The Project is funded by the European Union

Techno-economic analysis of production and valorisation of seaweed

Macro Cascade - Project

H2020-BBI-PPP-2015-1

Jan Wilco Dijkstra

Dick F. Meyer

Deliverable D6.2

Work package 6

Project number: 720755

Summary

The Macro Cascade project aims to develop a cascading seaweed biorefinery concept. This production platform covers the whole valorisation chain starting from cultivation of sustainable cultivated macroalgae biomass (seaweed) up to the production of highly processed value added products. Task 6.2 of the Macro Cascade project aims to present a techno-economic assessment of the envisaged value chains.

The analysis was done considering a seaweed production of 10 $ktonne_{dw}$/yr, which is the size of a typical alginate plant. For the evaluation technical designs was made for seaweed production, storage and valorisation, including the development of mass and heat balance and equipment selection and sizing. These results were used for the economic evaluation providing the capital required and cost-plus prices for the main products which includes all costs including a 10% return on investments.

Cultivation of seaweed with a 1-dimenionsional concept

An economic evaluation of the cultivation of seaweed (*Saccharina lat.*) was performed. The cultivation concept was taken from literature and scaled to the required project size. The estimated costs for cultivated seaweed are 12 500 EUR/$tonne_{dw}$. The cost-plus price of cultivated seaweed contains almost equal shares of operating costs (56%) and capital related costs (44% for depreciation and margin on capital). In the operating costs a large share is in material costs for maintenance, with seeding and harvesting also being important.

Purchased equipment costs are dominated by the cost for the cultivation system (67%), while costs for seeding and harvesting also contribute. The total depreciable investment including seeding and harvesting equipment, deployment, indirect costs, contingencies and facilities are significant and are estimated at 276 MEUR for the projected project size.

Uncertainties are in the future costs reductions of the cultivation concept and in the cost structure of the future value chain. Variations on model parameters arrived at prices between 8 000 and 25 000 EUR/$tonne_{dw}$, with the largest impact from the investment cost (most importantly those of the cultivation rig) and seaweed yield (the amount of seaweed produced per rig per year), but price reductions may go beyond that range. The price for seaweed is significantly higher than the price for wild harvest seaweed (approx. 365 EUR/tonne), for which supply is however limited.

Storage of seaweed through either drying or ensiling

Preservation of seaweed can be done through ensiling or through drying, after which it can be stored in large storage tanks or a warehouse respectively. Both may have a

different effect on the composition and characteristics of the seaweed, which was beyond the scope of the analysis. The energy demand for drying is considerable, whereas it is negligible for ensiling. For the evaluation two scenarios are taken for the harvesting: 30 days and 125 days, which translate into required storage periods of 12 and 6 months respectively.

For the scenario with 125 harvesting days the cost for drying are the highest with 850 EUR/tonne$_{dw}$, whereas it is limited to 220 EUR/tonne$_{dw}$ for ensiling. This is because of the higher investment (12.3 MEUR for drying, vs. 9.4 MEUR for ensiling) but especially because of the higher energy cost for drying. For the 30-day harvesting scenario these costs are 436 for ensiling and 1 077 EUR/tonne$_{dw}$ for drying. In the parameter variation study, the largest uncertainty found for both preservation technologies is found in impact of the water content of the seaweed.

Valorisation of brown seaweed towards mannitol, laminarin, fucoidan, alginate, and solid residue product.

A biorefinery is evaluated as developed in close cooperation with WP4 of the Macro Cascade project. The targeted products are alginate, mannitol, laminarin (high-branched and low-branched), fucoidan and a protein containing solid residue product.

The main cost drivers in the cascading valorisation are the variable costs (71%), which are dominated by the price of cultivated brown seaweed. Assuming market prices for the co-products, and a seaweed price of 10 000 EUR/tonne, an alginate price of 84 000 EUR/tonne is found. Only when considering the price of wild harvest seaweed (365 EUR/tonne$_{dw}$), the alginate cost-plus price found (21 000 EUR/tonne) is the order of, but still higher than, the current market price of alginate (up to 12 000 EUR/tonne).

The cascading production of mannitol, laminarin, fucoidan and solid residue product next to alginate lead to increased use of the seaweed constituents. Compared to the conventional process for alginate production only, the revenues are increased with 66%. This can however not compensate for the significant increase in capital associated costs (with over a factor 4), which makes that the overall economics of this specific cascading case are worse than those of the alginate-only case. From the investments of the cascading sections it is seen that there is a not a single step that is dominating the investments. An improved process should aim at working with more concentrated streams to reduce costs for equipment and the costs of drying.

Valorisation of red seaweed to prebiotic oligosaccharides

Pre-biotic oligosaccharides can be manufactured via the extraction of xylans (polysaccharides) from red seaweed (*Palmaria palmata*), followed by enzymatic transglycosylation of the xylans. Alternatively, the xylans can also be used for the pre-biotic characteristics directly. The techno-economic evaluation is based on a high-level mass balance, an estimated heat demand and a high-level estimation of the investments. The cost for seaweed are assumed 10 000 EUR/tonne$_{dw,}$ but it must be noted that cultivation of red seaweed is currently very challenging. The main cost drivers in the process are the very large heat use and large investments for the recovery of solvent used for precipitation of the xylans. The cost-plus price of pre-biotic oligosaccharides (59 000 EUR/tonne) is one order of magnitude higher than the market price for common conventional pre-biotics. The cost-plus price of the xylans is 54 000 EUR/tonne, which is only a small reduction in relative terms since the contribution of the transglycosylation is relatively small. For economic feasibility it must be proven that the specific pre-biotics produced have an additional value compared conventional pre-biotics. This could come from pre-biotic activity, additional health benefits, or from marketing factors referring to the seaweed origin.

Valorisation of seaweed through functional feed and food by co-fermentation with canola meal

Seaweed and canola can be co-fermented, which improves the digestibility and allows functional components (prebiotics, probiotics and bioactive components) to be formed. The resulting feed has anti-microbial and anti-inflammatory activity which can be marketed as health-promoting feed since the need for antibiotics is reduced. With the same process, functional food for human use can be produced featuring the same anti-microbial and anti-inflammatory activity. Production is associated with stricter requirements for the canola meal and equipment used adding to the costs. Plant sizes were adapted to the anticipated market size of the products: 25 ktonne$_{dw}$/yr of seaweed/canola product and 8 ktonne/yr for food.

The results of the techno-economic evaluation show that the most important factor of the functional feed price is the seaweed price followed by the canola price. The cost plus price for the functional feed for the base case (using a seaweed price of 10 000 EUR/tonne$_{dw}$) is 1516 EUR/tonne with variations between 870 and 2700 EUR under the parameter range considered.

For food applications the price of feedstock canola meal is significantly higher compared to the feed application, as well as cost of equipment and amount of labour. The contribution of seaweed costs is limited to 18% (variations up to 32%), leading to and overall costs plus price of functional food of 4208 EUR/tonne with variations from 3500 to 5000 EUR/tonne under the parameter range considered.

Valorisation of residue streams and seaweed through anaerobic digestion

All waste streams from the processes considered have been evaluated for their suitability for anaerobic digestion. It was found that for processing of brown seaweed, waste streams from alginate production and mannitol crystallization are most suitable for fermentation. From the system for production of pre-biotic oligosaccharides the waste streams from xylans precipitation and from trans-glycosylation are both suitable.

The main cost driver and uncertain factor is the interface costs of the feed stream. For zero interface costs of the feed stream the cost are below the reference costs for natural gas-based heat. For negative interface costs (including waste disposal costs) the cost-plus price for heat is even negative. For cultivated seaweed gives heat that are two orders of magnitude larger than the reference price for natural gas generated heat which indicates that making a biorefinery CO_2 neutral by covering any net heat demand by anaerobic digestion will come at significant costs.

ACKNOWLEDGEMENT

This deliverable is part of the Macro Cascade project. This project has received funding from the Bio-Based Industries Joint Undertaking under the European Union Horizon 2020 research and innovation programme under grant agreement No 720755.