estimation of seaweed derived products

<table>
<thead>
<tr>
<th>Product category</th>
<th>Global market in Million €</th>
<th>Global market in tonnes DW</th>
<th>Average price kg/DW in €</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alginate</td>
<td>500</td>
<td>50,000</td>
<td>10</td>
</tr>
<tr>
<td>Mannitol</td>
<td>1000</td>
<td>142,857</td>
<td>7</td>
</tr>
<tr>
<td>Fucoidan</td>
<td>3</td>
<td>15</td>
<td>200</td>
</tr>
<tr>
<td>Laminarin</td>
<td>300</td>
<td>100,000</td>
<td>3</td>
</tr>
<tr>
<td>Plant Nutrition</td>
<td>500</td>
<td>52,632</td>
<td>9.5</td>
</tr>
<tr>
<td>Sea vegetables</td>
<td>100</td>
<td>6,667</td>
<td>15</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2403</strong></td>
<td><strong>352,170</strong></td>
<td></td>
</tr>
</tbody>
</table>

*Examples from MAB4 project*
Macroalgae species in Nordic perspective

<table>
<thead>
<tr>
<th>Species</th>
<th>Minimum yield (kg FW m(^{-1}))</th>
<th>Maximum yield (kg FW m(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Saccharina latissima</em></td>
<td>0.5</td>
<td>20.7</td>
</tr>
<tr>
<td><em>Alaria esculenta</em></td>
<td>3</td>
<td>6.8</td>
</tr>
<tr>
<td><em>Laminaria digitata</em></td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td><em>Laminaria hyperborea</em></td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td><em>Undaria pinnatifida</em></td>
<td>9.6</td>
<td>10</td>
</tr>
<tr>
<td><em>Saccorhiza polyschides</em></td>
<td>17</td>
<td>17</td>
</tr>
</tbody>
</table>


Technology Readiness Level (TRL) for Cultivation

*Saccharina latissima* (TRL=6-8)
Advanced cultivation of *S.latissima*

Increase biomass yield by a factor of 5
(from 1-6 kg/m² to 15-25 kg/m²)
Advanced cultivation of *S.latissima*

Up to 19 kg seaweed (wet weight) per meter in Norway (Hortimare)
SeaRefinery: The Seaweed Biorefinery – for high value added products

1. 1st November 2015 – 31st October 2018 (Duration: 36 months)
2. Funded by: Era-Net, Marine Biotechnology
3. Budget: ~ 2.6 million Euros (~1.4 million Euro granted)
4. Project coordinator: Danish Technological Institute, Denmark
   Prof. Anne-Belinda Bjerre
5. Consortium: 8 partners from five EU countries, incl. RTD, SMEs, and large enterprises
Objectives: To develop eco-friendly chemical and enzymatic processes to extract and purify high value-added components such as antioxidants (phlorotannin), hydrocolloids (alginate), and other bioactives (laminarin, fucoidan and protein) from cultivated seaweed in an integrated biorefinery.
SeaRefinery: Stepwise extraction

Step 1

- Dried Seaweed
  - 99% Ethanol extraction
    - 24 h
    - 400 rpm at room temp.
    - Centrifugation to separate
  - Polyphenol crude extract
  - Cellulose membrane filtration (0.2 μm)
  - Concentrated polyphenol extract

Solid fraction

Dry at 70 ºC

Step 2

- Water extraction
  - 4 % (w/w)
  - 2 h
  - 200 rpm at 60 ºC
  - Centrifugation to separate
  - Laminarin crude extract
  - Membrane filtration 100 kD pore size
  - Concentrated laminarin extract

Solid fraction

Extraction efficiency (%): 77
MAB 4 - Macroalgae Biorefinery for Value-Added Products
MAB 4 - Overview

- **Funded by:** Innovations Fund Denmark (Grant agreement no. 5157-00003B)
- **1st May 2016 – 30 April 2020** (Duration: 48 months)
- **Budget:** ~ 24 million DKK (Invested 11.8 million DKK by Innovations Fund Denmark)
- **Project coordinator:** Danish Technological Institute, Prof. Anne-Belinda Bjerre
- **Consortium:** 17 partners from Denmark (Faroe Islands), Belgium and the Netherlands, incl. RTD, universities, SMEs, and large enterprises
MAB 4 - Objectives

MAB4 aims at developing and exploring value-added products from seaweed for local and global markets within the food, feed and skin-care segments.

Specific research MAB4 aims at cultivating and refining two types of brown seaweeds for algal products and to develop mechanical, chemical and enzymatic processes for the extraction and valorization of high value compounds.
MAB 4 Polyphenol extraction by different solvent

Saccharina latissima, Harvested from May 2016, Ocean Rainforest, Faroe Islands

Table 1 Total phenol content (TPC) and DPPH inhibition (%) in the polyphenol crude extracts

<table>
<thead>
<tr>
<th>Solvent</th>
<th>( I (%)^a )</th>
<th>TPC (mg/L)(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>99% Ethanol</td>
<td>75.3 (± 1.67)</td>
<td>162.5 (± 6.08)</td>
</tr>
<tr>
<td>70% Ethanol</td>
<td>76.3 (± 4.71)</td>
<td>279.5 (± 6.29)</td>
</tr>
<tr>
<td>50% Ethanol</td>
<td>82.6 (± 3.82)</td>
<td>243.8 (± 12.36)</td>
</tr>
<tr>
<td>90 w/v% glycerol</td>
<td>36.8 (± 5.21)</td>
<td>630.2 (± 18.73)</td>
</tr>
<tr>
<td>50 w/v% glycerol</td>
<td>28.4 (± 5.85)</td>
<td>607.3 (± 6.57)</td>
</tr>
</tbody>
</table>

\(^a\): DPPH inhibition (%), \(^b\): Catechol Equivalent Total Phenolic Content
MacroCascade
Cascading Marine Macro-algal Biorefinery

Prof. Anne-Belinda Bjerre, Project Coordinator, Danish Technological Institute (DTI)
Project overview

- Call (part) identifier: H2020-BBI-PPP-2015-2-1
- Started 1st October 2016
- Duration 48 months
- 13 partners
- Budget: 4 156 356.25 EURO
Objectives:
MacroCascade aims to develop a **concept** of the **cascading marine macro-algal biorefinery** *i.e.* a production platform that covers the whole technological chain for processing sustainable cultivated macro-algae biomass – also known as seaweed - to highly processed value added products.
Impact of MACRO CASCADE

- Wild harvest of European macroalgae
- Cultivated and pre-conditioned macroalgae
- + 1st Cascade (Microbial refining for feed & food)
- + 2nd Cascade (Extraction/separation into commodities)
- + 3rd Cascade (Enzymatic refining of high value products)
- + 4th Cascade (Left-over residuals for fertilizers & energy)
MacroFuels – Developing the next generation Macro-Algae based biofuels for transportation via advanced bio-refinery processes

- 1st January 2016 – 31st December 2019 (Duration: 48 months)
- Funded under: the ‘Low Carbon Economy’ sub-topic in European Union’s Horizon 2020 (Grant agreement No 654010)
- Budget: ~ 6 million Euros
- Project coordinator: Danish Technological Institute, Prof. Anne-Belinda Bjerre
- Consortium: 11 partners from six EU countries, incl. RTD, universities, SMEs, large enterprises and sole proprietors

www.macrofuels.eu
Objectives:
MacroFuels aims to develop technologies to produce advanced liquid biofuels from seaweed for transportation i.e. aviation, cargo and truck fuels. The targeted biofuels are ethanol, butanol, furanics and biogas.
Objectives in pictures

1. Sun, CO₂, no added fertilizer
2. Advanced cultivation
3. Mechanical harvesting, storage, and logistics
4. Advanced biofuels
5. Advanced (bio)chemical fuel production
6. Advanced pre-treatment
Seaweed biorefinery

Seaweed → Fractionation → Proteins

Seaweed → Fractionation → Minerals

Seaweed → Fractionation → Sugars

Sugars → Thermo- & Biochemical conversion

Residues

Digestion

Residues

Feed/Fodder

Fertiliser

Fuels

Bulk Chemicals

High-value Chemicals

Biogas

ABE=0.4 g/g fermentable sugars

Ethanol end concentration ≥ 4%

≥ 350 L CH4/kg VS

www.macrofuels.eu
Acknowledgement

• SeaRefinery: ERA-MBT Joint Call Secretary

• MacroFuels: European Union’s Horizon 2020 research and innovation program

• MAB4: Innovation Fund Denmark

• MacroCascade: Bio-Based Industries Joint Undertaking under the European Union Horizon 2020 research and innovation programme

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