BioEconomy
Research & Advisory

Valorization of Marine Seaweed in a Blue Biorefinery

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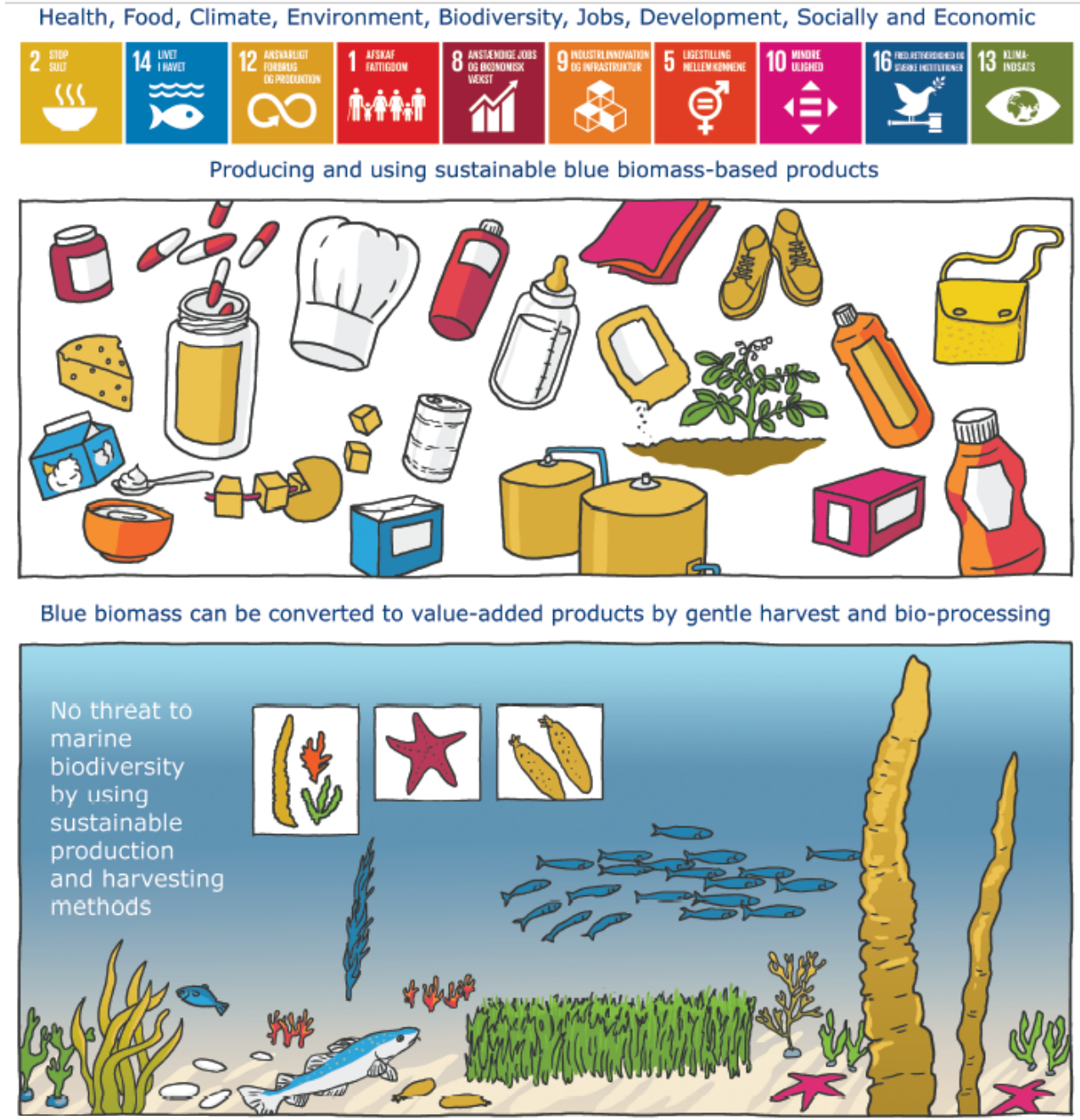
The Blue Bioeconomy

A significant contribution to Meeting several of the UN Sustainable Development Goals, locally as well as globally

”Blue Bioeconomy” folder now available in English, Icelandic, and Danish. Swedish version is in the tube

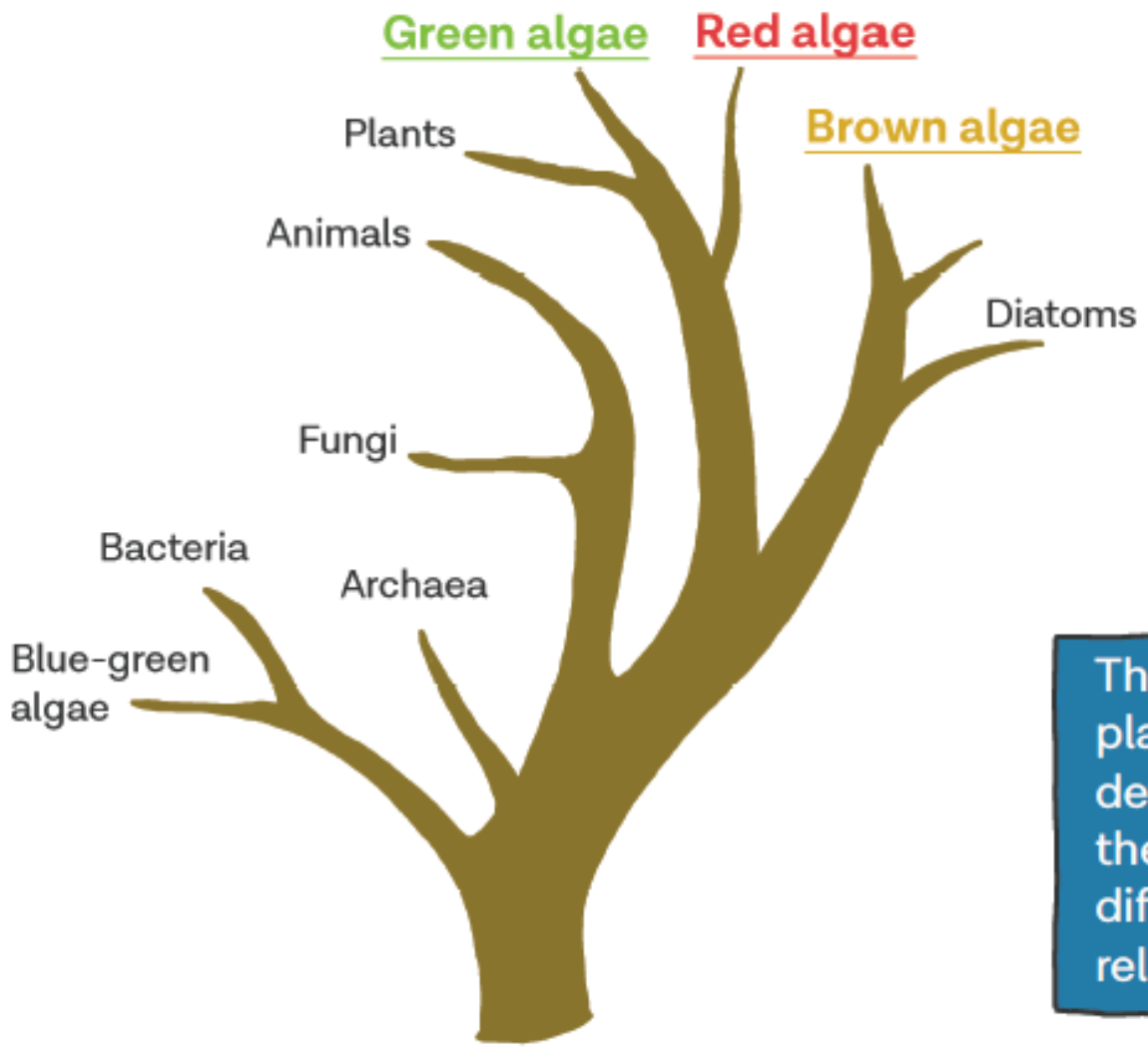


by Lene Lange, Urd Grandorf Bak, Steffen C. B. Hansen, Maria Dalgaard Mikkelsen, Anne S. Meyer, Eva Nordberg Karlsson, Pareskevi Polymenakou, Ioannis Pavlidis & Gudmundur Hreggvidsson. Illustrations by Johan Krarup

3F Fagligt Fælles Forbund

3F: Jesper Lund-Larsen

Brown, Red and Green algae are very different

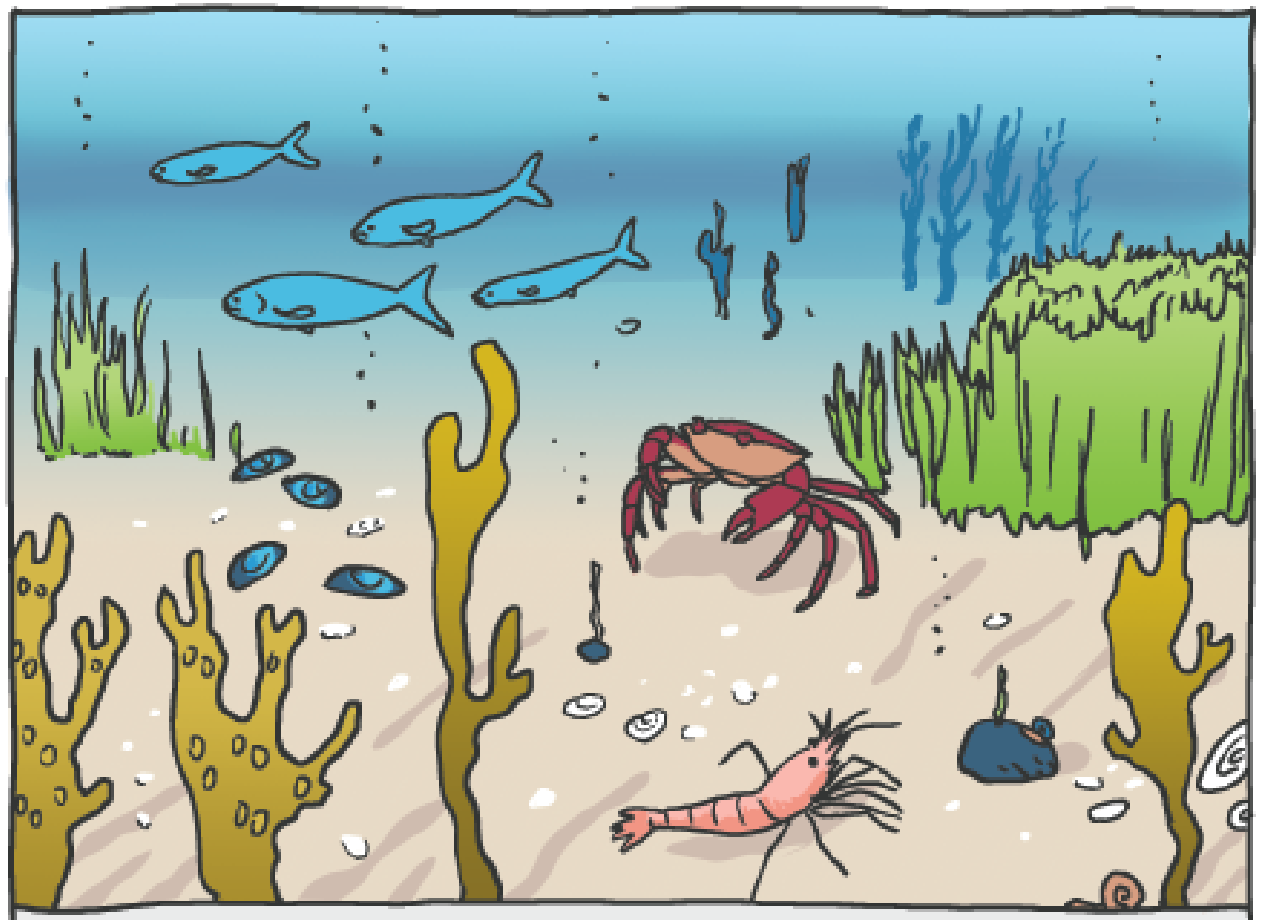


There are **three main groups** of seaweeds, the brown algae, the red algae and the green algae.

These three groups have through evolution developed to be very different from each other. DNA analysis has shown that these three types of algae are branched out from the Tree of Life at different points (see phylogenetic tree).

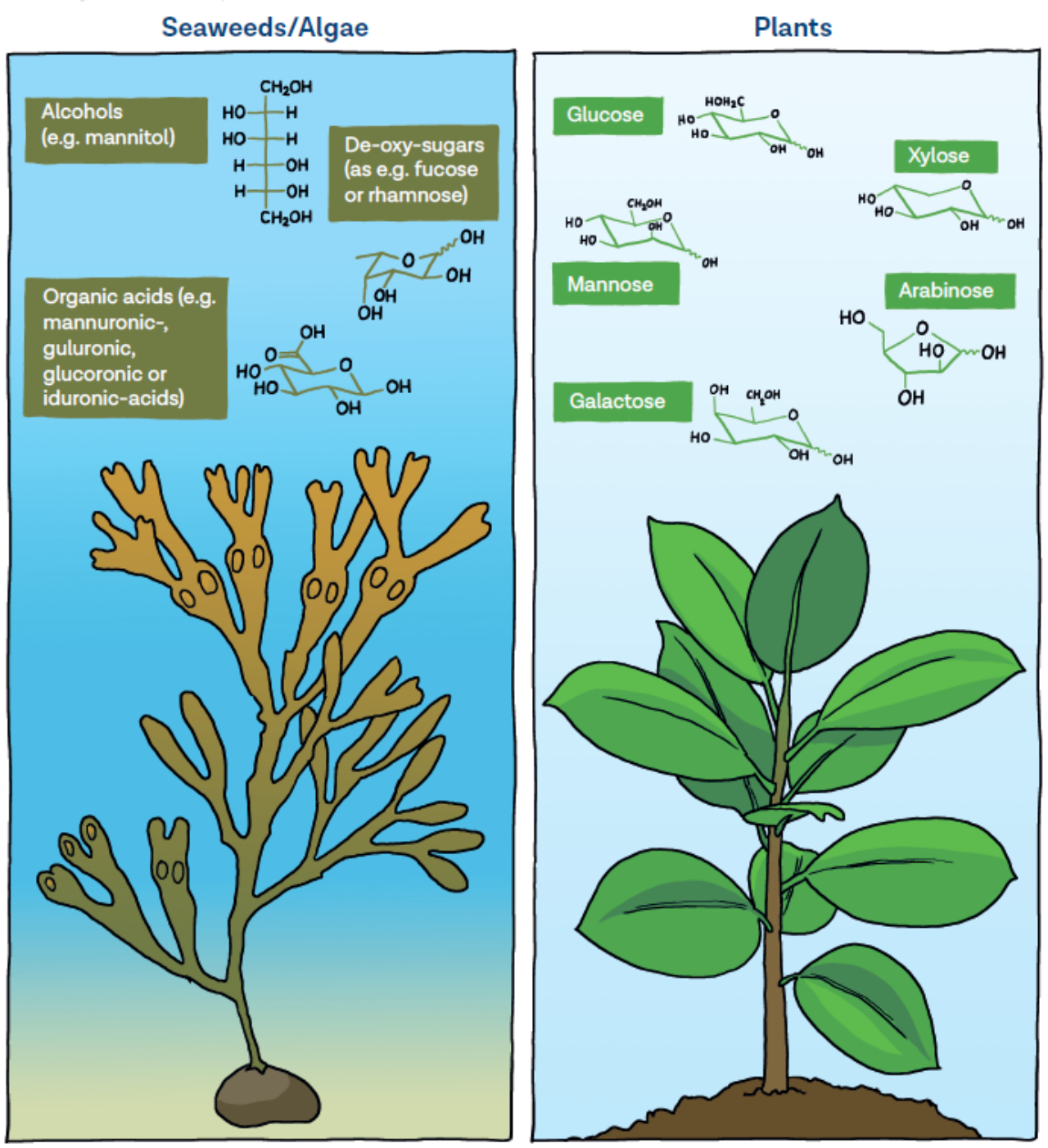
The green algae are closest to the terrestrial plants; the red algae are evolutionarily developed earlier than the green algae; and the brown algae are placed at a totally different branch of Tree of Life, closest related to diatoms.

Cultivation of Macroalgae most be sustainable –not harming the biodiversity of the sea



A healthy sea has clear water, hard sand and many species of fish, seaweeds, shrimps, snails etc.

- Seaweeds capture and use large amounts of CO2 as they grow. Seaweeds utilize nutritious compounds from the marine water.
- Waters close to the shores are often polluted by run-off of too much nutrients from agricultural land.
- Cultivating seaweeds in such areas can contribute to reducing the pollution as the algae use the excess nutrition for growth; and reduced level of pollution contribute to stopping loss of biodiversity.



- **Seaweeds hold other types of chemical compounds, and contain different types of carbohydrates, than plants**

- Many algae have have no **lignin** as seaweeds do not need strengthening their thallus to be kept upright as the water is supporting them

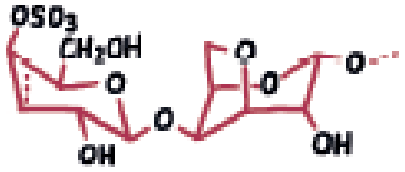
- The lack of lignin in the seaweeds makes it easier to process the seaweed biomass

The unique Biochemical Building Blocks of Algae/Seaweeds

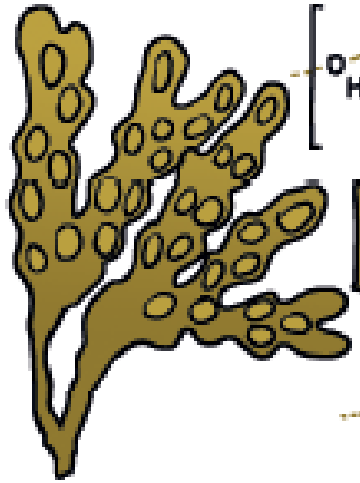
From red algae you can extract and recover:

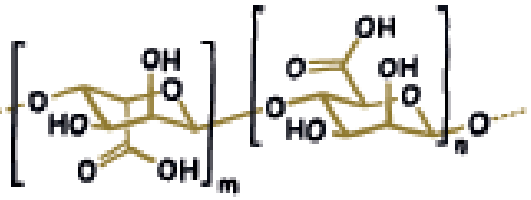
Agar

and carrageenan

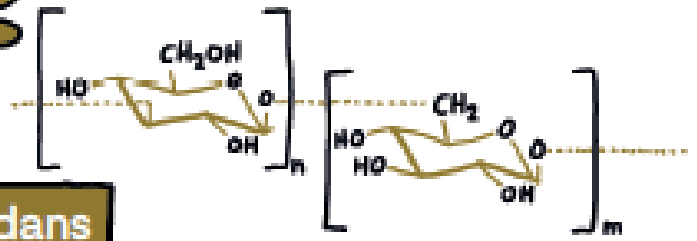


From brown algae you can extract and recover:





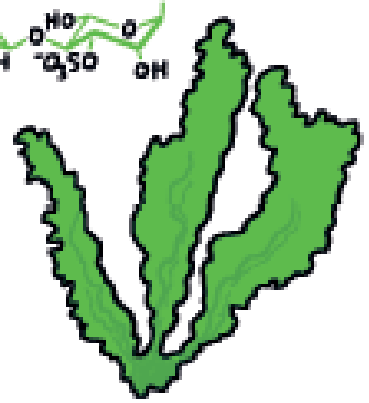
alginate, laminarin



and fucoidans

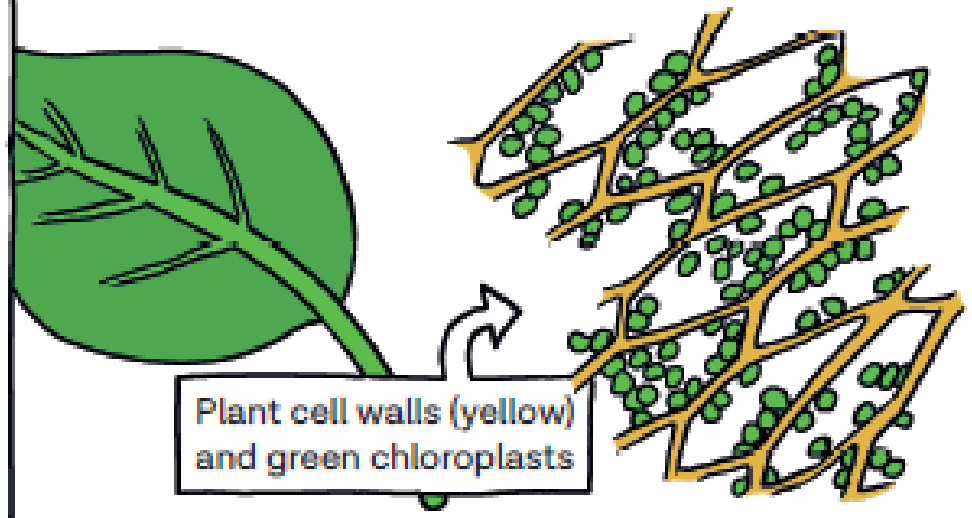
From green algae you can extract and recover:

Ulvan

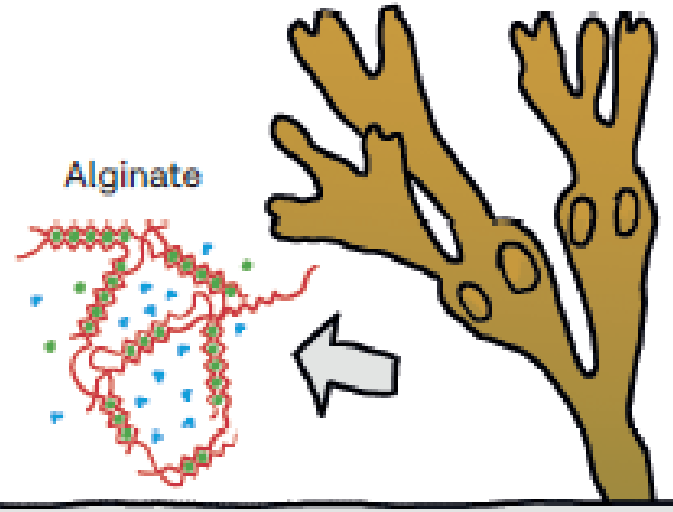


And a special type of cellulose, with a characteristic unique crystallite-structure.

Algae/Seaweed carbohydrates are very different from what is found in plants (see p8).



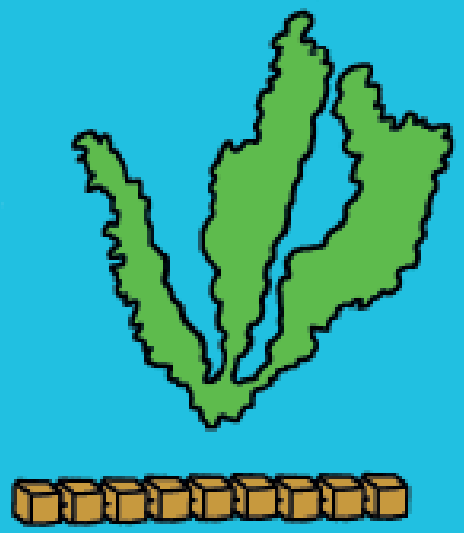
Uronic acid



Interestingly, the same type of biochemical building block, e.g. Uronic acid is used to form different types of compounds: In plants, Uronic acid is used for making pectin cell wall materials.

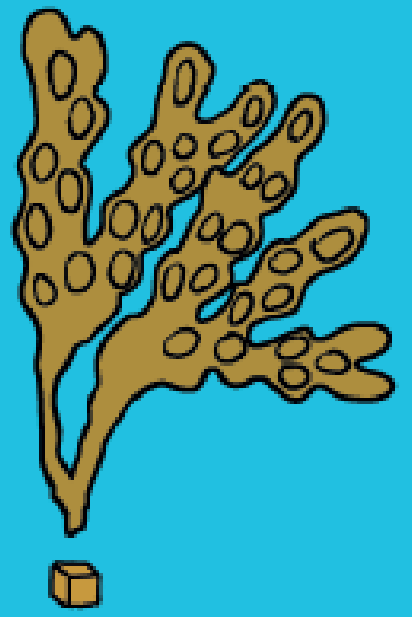
While in algae Uronic acid is used as building block in alginate; alginate gives the algae its viscous texture, withstanding both waves and high level of salt.

Cellulose in algae? The main part of cell wall materials of terrestrial plants is cellulose and lignin. In seaweed there is almost never lignin and most often only very limited amounts of cellulose.



Most cellulose fibers are found in green algae (closest related to the terrestrial plants).

Less cellulose is found in red algae.



And almost nil cellulose is found in the brown algae.

Further, there is no starch or gluten in seaweeds.

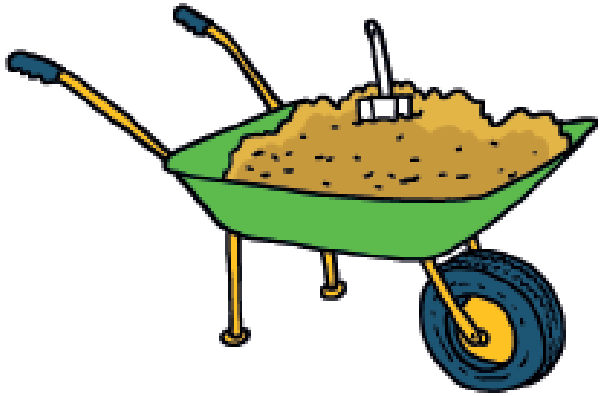
Health, Healthy Food Ingredients and Food

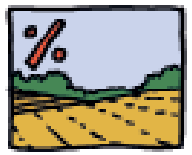
Healthy and delicious food from seaweed

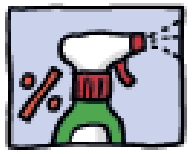
Using seaweed daily for consumption has for centuries been an integrated part of the healthy Asian food in Japan, Korea, Thailand and China. In the Nordic countries consumption of seaweed has grown dramatically over the last decades. It is used fresh or pickled in salads, for sushi wrapping and as ingredients in e.g. crackers and many gourmet dishes. The amino acid profile of seaweed proteins opens for developing the characteristic Umami flavor of seaweed containing dishes.

The technology development for sequencing the gut-microbiome has opened a new type of research. It is now possible to demonstrate the effect of specific food or feed ingredients on the gut microbiome in man or animals. More specifically, claiming a specific food or feed ingredient to be gut-health promoting can now be better supported by scientific evidence.

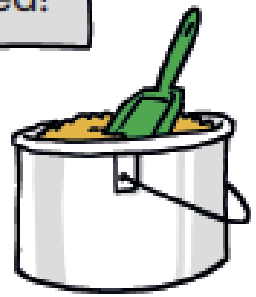
Animal feed can be produced sustainably from seaweed without use of land, pesticides, fresh water or fertilizer.

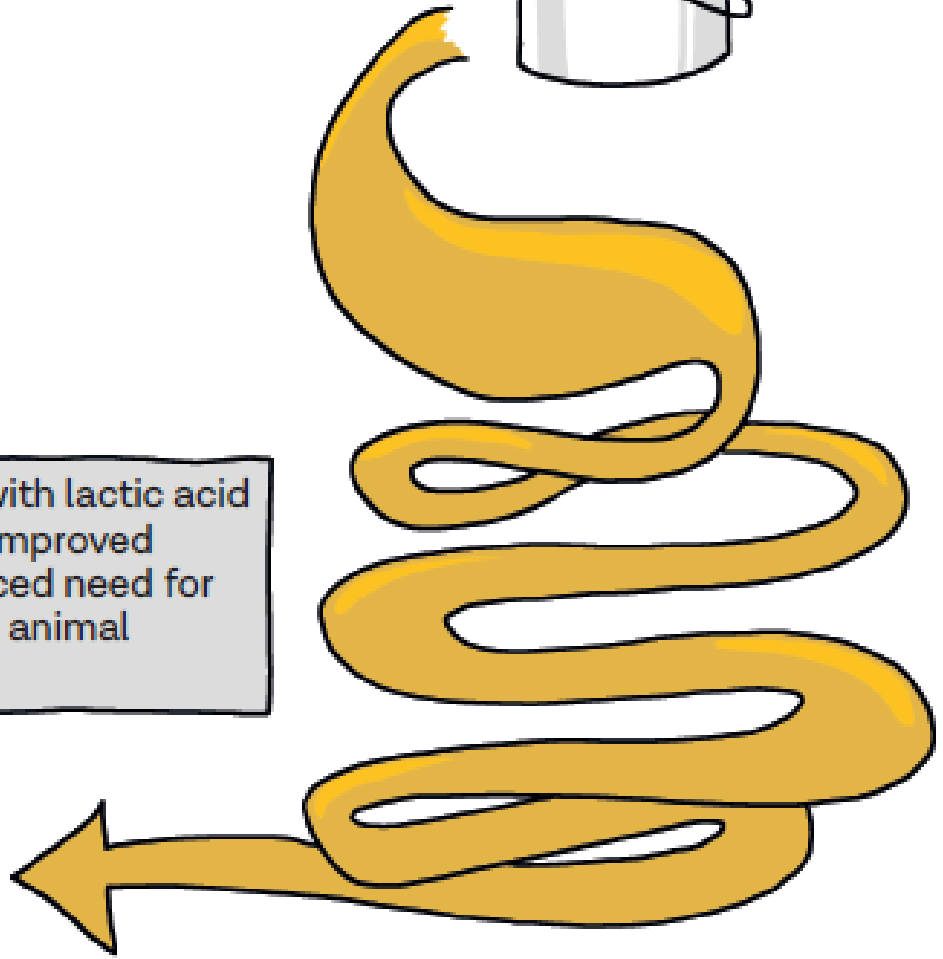




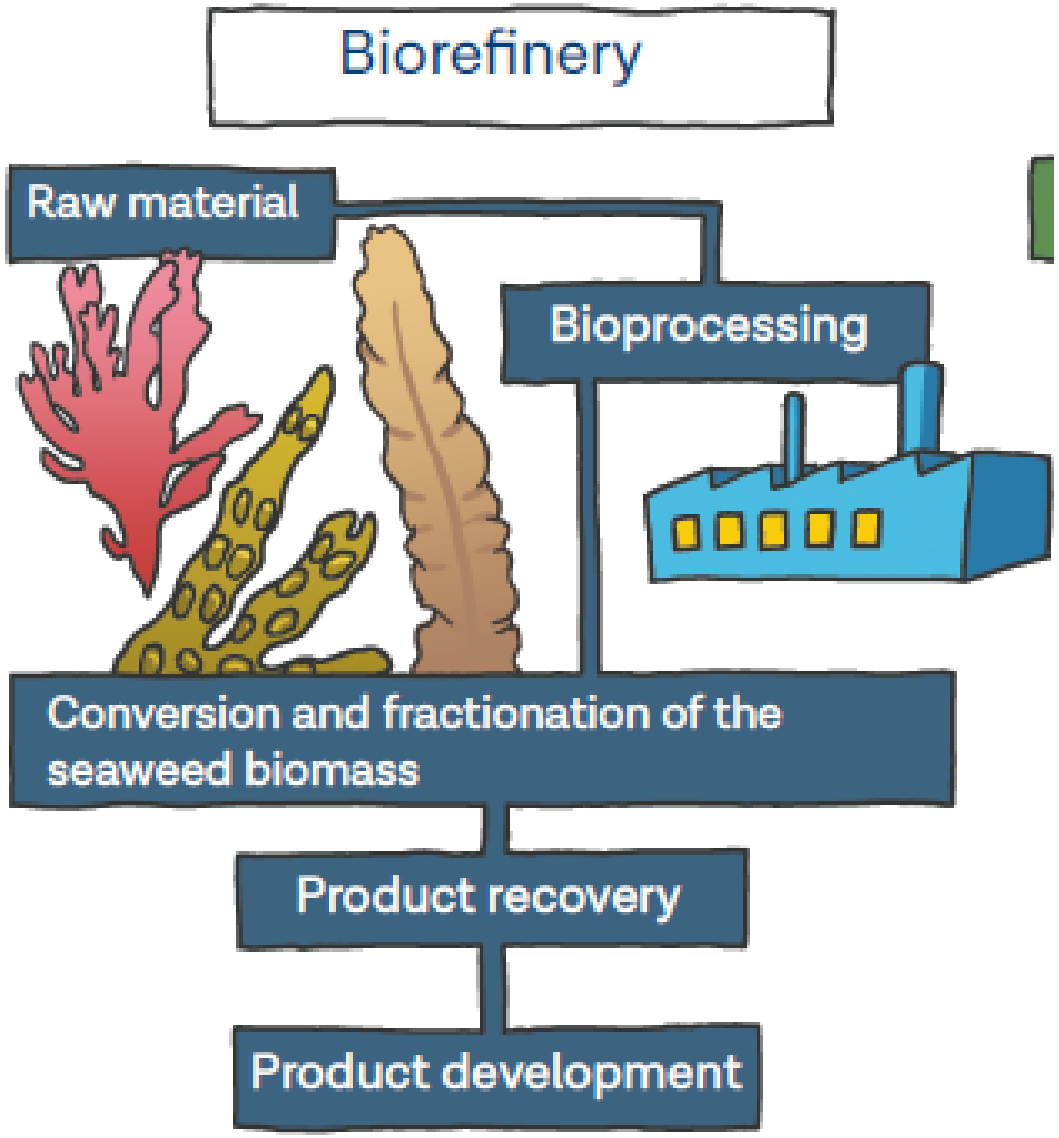


Gut-healthy feed!





Seaweed-based animal feed, e.g. fermented with lactic acid bacteria, can improve gut-health of e.g. pigs; improved gut-health can lead to reduced need for antibiotics and improved animal welfare.



Seaweed Biorefineries

- Sustainable exploitation of seaweeds can open up locally for new start-ups and SMEs, by attracting investments e.g. from existing industries, nationally and internationally

Seaweed Biorefineries can produce high-value products

- Coastal cities can attract both locally cultivated and wild harvested seaweed; and state-of-the-art seaweed biorefineries can expand its capacity to attract also seaweed biomass cultivated or harvested by other countries

Examples of Nordic Seaweed-based companies

"Nordisk Tang" develops consumer-attractive and accessible seaweed-based products.

"CP Kelco" produces natural food ingredients based on red seaweed biomass and citrus peels.

"Leroy" is a Norwegian producer of quality products from the sea.

"Ocean Rainforest" is a Faroean company, cultivating seaweeds and produces seaweed-based products for food, cosmetics and packaging. Several types of new products in the tube.

"Dansk Tang" develops delicious food products based on seaweeds. Sustainability is a prime priority.

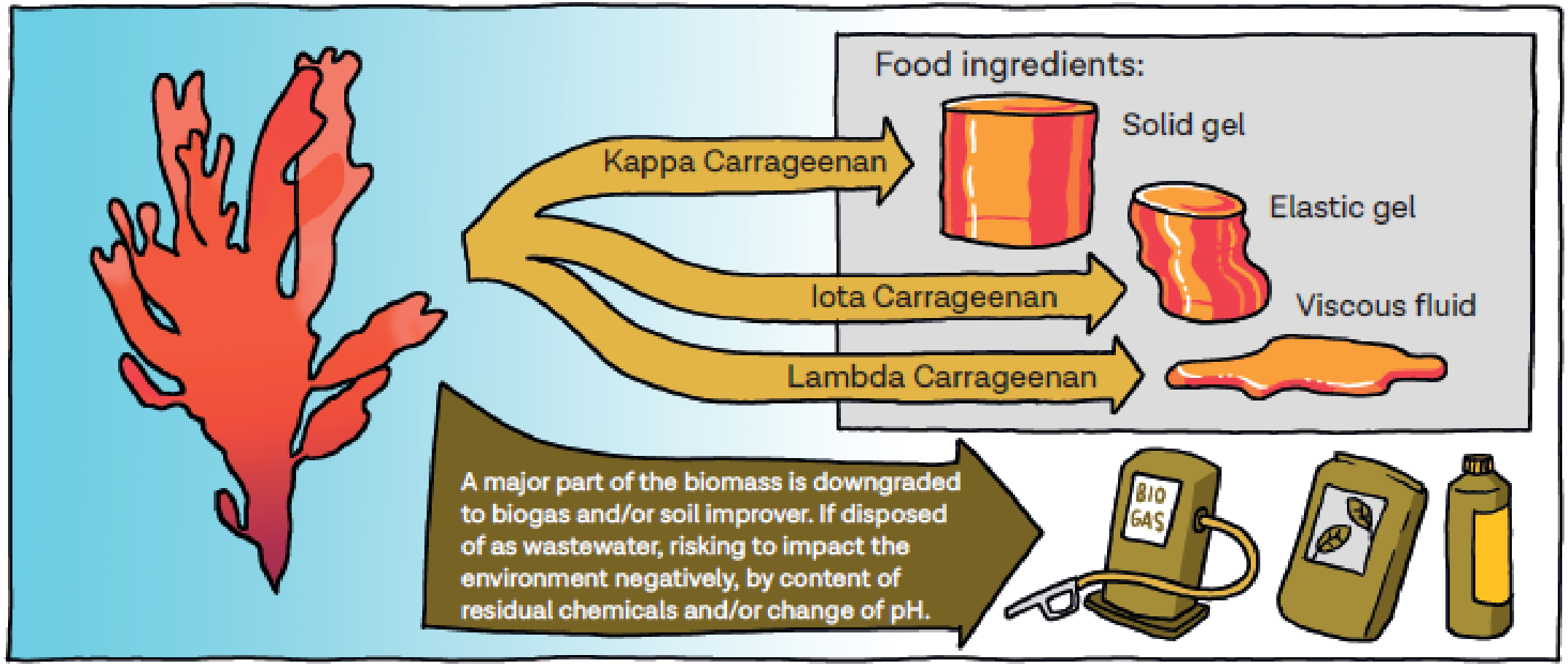
"FMC" produces food ingredients and (water soluble) capsules for pharmaceutical products from seaweed.

"Enzymatica", A Swedish company, developing and selling medicine-based on marine biomass.

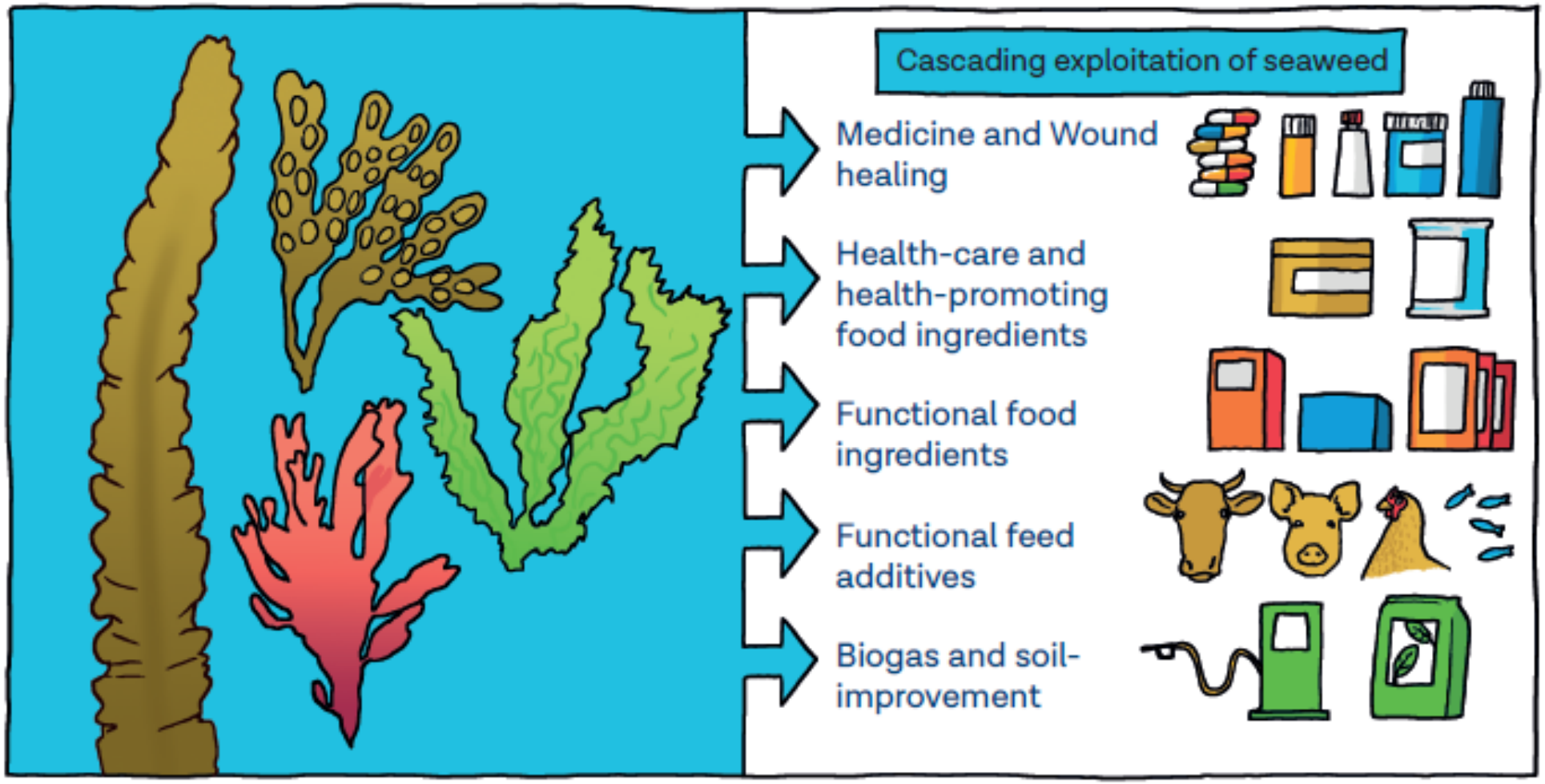
"Oceanbasis GmbH" markets a range of cosmetics and food products based on seaweeds.

"Oceanium" produce products from sustainably-farmed seaweeds based on biorefinery technologies.

Classical exploitation of seaweed biomass focuses on extraction of one major component of the seaweed, e.g. carrageenan, which is used in food processing industries as a hydrocolloid to give the final product the desired viscosity due to its gelation properties. Such processes build on combining chemical treatment, sequential change of pH and separation and recovery technologies. The residual parts of the seaweed biomass are typically downgraded to biogas, as soil improver, or discharged with the wastewater.



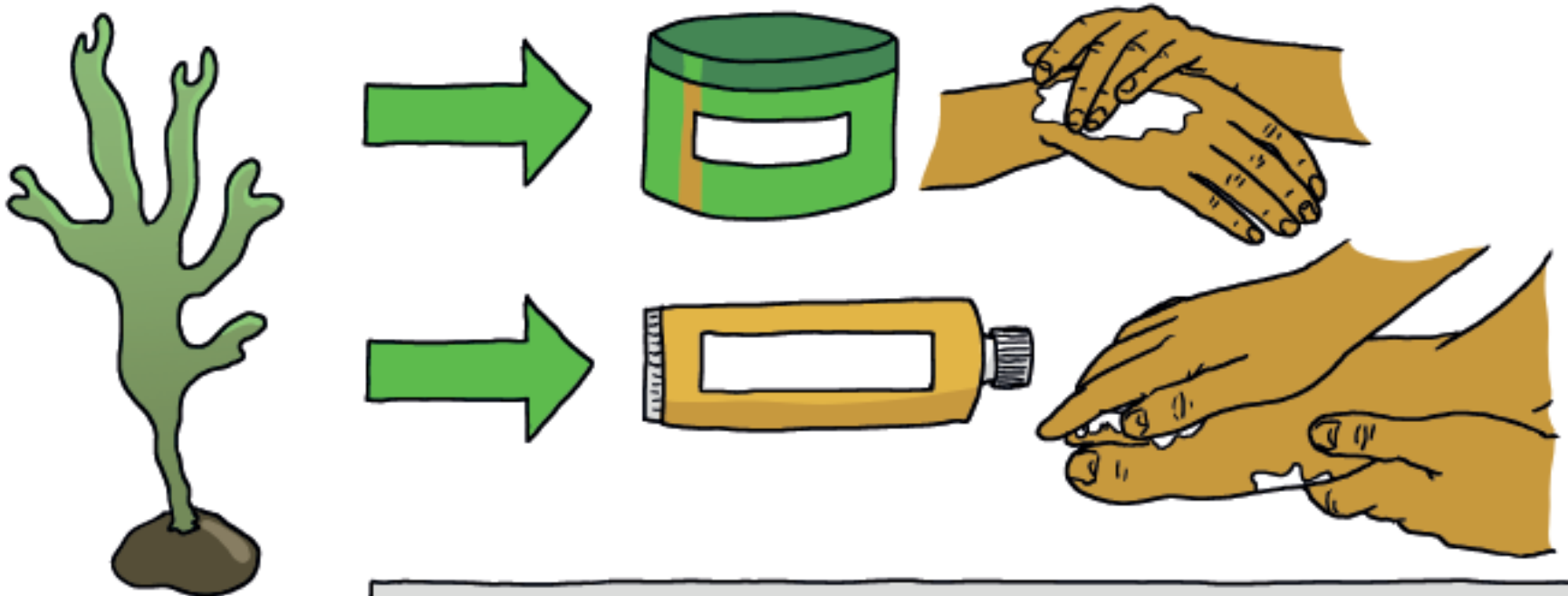
A new exploitation approach to seaweed biorefinery is focusing on optimized use of all components of the biomass and by applying environmentally benign bioprocessing technologies, using several types of enzymes. Further, in this new seaweed biorefinery concept, focus is also on gentle but efficient separation and recovery technologies, which do not harm environment. The cascading approach to seaweed biorefinery is applied: recovering the highest value, highly complex products upfront; the less valuable components can then be developed to a range of products, for which there are consumer demand and market potential.



New Seaweed-based non-food Applications

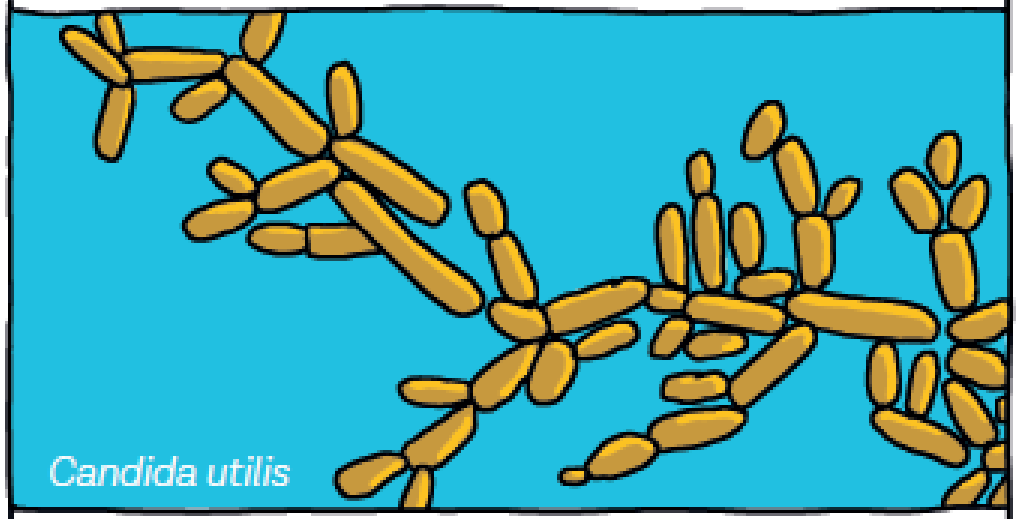
Facts: Seaweeds are surrounded by saline water without diluting their own thallus, through osmosis or leaking.

Inspired by this fact of marine algae lifeforms it has been tested and documented that certain seaweed components can have a positive effect on human skin; softening the skin and protecting the humidity of the skin; sold and used for promoting both health and beauty.



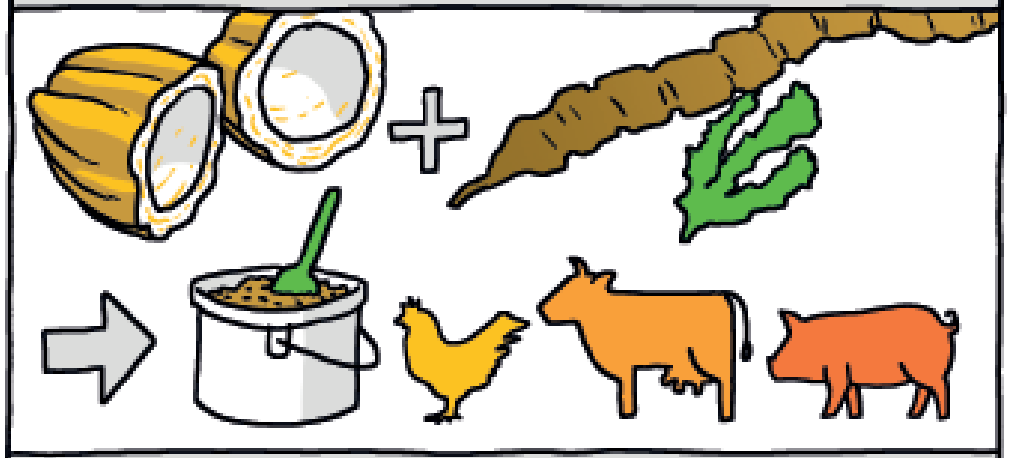
More important, seaweed-based ingredients have in many types of products been shown to have wound-healing effects. Need for wound-healing is rapidly increasing, both due to an aging global population and due to a steep rise in the number of diabetes patients; where tissue is at risk to die faster than wounds heal.

A substrate for growing single cell fungal proteins (e.g. yeast biomass, *Candida utilis*) can be produced by adding seaweed biomass to wood paste (= ammonium-sulphate-treated wood-residues). Recipe: Add seaweed to the wood-paste, supply the necessary level of nitrogen required for the fungus to produce its proteins, essential for fungal growth:



The result is a nutritious "fungal single cell protein, suitable for animal feed", also known as "Yeast cream". The high nutritious value of Yeast cream was documented through many years the S. *cerevisiae* yeast biomass from production of human insulin by Novo Nordisk was provided and applied highly successfully for pig feed.

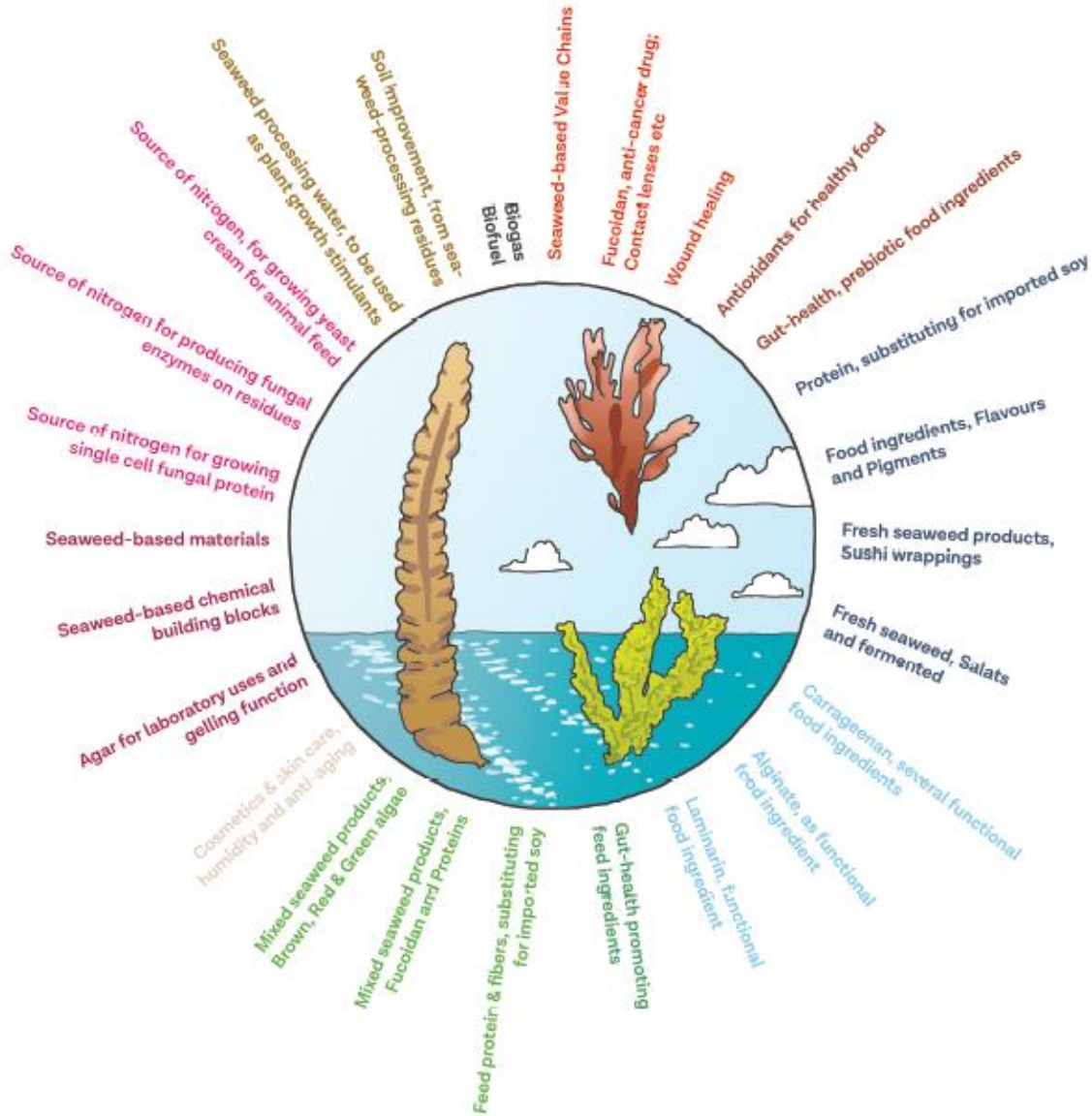
In Ghana, West Africa, successful upgrading of coco-pods has been shown by adding locally harvested seaweed biomass (primarily green but also brown algae). Again, the seaweed biomass has the effect of supplying nitrogen to support the growth of wood-degrading fungi. Notably, the culture broth of the cultivated wood-degrading species, holds a blend of enzymes, which can be used to convert the recalcitrant coco-pods biomass to animal feed.



Notably the harvested culture-broth from the wood-degrading fungi can also be recovered and used for biorefinery upgrade of other types of crop residues or industrial side-streams (e.g. cassava pulp, residual after extraction of starch).

Seaweed is HOT!

Below is an overview figure from an Introductory chapter to the new book: Technologies for sustainable cultivation and exploitation of seaweed (Elsevier; Lange et al, 2020).



Marine microbial lige is a goldmine of fascinating lifeforms and products

- Marine microbes can live and flourish in some of the most extreme environments on the planet, such as hydrothermal vents or submarine volcanoes, geothermal hot springs, deep terrestrial subsurface, or extreme deep ocean trenches
- They can thrive in extreme hot niches, 122°C, in frozen sea water at −20 °C, in high salt solutions, in acidic (pH=0) and alkaline environments (pH=12.8) and at high pressures, up to 110 Mpa!
- The marine microbiome contains billions of genes encoding the ability of producing extraordinary and unique functional and metabolic properties; they express and secrete an unimaginable arsenal of proteins and small molecules, as well as other classes of products with great potential in different biotechnological sectors.

Vision: Producing seaweed-based Products for the Future by more simple, lower Cost processing?

1. As we have now identified and described a range of compounds from seaweeds with value added potential, maybe we can produce even better products in the future, holding several types of compounds in one and the same product? – being less costly to produce as the raw material is utilized better and less efforts are needed for separation and recovery.

It could e.g. be products, which include both nutritious proteins and gut-health-promoting oligo-sugars?

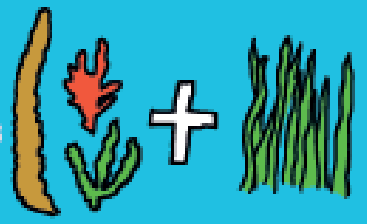
Or a product, which includes health-promoting fucoidans, which are notoriously difficult to purify along with a content of seaweed proteins and antioxidants?

For both examples, the residual polymer fractions could be used to generate natural functional carbohydrates ...

...e.g. as basis for producing functional food ingredients?

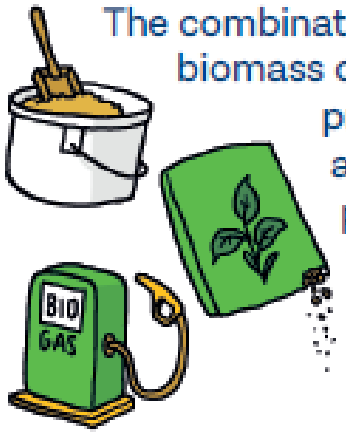
Or as ingredients in skin care products?

2. Another possibility is to harvest and process seaweeds (an algae) and seagrass (a plant) together in one go?



Or similarly, harvesting duckweed (a flowering plant, floating on water) and algae together?

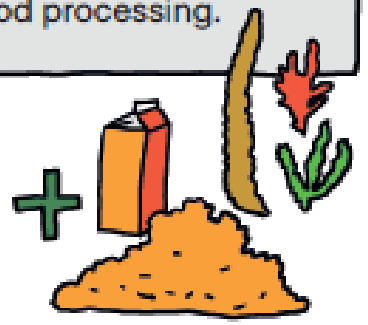
Or -in tropical and sub-tropical areas, harvesting seaweed and water hyacinths together?
– notably water hyacinth is often a nuisance locally, as it can grow so dense that it is blocking for boat-transport in lakes and rivers.

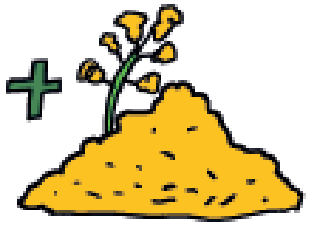


The combination of duckweed and seaweed biomass can be used as feedstock for producing animal feed as well as biogas plus soil improving products (the latter made from the residual digestate after biogas production, enabling returning minerals back to the soil).

3. A third option is to mix seaweed biomass with side-streams from industrial food processing.

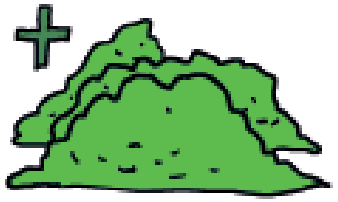
E.g. seaweed biomass mixed with press pulp after juice production, to be used as growth substrate for growing filamentous fungi; hereby enriching the protein content for animal nutrition?



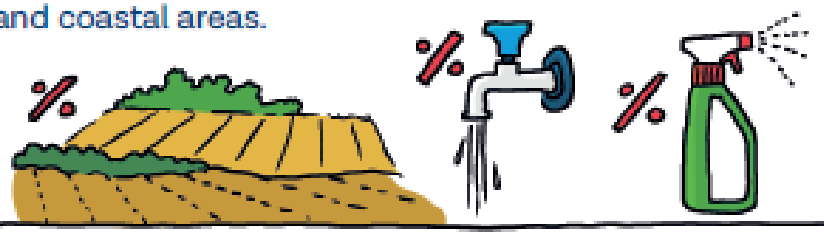


Or co-fermenting seaweed with press pulp from rape seed oil production and use the composite product as animal feed?

Or mix the seaweed with the fibrous pulp from the green biorefinery (after protein has been extracted) and make it into a new gut-healthy food ingredient?



With this approach nutritious and gut-health-promoting food and feed products can be produced without use of extra land, water or pesticides! With add-on social benefit by generating jobs and improved livelihood, locally and in less developed rural and coastal areas.



Hotspots for Exploitation of Seaweed globally

Socio-economy: Sustainable, upgraded use of the Blue Biomass gives basis for Job-creation and Development in both coastal and rural Areas

Many types of skills, talents, specialization, interests and educations are needed for cultivation, harvesting, processing, product development, marketing and sale of seaweed-based products. Similarly, there are many jobs for many types of skills in upgrading fish-processing cut-offs, innards, by-catch and invertebrates as sea stars and sea cucumber. Notably, seaweed exploitation opens new opportunities for women in developing countries.

Even more jobs, followed by more both socially and economic development are achieved, when the seaweed and other types of blue biomass are used as basis for production of the many types of specialized products:

To food and feed.

To new types of textiles, for health and gourmet deliciousness.

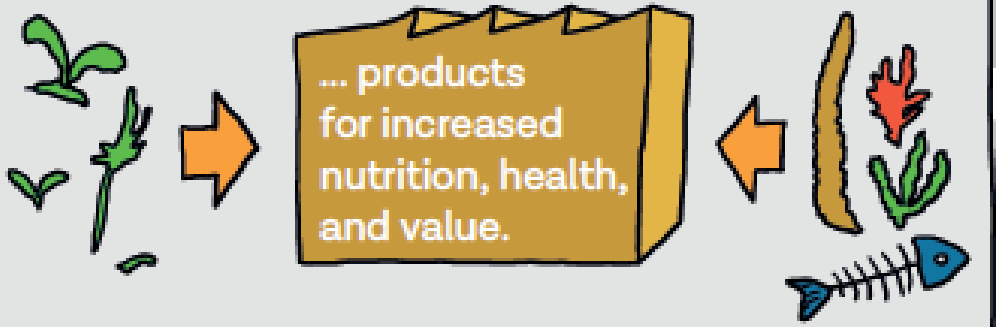
To new functional ingredients (e.g. to give soft ice or tooth paste the preferred consistency)

The coastal Blue Biorefinery, efficiently uses fish-cut-offs and Seaweed as feedstock –plus food processing sidestreams?

If you for every current fish processing factory, establish an add-on production for upgrading also the cut-offs and the innards of the fish -then you could stimulate livelihood, job-creation and economic development in coastal areas.

Notably, when using only the filets for food 50% of the fish is going wasted!

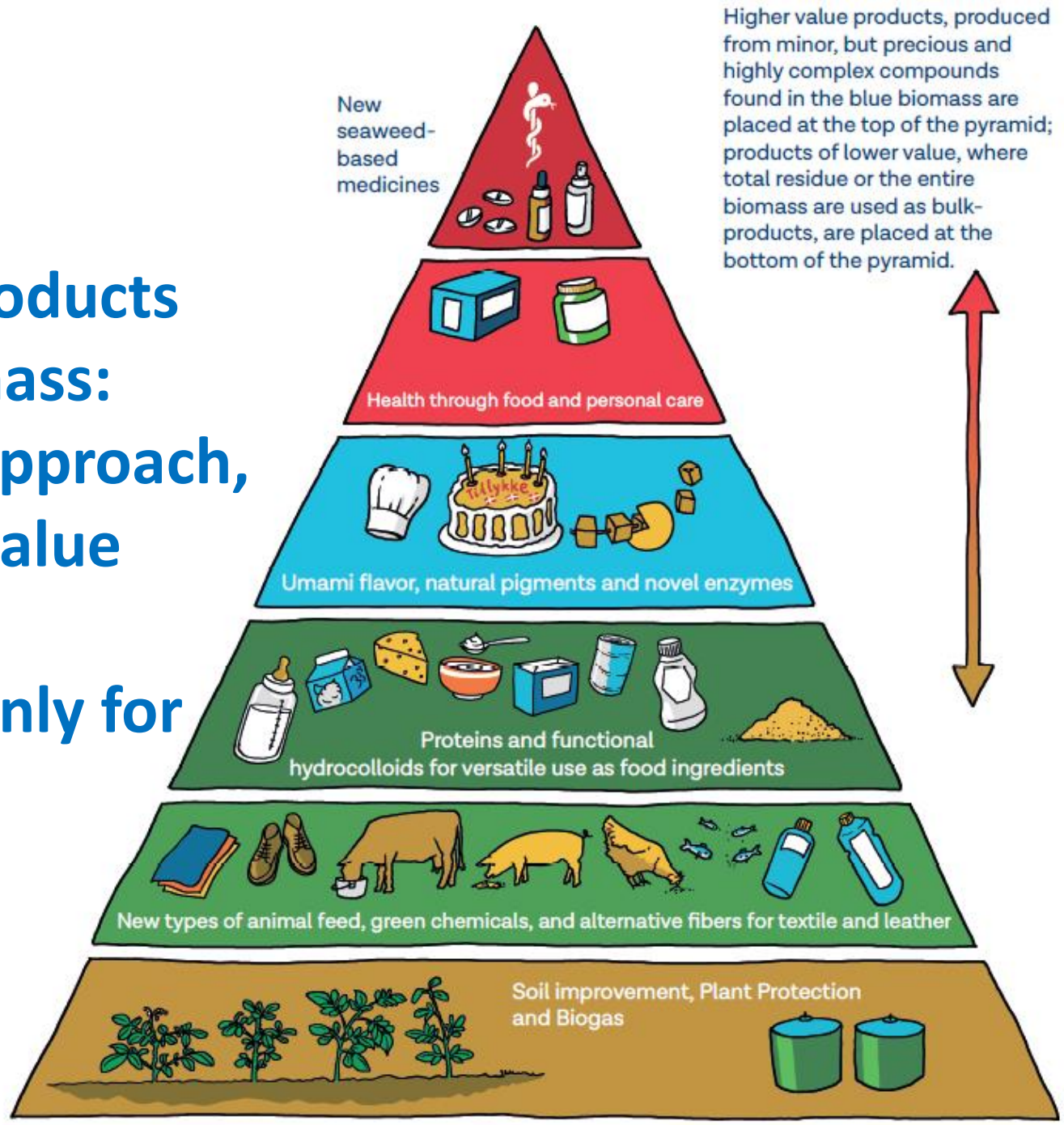
Even more development is possible if the aquatic, blue biomass (seaweeds and cut-offs etc) is combined with residues and side-streams from terrestrial agricultural food processing. Then there are options for...



Notably, the customers for blue biomass-derived products are often the same, indiscriminately of the products are being produced from biomass of seaweed or fish-cut offs.

Blue Bioeconomy contributes to several UN Sustainable Development Goals

Value Pyramide: Products from the Blue Biomass: Choose cascading approach, recovering higher-value products first
-use residual part only for low value products



Thanks a lot for your kind attention

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