Interreg Baltic Sea Region

Co-funded by the European Union

CIRCULAR ECONOMY Blue-Green Bio Lab

Initiating bio-industrial symbiosis based on blue and green biomasses: A toolkit for local authorities

Graphic: Lyskil Municipality (Sweden)

Blue Green Bio Lab Associated Partners:

Food & Bio Cluster Denmark

Kurzeme Planning Region

Innovatum science park

Chalmers Industriteknik

CBIO Aarhus University Centre for Circular Bioeconomy

Blue Green Bio Lab Partners:

Lysekils Kommun

Skive Kommune

Klimafonden Skive

Zemgale Planning Region

Latvian Institute of Aquatic Ecology

LEVA i Lysekil

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Blue Green Bio Lab Associated Partners:

Blue Green Bio Lab Partners:

Introduction to the Blue Green Bio Lab project

This Blue Green Bio Lab project targets the urgent challenge to reduce the influx of nutrients to Baltic Sea Regional waters, limit Green House Gas (GHG) emissions, and quickly enhance European self-supply with food, feed, and energy. Together, aquaculture, agriculture, and industry can provide solutions to these challenges by connecting industrial symbioses based on full exploitation of local blue/green biomasses that are initially grown and/or harvested with the particular objective to produce positive ecosystem services.

In "bio-industrial symbioses" (BIS), each company produces bio-products and transfers residuals as resources to the next company in the chain. Thus, one biomass leads to more consumer goods across sectors, and to an improved local environment. The very production of e.g. grass, mussels or seaweed, that have the potential to supply a BIS, improves carbon storage and reduces nitrogen deposits to the atmosphere and water. BIS is a vital part of a circular economy, which focuses on providing environmental, financial, and social benefits.

Experience has shown that local authorities can play crucial roles in initiating industrial symbioses. Industrial symbioses can also benefit municipalities through attracting companies, creating jobs and supporting the development of a strong local brand.

A few industrial symbiosis toolkits are already available, for example:

- Guide: How can municipalities support the development of industrial symbiosis
- Guide for Industrial Symbiosis Facilitators

Practitioners from local authorities, however, lack a toolkit, that addresses the enhanced complexity when the symbiosis is closely linked to the landscape and primary production (agriculture, aquaculture). The Blue Green Bio Lab Toolkit therefore targets these practitioners and shares our experiences about taking the initial steps to:

- Identify local resource streams
- Facilitate discussions and support value-chain development through workshops
- Mediate conducive policy environments

This Toolkit is developed in the small-scale project Blue-Green BioLab Across the BSR with financing from Interreg Baltic Sea Region. We have formulated a generic manual supplemented with case-based briefs from the project partners where relevant biomasses are selected, methods for collaboration in workshops are brought to use, and challenges are identified in policy contexts. The methods are developed and tested in practice in Lysekil Municipality (SE), Skive Municipality (DK) and Zemgale Planning Region (LV).

Blue Green Bio Lab project partners

Cooperation in the Blue Green Bio Lab has been undertaken by the 6 partners and 5 associated partners in the project.

Partners

- Skive Municipality (DK)
- Climate Foundation Skive (DK)
- Lysekil Municipality (SWE)
- LEVA in Lysekil (SWE)
- Zemgale Planning Region (LV)
- Latvian Institute for Aquatic Ecology (LV)

Associated Partners

- Aarhus University, Center for Circular Bioeconomy (DK)
- Food and Bio Cluster Denmark (DK)
- Innovatum Science Park (SWE)
- Chalmers Industriteknik (SWE)
- Kurzeme Planning Region (LV)

Map showing the location of the Blue Green Bio Lab partners.

Extra materials

During the project, additional analyses were done to advance our understandings of circular bio-industrial symbiosis potential with blue and green biomasses. Therefore, two additional studies were conducted:

- Water and wastewater supply for a bio-industrial symbiosis park, by LEVA i Lysekil
- Additional report on biomass types, by Anda Ikauniece, Latvian Institute of Aquatic Ecology

For more information about the Blue Green Bio Lab project please visit the project website at: [Blue-Green Bio Lab- Interreg Baltic Sea Region (interreg-baltic.eu)]

Blue Green Bio Lab Toolkit
Introduction to the step-by-step guide

This step-by-step guide is based on experiences from local/regional authorities as facilitators for business development within the circular economy through Bio-Industrial Symbiosis (BIS). Previous findings indicate that municipalities can play a significant role in seeding and fostering the development of local symbioses, and there are various approaches to this role. The various roles that municipalities can take is discussed more in depth on pages 6-9 in Guide: How can municipalities support the development of industrial symbiosis?

The Blue Green Bio Lab Toolkit provides in-depth learning and details of our process in starting up discussions on bio-industrial symbiosis, drawing from the approaches utilized in the Blue Green Biolab project and our experiences employing the methods described. For each step in the guide, a set of briefs has been developed, serving as specific cases to illustrate how we worked through each stage and what outcomes were achieved.

The guide is structured into three steps, mirroring our work process:

1. **Selecting biomasses**: Gathering data to map local blue and green biomasses with symbiosis potential and contributing to ecosystem services such as nutrient and CO_2 absorption.

2. **Engaging stakeholders:** Bringing together relevant individuals and for workshops to disseminate knowledge and generate local awareness about circular potential with the chosen biomasses. This step aims to plant the initial seeds of new ideas and thinking, allowing stakeholders to envision themselves as part of a future BIS. All workshops were designed as participatory workshops and a generic design was adjusted to local needs.

3. **Working with polic**y- it is essential to examine regulatory and other barriers that may hinder the implementation of market-driven bio-industrial symbioses. In our case, we gathered and began to work further with relevant insights from the national-level workshops and reviewed experiences from other symbiosis projects and research.

The step-by-step process is outlined also contains iterative and interactive components. For instance, examining legislation and regulation are important in the selection process for biomasses with potential in the circular economy and can potentially hinder stakeholders from developing circular processes using blue and green biomasses.

For each step, we will present:

- What we did
- Key learnings and recommendations
- 4-5 Briefs demonstrating the outcomes of our casework with each of the steps

The structure of the toolkit

Step 1:
Selecting biomasses

What we did

Key learnings and recommandations

Briefs:

- Mussels
- Common reed
- Seaweed
- Terrestial cultivaton of aquatic species
- Grass

Step 2:
Engaging Stakeholders

What we did

Key learnings and recommandations

Briefs:

- Generic Participatory Workshop Design
- Workshop Denmark
- Workshop Sweden
- Workshop Latvia

Step 3:
Working with policy

What we did

Key learnings and recommandations

Briefs:

- Common Policy Brief
- Policy brief Sweden
- Policy brief Denmark
- Policy brief Latvia

Step 1: Selecting biomasses
Identifying and describing blue and green biomasses with the potential for bio-industrial symbiosis

What we did

Our first step to furthering the circular bioeconomy at each partner site was to identify the relevant, local bio-resources.

Our research institute partner, the Latvian Institute for Aquatic Ecology created a survey for the municipal and regional partners in the project and gathered data and knowledge on site-specific biomasses in three areas: Skive (DK), Lysekil (SE), and Zemgale (LV).

Local biomasses in natural environments

For Skive and Zemgale, each potential biomass, such as grass, mussels and algae, was described concerning growth requirements, origin, biology, and its capacity to accumulate nutrients and CO2. This information was aligned with the climate and environmental goals for the entire Baltic region, while also considering local site-specific climate and environmental objectives. Additionally, experiences involving the incorporation of these specific biomasses as resources in a circular economy were reviewed.

Blue biomasses cultivated in controlled conditions

In Lysekil, an analysis was conducted on three species that can be cultivated on land, in controlled conditions using circular utilization of residual energy streams from other industries. This analysis was aligned with the climate and environmental goals for the Baltic Sea region and local objectives for the Lysekil municipality.

Key learnings and recommendations

- The local climatic and geographic features should be well investigated and considered for finding the best possible biomass.
- A well-known species or group of species should be given preference when selecting a biomass because this enables the collection information and local knowledge.
- If a local or regional plan does not have numerically defined climate and/or environmental goals, then the next level plan/policy document should be consulted.
- A variety of possible biomass uses should be collected to increase the number of options for moving toward a circular economy.

For more information on the biomasses selected by Blue Green Bio Lab partners, please take a look at our biomass briefs:

- Mussels as a potential biomass for symbioses
- Common reed as a potential biomass for symbiosis
- Seaweed as a potential biomass for symbiosis
- Terrestrial cultivation of aquatic species as a potential biomass for symbiosis
- Grass as a potential biomass for symbiosis

Mussels as a potential biomass for symbiosis

This brief is a part of the Blue Green Bio Lab Tool Kit, that represents the findings in the Blue Green Bio Lab project. The project targets the urgent challenges of reducing nutrients to waters of the Baltic Sea Region, limiting greenhouse gas emissions, and enhancing European self-supply with food, feed, and energy. Together, aquaculture, agriculture and industry can provide solutions to these challenges through industrial symbiosis based on the sustainable exploitation of local blue and green biomasses initially grown and/or harvested with the objective to produce positive ecosystem services. The Blue Green Bio Lab project is co-financed by Inter-Reg Baltic Sea Region with partners in Denmark, Latvia, and Sweden.

Anda Ikauniece, Ph.D., Latvian Institute of Aquatic Ecology, Agency of Daugavpils University.

Description of mussel species

Mussels are a group of marine and freshwater bivalve mollusks characterized by sedentary behavior and feeding by filtering the ambient water. In the Baltic Sea several species of mussels and clams are found inhabiting hard surfaces (rocks, reefs), soft sand and mud. The most frequent species of bivalves in the Baltic Sea are Mytilus trossulus or blue mussel, Limecola balthica or Baltic clam, Cerastoderma glaucum or lagoon cockle and Dreissena polymorpha or zebra mussel. In this brief the blue mussel and zebra mussel will be described in more detail, as they have the widest distribution in the Baltic Sea.

In the Baltic Sea blue mussels inhabit marine rocky areas from Kattegatt and Skagerrak to the Bothnian Sea. The optimal salinity for their growth is 25 per mille, therefore the size of the bivalves decreases from 10 to 4 cm in the southern-northern direction (Picture 1). There are also indications of mussel size slightly decreasing in general since 1990s. Blue mussels efficiently filter very small particles (down to the size of 4 micrometers, i.e., 1/250 of 1 millimetre) and can potentially filter up to 7 litres of water per hour. Reproduction of blue mussels involves spawning at springtime and the forming of larvae. The larvae drifts for 1-3 months and then settles on a solid substrate- be it another mussel, a rock, or a cultivation substrate for mussel farming. The first spawning of blue mussels takes place during the mussels second year of life. The total life span of a blue mussel is around 12 years and generation time is 1-2 years. The mussel density can be up to 2000 animals per m2, and the biomass can extend to 1 kg per m2.

Zebra mussel is an invasive species originating from the Caspian/Black Sea region. It invaded the rest of Europe and the Baltic Sea basin in 18-19th century. Shell size of adult zebra mussels varies between 1,35 cm to 2 cm (Picture 2). Optimal water temperature for the development and filtration of mussels is between 12-22 degrees Celsius, while salinity preference is up to 6,2 PSU (grams of salt per kilogram of seawater) and sometimes even up to 10 PSU. Zebra mussels can filter 10 times smaller particles than blue mussels, and their filtration volume is 1 liter/day. Their consumption rate peaks at 15 degrees, as originally zebra mussels are from warmer regions. Being 1,5- 5 times smaller as the blue mussel, zebra mussels can form very dense colonies. Density of zebra mussels in the Baltic Sea can reach 10,000 individuals/m2 with biomass up to 3 kg per m2.
For successful survival zebra mussels need hard

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- Options for biomass use in achieving climate and environmental goals

substrates and a water depth of at least 30 cm. In the Baltic Sea zebra mussels prefer lagoons and coastal areas, exposed to freshwater inflows. Zebra mussels are a dominant species in the Curonian Lagoon, where mussel beds cover 23% of the bottom of the lagoon.

Climate and environmental goals in the Baltic Sea region

European Water Framework Directive (WFD) focuses on ensuring good qualitative and quantitative health of rivers and lakes, ground water and bathing waters. The emphasis is on reducing and removing pollution and on ensuring that there is enough water to support wildlife at the same time as human needs.
. The key objectives of the WFD are to protect and, where necessary, restore water bodies to attain good water status and prevent deterioration. Good status means both good chemical and good ecological status. WFD requires Member States to use their River Basin Management Plans (RBMPs) and Programmes of Measures. The river basin district approach is applied to make sure that neighboring countries cooperate.

Like the European Union's aims for climate neutrality, the Baltic Sea region also has the goal to be a climate neutral region in 2050, according to the European Union Strategy for the Baltic Sea Region. The region has aims for clear water in the sea, rich and healthy wildlife, climate change adaptation, risk prevention and management. The Action Plan of the Strategy includes 9 actions in 3 policy areas, relevant for these aims. The emphasis of actions is on the reduction of nutrient emissions, recycling of nutrients, prevention of pollution and strengthening of a sustainable and circular bioeconomy.
The Baltic Sea Action Plan (BSAP) by Helsinki Convention is the central framework for implementation of the Strategy, with the overall objective of reaching good environmental status for the Baltic Sea by 2030. The plan has four sections with specific goals:
— Biodiversity, with its goal of a "Baltic Sea ecosystem (that) is healthy and resilient",
— Eutrophication, with its goal of a "Baltic Sea unaffected by eutrophication",
— Hazardous substances and litter, with its goal of a "Baltic Sea unaffected by hazardous substances and litter", and

Picture 1: Blue Mussels. Source: Per Dolmer, Blue Research.

— Sea-based activities, with its goal of "Environmentally sustainable sea-based activities".
The 4 sections of the BSAP are related. For example, attaining the goal under the "biodiversity" section also relies on the successful implementation of actions included under the other three sections. Actions and measures within all sections are designed to strengthen the overall resilience of the Baltic Sea, thus improving its ability to respond to the effects of climate change. The "eutrophication" section includes 36 actions in various sectors – such as agriculture, wastewater, data reporting, atmospheric depositing, and nutrient recycling. Such actions should help reach the desired state of the marine environment with concentrations of nutrients close to natural levels, clear water, algal blooms at natural levels, plants and animals with natural occurrence and distribution, and natural oxygen levels.

HELCOM Baltic Sea Regional strategy for Nutrient Recycling is another tool for improving nutrient use and reducing leakages to the Baltic Sea environment from agriculture. The Nutrient Recycling Strategy aims for closing nutrient cycles, reducing greenhouse gas emissions, improving soil quality and enhancing carbon sequestration. The circular use of nutrients should be safe and secure, based on the best available knowledge and should encourage new business models together with improved policy coherence. The Strategy has a list of possible measures in the form of tool box with ideas for nutrient recycling development in the region.

Biomass Types
Policy Brief

Local climate and environmental goals

This section looks at the translation of goals at the Baltic Sea level to the local scale, through the objectives and actions of two project partner regions of the Blue Green Lab project.

Skive Municipality in Denmark adopted a new climate action plan in 2022 with the goal of a 70% reduction in CO2 emissions by 2030 and climate neutrality by 2050. These climate targets are in accordance with international agreements and with national targets established for greenhouse gas reduction formulated in the Danish Climate Act. To reach the 70% reduction

Picture 2: Zebra Mussel. Source: Wikimedia Commons.

target by 2030, Skive Municipality must half their CO2 emissions per year by 2030, i.e. by 314,000 tonnes CO2/year. If the implementation of the climate action plan is successful, Skive Municipality will achieve:
- 82% reduction in CO2 emissions in 2030 compared to 1990
- 97% reduction in CO2 emissions in 2050 compared to 1990.

The large reduction in CO2 emissions by 2030 in Skive Municipality is expected largely due to the development of the Power-to-X industry (PtX) and the transition of the agricultural sector, especially in terms of land use. PtX production of green fuels such as hydrogen, methanol and green ammonia will reduce emissions in the transport sector. In addition, the expected green transition of the agricultural sector, based on the Danish Agricultural Agreement, aims for a more than 50% reduction in CO2 emissions from land use in Skive Municipality.

River basin management plans of 2021-2027 are also relevant for Skive Municipality to gradually improve the water quality in Skive Fjord, Lovns Bredning, Hjarbæk Fjord and Risgårde Bredning. For Skive Fjord, Risgårde, Lovns Bredning and Bjørnsholm Bugt it is required to reduce 739.5 tonnes of nitrogen/year, while for Hjarbæk Fjord, the reduction requirement is 894.6 tonnes N/year.

Kurzeme Planning Region in Latvia has adopted a development programme for its region until 2027. The programme "Kurzeme 2027" aims to secure balanced and sustainable growth of the region in accordance with national climate and environmental goals. Climate neutrality, conservation of biodiversity and natural environment are named as priority action areas, although no specific numeric values are provided. The region aims to improve the energy efficiency of public buildings and adopt additional local municipal plans as measures for climate neutrality. Implementation of integrated blue and green infrastructure solutions is also foreseen. Use of renewable energy sources is planned but without specific values mentioned.

Options for biomass use in achieving climate and environmental goals

Skive Municipality already anticipates the use of aquatic (=blue) biomasses, potentially including blue mussels, for achieving climate goals and improving water quality in Skive Fjord. It has already been calculated that blue biomasses could decrease CO2 emissions by 26,000 tons per year by 2050, i.e., about 8% of the total necessary reduction in Skive's climate action plan. Blue mussels capture CO2 during their shell formation, which is not released when the shells are broken. The same principle of carbon removal is true for zebra mussels. The shells of mussels can form a part of construction materials, be an ingredient of chicken feed or nutraceuticals.

Furthermore, both species of mussels can reduce the water turbidity by filtration substantially and thus improve the ecological status of the respective area.

Biomass Types
Policy Brief

Use of zebra mussel for water treatment has been explored in Swedish lake Ekoln and evidence shows zebra mussels being capable of removing 1,2-1,8 t of phosphorous per year (or approx. 60 % of annual load). Zebra mussels can also remove pathogens by filtration. As zebra mussels do not require large depth, the substrate for growth in a water reservoir can also be a reedbed with ropes below it.

Calculations on the filtration capability of blue mussels indicate that if the allowed amount of mussels is cultivated at 13 farms in Skive Fjord then 731 tons of nitrogen can be removed. This constitutes 98% of the necessary nitrogen removal of coastal waters not only of Skive Fjord, but also of Bjørnsholm Bugt, Risgårde Bredning and Lovns Bredning. The cost of nitrogen removal through the cultivation of blue mussels is between 48-64 Danish kroner kg/N. Mussels are regarded as one the most cost-effective measures for nutrient reduction in the Baltic Sea. Kurzeme Planning Region as well as other coastal municipalities could also use mussel cultivation as an option for achieving environmental goals.

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Project facts

The Blue-Green Biolab project is co-financed by Interreg Baltic Sea Region.

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Homepage: https://interreg-baltic.eu/project/blue-green-bio-lab/

Lead partner: Energibyen Skive, Skive Municipality.
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Blue Green Bio Lab Associated Partners:

Common reed as a potential biomass for symbiosis

This brief is a part of the Blue Green Bio Lab Tool Kit, that represents the findings in the Blue Green Bio Lab project. The project targets the urgent challenges of reducing nutrients to waters of the Baltic Sea Region, limiting greenhouse gas emissions and enhancing European self-supply with food, feed, and energy. Together, aquaculture, agriculture and industry can provide solutions to these challenges through industrial symbiosis based on the sustainable exploitation of local blue and green biomasses initially grown and/or harvested with the objective to produce positive ecosystem services. The Blue Green Bio Lab project is co-financed by Inter-Reg Baltic Sea Region with partners in Denmark, Latvia and Sweden.

Anda Ikauniece, Ph.D., Latvian Institute of Aquatic Ecology, Agency of Daugavpils University.

Description of common reed

The common reed (Phragmites australis) is a cosmopolitan, highly productive grass inhabiting the banks of rivers, lakes, ponds, marshes and also brackish waters like Baltic Sea (Picture 1). It is often the dominating species in the ecosystem it inhabits. Being so widely spread it has a capacity to adapt to various environmental conditions and thus can benefit from the changing climate. In Europe its height is about 2-3,5 m. The reed survives in temperatures from-14 to 27,5°C, while the optimal temperature is around 20°C. Temperature fluctuations induce increased shoot growth, however elevated CO2 levels do not have any specific impacts on shoots but rather below ground where more carbon is stored.

Picture 1. Common reed at the coast of a lake.

The natural salinity range for the reed is between 0 to 18 PSU, but it can change in prevailing local conditions. Reeds, originating from freshwater marshes or coasts, will decline in biomass and survival rate in saline conditions. In high nutrient concentrations the stems of reed may become weaker and more susceptible to mechanical damage, but there is also evidence that no negative effects are observed, and increased growth is recorded. In cases of flood conditions reed cannot withstand permanent flooding and especially juvenile stems have low flooding tolerance. The dynamics of floods determine the occurrence and growth of reed in lakes.

Reeds are considered an option for coastal protection from waves and surge damage during storms, increasing the efficiency of heavy metal removal from wastewater and as a phytoremediator to reduce high concentrations of phosphorus. The reed can remove also other pollutants and various nitrogen compounds from water environment successfully. Reed growth of one hectare can contain 10 kg of phosphorus, 100 kg of nitrogen, and a couple of tonnes of carbon.

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Biomass Types

Policy Brief

Climate and environmental goals in the Baltic Sea Region

The European Union's Common Agricultural Policy (CAP) 2023-27 has recognized the need for a more sustainable agricultural sector in Europe. Shifting from drainage-based agriculture to paludiculture is one option and one of the biggest carbon farming game-changers of this decade. Paludiculture is the productive land use of wet and rewetted peatlands that preserves the peat soil and thereby minimizes CO2 emissions and subsidence. Food production might be limited, but high-quality biomass to use as fiber, construction materials, substrates in horticulture etc. can be produced in a potentially carbon-negative way. By rewetting just 3% of EU agricultural land, the EU can cut up to 25% of greenhouse gas emissions from EU agriculture and agricultural land use. Common reed is one of the crops suggested for paludiculture.

Like the European Union's aims for climate neutrality, the Baltic Sea region also has the goal to be a climate neutral region in 2050, according to the European Union Strategy for the Baltic Sea Region. The region has aims for clear water in the sea, rich and healthy wildlife, climate change adaptation, risk prevention and management. The Action Plan of the Strategy includes 9 actions in 3 policy areas, relevant for these aims. The emphasis of actions is on the reduction of nutrient emissions, recycling of nutrients, prevention of pollution and strengthening of a sustainable and circular bioeconomy.

The Baltic Sea Action Plan (BSAP), part of the Helsinki Convention, is the central framework for implementation of the strategy, with the overall objectives of good environmental status for the Baltic Sea by 2030. Actions and measures are designed to strengthen the overall resilience of the Baltic Sea, thus improving its ability to respond to the effects of climate change. The management objective of the BSAP with respect to eutrophication is to minimize inputs of nutrients from human activities. Such actions should help reach the desired state of the marine environment with concentrations of nutrients close to natural levels, clear water, algal blooms at natural levels, plants and animals with natural occurrence and distribution, and natural oxygen levels.

HELCOM Baltic Sea Regional strategy for Nutrient Recycling is another tool for improving nutrient use and reducing leakage to the Baltic Sea environment from agriculture. The Nutrient Recycling Strategy aims for closing nutrient cycles, reducing greenhouse gas emissions, improving soil quality and enhancing carbon sequestration. The circular use of nutrients should be safe and secure, based on the best available knowledge and should encourage new business models together with improved policy coherence. The Strategy has a list of possible measures in the form of tool box with ideas for nutrient recycling development in the region. The emphasis is on the use of organic fertilizers and nature-based solutions for achieving the objectives.

Climate and environmental goals for Skive Municipality and Zemgale Planning Region

This section looks at the translation of goals at the Baltic Sea level to the local scale, through the objectives and actions of two project partner regions of the Blue Green Lab project.

Skive Municipality in Denmark adopted a new climate action plan in 2022 with the goal of a 70% reduction in CO2 emissions by 2030 and climate neutrality by 2050. These climate targets are in accordance with international agreements and with national targets established for greenhouse gas reduction formulated in the Danish Climate Act. To reach the 70% reduction target by 2030, Skive Municipality must half their CO2 emissions per year by 2030, i.e., by 314,000 tonnes CO2/year. The large reduction in CO2 emissions up to 2030 in Skive Municipality is expected largely due to the development of the Power-to-X industry (PtX) in the Skive region and the transition of the agricultural sector.

Skive Municipality's goals aim toward significant CO2 reductions from land use and plant cultivation up to 2030. Removal of 30% of lowland soil will result in reduction of 24,000 tonnes CO2/year in 2030 and removal of 52% of lowland soil will bring a reduction of 42,000 tonnes CO2/year in 2050. Skive Municipality has a number of wetland projects in the pipeline, including a major project on the Røddinge River with approximately 280 ha of lowland soil to reduce the leaching of nutrients from cultivated areas. Furthermore, the goal of conversion of 4% of agricultural land to forest by 2050 will provide a reduction of 11,000 tonnes CO2/year in 2050.

Zemgale Planning Region has adopted a development programme for the period 2021-2027. Sustainable development is a horizontal priority in the programme to achieve climate, environmental and biodiversity goals in accordance with the European Union's Green Deal policy. "Environment, nature and climate change" is one of the development priorities. The programme emphasizes that the region's development requires smart and sustainable governance, the introduction of green development principles into management and everyday life, and adaptation to climate change.

The region aims for a reduction of CO2 emissions from 230,229 t in 2020 to 190,000 tons CO2 by 2027. Activities to reduce CO2 emissions include increasing energy efficiency of buildings and using a larger share of renewable energy sources, though without any numerical targets mentioned. Better protection of biodiversity should occur through the enlargement of protected and forest areas, as well as the restoration of natural riverbeds. Adaptation to climate change is planned through the establishment of green and blue infrastructure and improving the environmental status of water ecosystems. Furthermore, the volume of inflowing nutrients with wastewater should be reduced from an estimated 3322 tons in 2019, though no numerical targets are given for 2027.

Options of biomass use for achieving the climate and environmental goals

The common reed could be a truly good biomass to use to reach climate and environmental goals. The ability of the common reed to capture CO2 and store carbon was recently assessed at the coastal wetlands along the Southern Baltic Sea bordering land areas with various uses- arable land, woodland, pasture and urban. It was found that these wetland sites stored, on average, 17.4 kg C m−2 with large variability between sites, ranging from 1.76 to 88.6 kg C m−2. It was also estimated that according to widths of the reed belts and carbon stocks at the sampled sites, approximately 264,600 t of blue carbon could be stored in the coastal reed belts along a typical lagoon system of the southern Baltic. Additionally, since 2020 a project on reed mowing has been initiated in Finland to reduce the nutrient loads to the water as the reed stores substantial amounts of nitrogen and phosphorous. Reed mowing thus removes nutrients from water decreasing the eutrophication and improving water quality. In areas where reed has been out competing other vegetation, mowing restores the previously more diverse landscape and improves biodiversity.

Harvested reed biomass provides a climate-friendly alternative for peat in the manufacture of growing substrates, drying agents, and absorbent materials. Reed has historically been used as roof material in coastal villages and can also be a substrate for building blocks (Picture 2). Furthermore, a 2004 study in Sweden proposes the harvesting and processing of reed for use in organic farming as fertilizer. The study concluded that this may be a particularly useful approach, where reed growth is dominating an ecosystem to the detriment of biodiversity and therefore harvesting will be beneficial for the environment and crop growth. Using reed as fertilizer can also be beneficial when reed growth is positive factor to help needed decreases in nutrient concentrations in water bodies.

Picture 2. A barn with reed roof in Kurzeme, Latvia. Photo: Andris Gertsons.

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Project facts

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Blue Green Bio Lab Associated Partners:

Food & Bio Cluster Denmark | Kurzeme Planning Region | innovatum science park | Chalmers Industriteknik | CBIO Aarhus University Centre for Circular Bioeconomy

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Seaweed as a potential biomass for symbiosis

This brief is a part of the Blue Green Bio Lab Tool Kit, that represents the findings in the Blue Green Bio Lab project. The project targets the urgent challenges of reducing nutrients to waters of the Baltic Sea Region, limiting greenhouse gas emissions, and enhancing European self-supply with food, feed, and energy. Together, aquaculture, agriculture and industry can provide solutions to these challenges through industrial symbiosis based on the sustainable exploitation of local blue and green biomasses initially grown and/or harvested with the objective to produce positive ecosystem services. The Blue Green Bio Lab project is co-financed by Inter-Reg Baltic Sea Region with partners in Denmark, Latvia, and Sweden.

Anda Ikauniece, Ph.D., Latvian Institute of Aquatic Ecology, Agency of Daugavpils University.

Description of seaweed species

Seaweed or macroalgae is the visible underwater vegetation in the sea and freshwater, composed of several groups of species. The species composition, size of plants, abundance and biomass depends on the salinity, turbidity and bottom substrate in the location where the seaweed is growing. All seaweed, however, will require a certain amount of light and nutrient content in the water for building biomass. In the Baltic Sea where the gradient of salinity is present in a southern-northern direction, species composition and dimensions change quite substantially. The coastal underwater habitats of Denmark, Germany and southern Sweden are inhabited by quite large (up to 2-3 m long) brown algae Saccharina latisima (sugar kelp) and Laminaria digitata (oar weed). Further east and north at the coasts from Lithuania to Finland the red algae Furcellaria lumbricalis and brown algae Fucus vesiculosus (bladderwrack) are 4-5 times smaller in size. In the Baltic Sea there are more than 300 seaweed species near the Danish coasts, though only seven species have been found suitable for cultivation. This brief will describe the five best investigated perennial species.

Sugar kelp is the target species for cultivation in Europe and several parts of the world, and thus also in the Baltic Sea south-western areas (Picture 1). The optimal salinity for the kelp is around 25 per mille and in natural conditions it grows, attached to rocks. Sugar kelp thrives in areas with good water exchange but without excessive wave exposure. In Denmark, up to 16 tons (wet weight) of sugar kelp have been produced annually in recent years by two commercial producers. Sugar kelp can be used as a sweetener and thickener in the food industry, as nutriceutical, in cosmetic products, as an additive to feed and as source of biomass for energy production as well.

Picture 1. Danish production line of sugar kelp in Horsens fjord, photo: Teis Boderskov.

Oar weed shows similar requirements of salinity and water exchange as sugar kelp but is more sensitive to higher temperatures. It tolerates a higher flexibility of salinity levels but grows slower than sugar kelp.

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The cultivation of oar weed does not yet exist on an industrial scale.

Bladderwrack is one of the dominant species of the coastal ecosystems in the Baltic Sea. It forms a canopy and therefore is also a keystone species for ecosystem structure and functioning in the Baltic Sea Region. Bladderwrack covers large areas from the surface down to around 10 meters depth in more open areas and 2–4 meters depth in nutrient enriched areas. Danish waters contain large populations of this Fucus species, for example the population of Fucus species in the Kattegat alone is estimated at approx. 82,000 tonnes of biomass. However, in many Baltic Sea areas from Poland to Finland bladderwrack belts have been decreasing due to diminished water transparency and dominance of annual algae. Cultivation of bladderwrack is currently at the experimental stage. Bladderwrack has healing properties and is used for digestion problems. It can be consumed fresh or cooked.

Red algæ (Furcellaria lumbricalis) grows on rocks to a depth of about 8-12 metres, but can also grow in large floating mats, which are easier to harvest (Picture 2). It is also an important habitat-forming seaweed, as its belts provide spawning habitat for many fish species, herring being the most important in the Baltic Sea.

Picture 2. Furcellaria lumbricalis in the Baltic Sea, Estonian waters. Photo: Tiit Hunt.

F.lumbricalis life-span is up to 10 years and it tolerates salinities down to 3.6 practical salinity units. F. lumbricalis forms monotypic dense meadows in the central and northern Baltic Sea. The floating type of Furcellaria nowadays inhabits only habitats with soft bottoms near western Estonia where it produces about 100,000-150,000 tons of wet weight every year. Of this amount about 2000 tons are harvested by bottom trawling. Furcellaria is used for production of agar in food industry, it contains natural red colorant phycoerythrin possible to use in cosmetics.

Sea lettuce (Ulva sp.) is a fast-growing green macroalgae. Sea lettuce are often the dominant species in the specific seaweed blooms called green tides. Due to its high growth rates and tolerance to varying salinity (6-30 PSU), sea lettuce is suitable for farming in nutrient-rich wastewater sources from for example fish farming. There have been attempts to cultivate two species of sea lettuce (Ulva lactuca and Ulva intestinalis) within the Baltic Sea Region in pilot and experimental projects. However, currently the land-based cultivation seems the most viable option. In areas of the Baltic Sea where green tides occur, sea lettuce can be harvested. Ulva sp. is considered one of the most usable seaweeds- in food with high protein and carbohydrate content, agriculture, pharmacology and medicine.

Climate and environmental goals in the Baltic Sea Region

The European Commission has foreseen wider cultivation and use of seaweed for food, feed, energy, and material production in a carbon neutral and circular way as recently adopted in the Algae Initiative. Member countries are encouraged to develop novel and sustainable ways for the use of seaweed resources as a part of European Green Deal and Farm to Fork strategy, calling for climate neutrality by 2050. The Commission has identified 23 actions, which aim to improve business environments, increase social awareness and acceptance of algae and algae-based products by consumers, and close the knowledge, research, and technology gaps. Actions include development of standards for algal products and strengthening the market, facilitation of access to marine space for seaweed farming, and conducting studies to gain better knowledge on seaweed climate change mitigation opportunities and the role of seaweed as blue carbon sinks.

Similar to the European Union's aim for climate neutrality, the Baltic Sea region has a goal to be a climate neutral region in 2050, in accordance with the European Union Strategy for the Baltic Sea Region. The region aims for clear sea waters, rich and healthy wildlife, climate change adaptation, risk prevention and management. The emphasis of the planned actions is on reductions of nutrient emissions, recycling of nutrients, prevention of pollution and strengthening of sustainable and circular bioeconomy.

The Baltic Sea Action Plan, part of the Helsinki Convention, is the central framework for implementation of the mentioned Strategy, holding the overall objective of reaching good environmental status for the Baltic Sea until 2030. Actions and measures are designed to strengthen the overall resilience of the Baltic Sea, thus improving its ability to respond to the effects of climate change. The actions should help to reach the desired state for the marine environment regarding eutrophication when concentrations of nutrients are close to natural levels, meaning the water is clear, algal blooms are at natural levels, plants and animals have natural occurrence and distribution, and oxygen levels are also natural.

HELCOM Baltic Sea Regional strategy for Nutrient Recycling is another tool for improvement of nutrient use and reduction of leakages to the Baltic Sea environment from agriculture. The Nutrient Recycling Strategy aims for closing nutrient cycles, reducing greenhouse gas emissions, improving soil quality and enhancing carbon sequestration. The circular use of nutrients should be safe and secure, based on the best available knowledge and should encourage new business model development together with improved policy coherence. The Strategy has a list of possible measures in the form of a toolbox with ideas for nutrient recycling development in the region.

Climate and environmental goals for Skive Municipality and Zemgale Planning Region

This section looks at the translation of goals at the Baltic Sea level to the local scale, through the objectives and actions of project partner region of the Blue Green Lab project.

Skive Municipality adopted a new climate action plan in 2022 with the goal of a 70% reduction in CO2 emissions by 2030 and climate neutrality by 2050. These climate targets are in accordance with international agreements and with national targets established for greenhouse gas reduction formulated in the Danish Climate Act. To reach the 70% reduction target by 2030, Skive Municipality must half their CO2 emissions per year by 2030, i.e. by 314,000 tonnes CO2/year. If the implementation of the climate action plan is successful, Skive Municipality will achieve:
- 82% reduction in CO2 emissions in 2030 compared to 1990
- 97% reduction in CO2 emissions in 2050 compared to 1990.

The large reduction in CO2 emissions by 2030 in Skive Municipality is expected largely due to the development of the Power-to-X industry (PtX) and the transition of the agricultural sector, especially in terms of land use. PtX production of green fuels such as hydrogen, methanol and green ammonia will reduce emissions in the transport sector. In addition, the expected green transition of the agricultural sector, based on the Danish Agricultural Agreement, aims for a more than 50% reduction in CO2 emissions from land use in Skive Municipality.

The river basin management plans of 2021-2027 are relevant for Skive Municipality to gradually improve the water quality in Skive Fjord, Lovns Bredning, Hjarbæk Fjord and Risgårde Bredning. For Skive Fjord, Risgårde, Lovns Bredning and Bjørnsholm Bugt it is required to reduce 739.5 tonnes of nitrogen/year, while for Hjarbæk Fjord, the reduction requirement is 894.6 tonnes N/year.

Options of biomass use for achieving the climate and environmental goals

Skive Municipality already anticipates ways to use aquatic (meaning blue) biomass, potentially including seaweed, for achieving the climate goals and improving the status of water quality in Skive Fjord. It has already been calculated that blue biomasses could decrease CO2 emissions by 26,000 tons per year by 2050, i.e., about 8% of the total necessary reduction for Skive Municipality. However, reaching climate and environmental goals through the cultivation of various types of seaweed results in some contradictions.

Sugar kelp is already cultivated for research purposes in the Limfjord area (DTU Aqua, 4 ha) and trials have shown that 29.3 kg of nitrogen and 3.91 kg of phosphorus per hectare can be removed. Sugar kelp binds CO2 during growing, but the capture is not permanent. It should be noted that many seaweeds have a life cycle with the leaf plate shedding in the autumn, and thus also a large part of the carbon bound in the plant. Furthermore, the cultivation of sugar kelp can reduce biodiversity due to shadowing, thereby worsening light conditions in water. Another option could be restoration of eelgrass beds. Eelgrass is a flowering plant, not a seaweed. Eelgrass beds are important ecosystems that provide a range of ecosystem services - bind and retain nutrients, sequester carbon, act as a filter, slowing down water velocity as it passes through an eelgrass bed, thereby settling particles. Eelgrass beds contribute to high biodiversity as they provide habitat for a wide range of animals and plants.

Still, the costs of nutrient removal and CO2 sequestration through the cultivation of seaweed is quite high and not so area or cost efficient, as they require more space and technology. Therefore, it is recommended to combine cultivation of algae with mussels and investigate options for other macroalgal species. Fast-growing annual seaweed can also be biomass for removal of nutrients, yet technologies for their proper collection and use still need to be developed.

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Project facts

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Blue Green Bio Lab Associated Partners:

Food & Bio Cluster Denmark
KURZEME PLANNING REGION
innovatum science park
CHALMERS INDUSTRITEKNIK
CBIO AARHUS UNIVERSITY CENTRE FOR CIRCULAR BIOECONOMY

LATVIJAS HIDROEKOLOĢIJAS INSTITŪTS
LYSEKILS KOMMUN
LEVA i Lysekil
Klimafonden skive
ZEMGALES PLĀNOŠANAS REGIONS
SKIVEKOMMUNE

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Terrestrial cultivation of aquatic species as a potential biomass for symbiosis

This brief is a part of the Blue Green Bio Lab Tool Kit, that represents the findings in the Blue Green Bio Lab project. The project targets the urgent challenges of reducing nutrients to waters of the Baltic Sea Region, limiting greenhouse gas emissions, and enhancing European self-supply with food, feed, and energy. Together, aquaculture, agriculture and industry can provide solutions to these challenges through industrial symbiosis based on the sustainable exploitation of local blue and green biomasses initially grown and/or harvested with the objective to produce positive ecosystem services. The Blue Green Bio Lab project is co-financed by Inter-Reg Baltic Sea Region with partners in Denmark, Latvia, and Sweden.

Anda Ikauniece, Ph.D., Latvian Institute of Aquatic Ecology, Agency of Daugavpils University.

Description of cultivated species

The circular use of energy resources or sidelines of energy streams provide options for the terrestrial cultivation of various aquatic species. In this brief three examples are presented- Vannamei Shrimp, Asparagopsis and Clarias. The choice of species for terrestrial cultivation can be more extensive, however, if the necessary conditions can be established. Tilapia, crayfish, baramundi and several green algae are also well-suited for indoor aquaculture.

Vannamei Shrimp or white leg shrimp (Litopenaeus vannamei, Picture 1) is a species native to the Pacific coast of Mexico and Central and South America, living in tropical marine habitats like mangroves. The adult shrimp mostly occur in the open areas of the ocean where they also spawn, while juveniles tend to inhabit estuaries and coastal areas. Adult shrimp can be up to 22 cm long and about 35 g in weight. The optimal temperature for development and growth of these shrimp is between 28 and 32°C and the favourable salinity range is 25-35 per mill. Too low or too high salinity levels can be stressful to the species and can lead to poor growth rates, reduced survival, and increased susceptibility to disease. The white leg shrimp is now widely cultivated in many parts of the world, including Asia, South America, and the United States. In the Baltic Sea region, the white leg shrimp is cultivated at farm in Grevesmühlen, northern Germany and at experimental pilot facilities in Gdansk, Poland and Klaipeda, Lithuania. The shrimp is an excellent source of protein and is low in fat and calories, making it a popular choice for those looking for a healthy and nutritious food option.

Picture 1. White leg shrimp. Photo credits: Seafood.lv

Asparagopsis or **Asparagopsis taxiformis** (Picture 2) is a red alga native to the warm waters of the Atlantic, Pacific, and Indian Oceans. In its natural environment, A. taxiformis typically grows in shallow, rocky areas,

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and tolerates a wide range of temperatures and salinities, though the algae's optimal temperature range for growth is between 15°C and 25°C. Temperatures below 10°C or above 30°C can be detrimental to its growth and reproductive success. The algae's salinity the range is between 20 to 40 per mill with the best growth between 30 to 35 per mill. Exposure to salinities below 20 ppt or above 40 ppt can be stressful to the algae and may limit its growth and reproductive success. Asparagopsis has a complex life cycle with sexual and asexual reproduction and can reproduce both by spores and vegetative fragmentation. Its size and shape are highly variable from a few centimetres to several meters in length and may be bushy or more wire-like in appearance. The algae has an important ecological role in its native ecosystems as a primary producer, providing food and habitat for other marine organisms, as it can form dense mats on rocky substrates. It captures CO2 during photosynthesis when building its biomass and has the potential to reduce methane (also a greenhouse gas) production from beef cattle by up to ~99% when added to cattle feed. The methane reduction is caused by a chemical compound called bromoform in Asparagopsis which has anti-microbial properties and inhibits certain microorganisms in the cattle's gut that produce methane during digestion. The aquaculture of Asparagopsis is not widely occurring yet in Europe, one of the first pilots **Volta Greentech** is established in Lysekil, Sweden.

Picture 2. Asparagopsis taxiformis harvested for further treatment. Photo: A.N. Hristov, Penn State University.

Clarias or **African catfish** (Clarias sp.) is a group of species native to freshwater habitats throughout Africa (Picture 3). Catfish there are typically found in slowly flowing rivers, swamps, and other freshwater habitats with abundant vegetation and muddy bottoms. They are bottom-dwelling fish that feed on insects, crustaceans, and small fish. They may also scavenge for food, feeding on dead or decaying organic matter on the bottom of water bodies. Catfish can breathe air using a modified swim bladder that serves as a primitive lung, which allows them to survive in poorly oxygenated water and to cover short distances over land in search of new water sources. They have a high capability of adaptation, and can tolerate low pH, low oxygen levels, and high temperatures. In their native habitats, catfish typically live in freshwater with temperatures ranging from 22°C to 30°C, though some species are able to tolerate temperatures up to 35°C. In aquaculture settings, catfish are most often raised in temperatures from 25°C to 30°C, which is considered the optimal temperature range for growth and reproduction. They are relatively large fish that can reach lengths of up to 1-2 meters in some species. However, most species of catfish typically grow to a maximum length of around 50-100 centimetres in the wild. Catfish are also able to reproduce quickly and in large numbers, which can make them successful invaders in new habitats. Therefore, they have established populations in many parts of the world, where they are considered invasive species, competing with native fish for food and habitats. In some cases, catfish have been associated with environmental degradation, such as increased sedimentation or nutrient pollution, due to their feeding and burrowing behaviours.

Picture 3. African sharptooth catfish Clarias gariepinus. Photo credits: Eurofish.dk.

The aquaculture of Clarias catfish is relatively well-established in southern Europe (Spain, Portugal, Italy) where meteorological conditions are favourable for catfish production. In United Kingdom, Netherlands and northern Europe catfish is cultivated in indoor recirculating systems or in heated ponds, although not on a large scale.

Climate and environmental goals in the Baltic Sea Region

The circular economy action plan adopted by European Commission in March 2020 is one of the main building blocks of the European Green Deal, Europe's new agenda for sustainable growth. It is also a prerequisite to achieve the EU's 2050 climate neutrality target and to halt biodiversity loss. The action plan targets how products are designed, promotes circular economy processes, encourages sustainable consumption, and aims to ensure that waste is prevented and that resources used are kept in the EU economy for as long as possible. Measures that will be introduced under the new action plan aim to make sustainable products the norm in the EU, focus on the sectors that use most resources and where the potential for circularity is high such as: electronics and ICT, batteries and vehicles, packaging, plastics, textiles, construction and buildings, food, water and nutrients.

Like the overall European Union (EU) climate aims, the Baltic Sea region also aims for climate neutrality by 2050, as per the EU Strategy for the Baltic Sea Region (BSR). The region aims for clear sea waters, rich and healthy wildlife, climate change adaptation and risk prevention and management. The emphasis of planned actions is on reduction of nutrient emissions, recycling of nutrients, prevention of pollution and strengthening of sustainable and circular bioeconomy.

The Baltic Sea Action Plan (BSAP) adopted by the Helsinki Convention (HELCOM) is the central framework for implementation of the EU Strategy for the BSR, holding the overall objective of reaching good environmental status for the Baltic Sea by 2030. Actions and measures are designed to strengthen the overall resilience of the Baltic Sea, thus improving its ability to respond to the effects of climate change. These actions should help to reach the desired state for the marine environment with concentrations of nutrients at close to natural levels, clear waters, algal blooms at natural levels, plants and animals with a natural occurrence and distribution, and natural oxygen levels.

HELCOM Baltic Sea Regional strategy for Nutrient Recycling is another tool for improvement of nutrient use and reduction of nutrient leakage to the Baltic Sea environment from agriculture. Nutrient Recycling Strategy aims for closing nutrient cycles, reducing greenhouse gas emissions, improving soil quality, and enhancing carbon sequestration. The circular use of nutrients should be safe and secure, based on the best available knowledge and should encourage new business models together with improved policy coherence.

Climate and environmental goals for Lysekil Municipality

To understand how Baltic Sea Region level goals are being translated at the local scale, objectives and actions of Blue Green Bio Lab partner Lysekil Municipality are considered.

Lysekil Municipality has adopted their "Green Strategy", which runs until 2030. The strategy addresses expectations for the intensive development of green infrastructure and adaptation to climate change effects like extreme rainfall and flooding. The climate targets addressing reduction of emissions are approved on a regional scale (Västra Götaland). These regional climate targets are some of the most ambitious in Sweden with aims for a fossil-free region by 2030 and an 80% reduction in greenhouse gas emissions by 2030 compared to 1990 levels. Compared to 2010, emissions will be reduced by 30% (Fig.1).

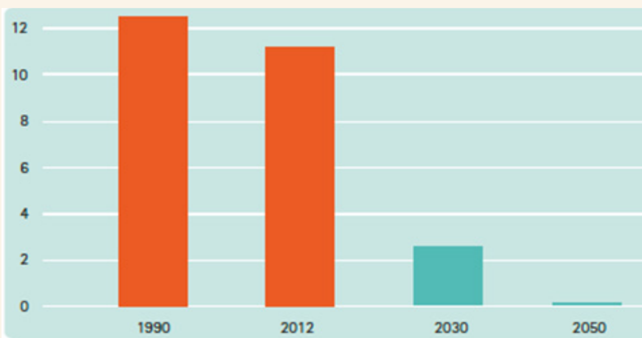

Fig.1. Total greenhouse gas emissions in Västra Götaland (million tons of CO2 equivalents/year) compared to the 2030 and 2050 target.

All municipalities in Västra Götaland have adopted climate pledges to achieve the regional targets. In 2022 of the 426 climate pledges adopted, about 90 per cent have been implemented or started. A total of 219 pledges have been already completed, resulting in estimated emission reductions of just over 44,700 tons of CO2. In 2021 reductions from implemented pledges were estimated at about 31,100 tons of CO2.

Options of biomass use for achieving the climate and environmental goals

The considerations of Lysekil Municipality to concentrate on the potential for indoor cultivation is due in part to the presence of the largest private business in the area, Preem refinery plant. Preem conducts extensive refinement of crude oil and the sale of petroleum products to oil companies active in Sweden and on the international market, mainly in north-western Europe. Preem is Sweden's largest fuel company and accounts for 80 percent of Sweden's refinery capacity and 30 percent of the Nordic refinery capacity. As the refining process generates excess heat, the plant is supplying the municipality with hot water for heating. Currently Preem provides 50 GWh, but the supply capacity is 800 GWh. Preem has the goal to become a climate neutral company by 2035, through investing in renewable fuels production, feedstock switching and carbon sequestration measures like carbon capture projects.

Establishing heated indoor facilities for the terrestrial cultivation of exotic aquatic species are in line with both the municipality's target for the sustainable use of resources and regional goals regarding fossil fuel use. Its not yet possible to accurately calculate the actual conributions of these indoor facilities to local and regional climate goals as cultivation efforts are still in the pilot stages. Conceptually however, production of additional biomass locally will reduce fossil fuel use, thereby reducing the region's carbon footprint associated with transportation, energy use and waste management.

Seawater salinity near Lysekil is optimal for all species discussed in this brief and filtered seawater is already used in Asparagopsis cultivation. Furthermore, the environmental status of the surrounding fjord will likely improve if mussels are cultivated there as a feed substance for African catfish, thereby ensuring even greater local circularity for these economic activities.

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Project facts

The Blue-Green Biolab project is co-financed by Interreg Baltic Sea Region.

Total budget: 499,399.60 Euro.
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Homepage: https://interreg-baltic.eu/project/blue-green-bio-lab/

Lead partner: Energibyen Skive, Skive Municipality.
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Blue Green Bio Lab Associated Partners:

Food & Bio Cluster Denmark
KURZEME PLANNING REGION
innovatum science park
CHALMERS INDUSTRITEKNIK
CBIO AARHUS UNIVERSITY CENTRE FOR CIRCULAR BIOECONOMY

LATVIJAS HIDROEKOLOĢIJAS INSTITŪTS
LYSEKILS KOMMUN
LEVA i Lysekil
Klimafonden skive
ZEMGALES PLĀNOŠANAS REĢIONS
SKIVEKOMMUNE

Biomass Types
Policy Brief

Grass as a potential biomass for symbiosis

This brief is a part of the Blue Green Bio Lab Tool Kit, that represents the findings in the Blue Green Bio Lab project. The project targets the urgent challenges of reducing nutrients to waters of the Baltic Sea Region, limiting greenhouse gas emissions, and enhancing European self-supply with food, feed, and energy. Together, aquaculture, agriculture and industry can provide solutions to these challenges through industrial symbiosis based on the sustainable exploitation of local blue and green biomasses initially grown and/or harvested with the objective to produce positive ecosystem services. The Blue Green Bio Lab project is co-financed by Inter-Reg Baltic Sea Region with partners in Denmark, Latvia, and Sweden.

Anda Ikauniece, Ph.D., Latvian Institute of Aquatic Ecology, Agency of Daugavpils University.

Description of grass composition

The species composition of grass is highly diverse and varies depending on the geographic location and environmental conditions. Grasslands are found in a wide range of habitats like meadows, pastures, heaths, and other open areas (Picture 1). The most common grass species in Europe include ryegrass (Lolium perenne), fescue (Festuca spp.), bentgrass (Agrostis spp.), meadow grass (Poa pratensis), timothy grass (Phleum pratense), and cocksfoot (Dactylis glomerata).

Picture 1. Grass in the meadow.

The ecology of grass species is characterized by seasonal growth patterns, with most growth occurring in the spring and summer and a period of dormancy or reduced growth in the winter. Additionally, grass species have adapted to grazing by regrowth and survival after grazing. Grasses are also tolerant of nutrient-poor soils where species have evolved mechanisms for efficient nutrient uptake and use, such as deep roots, mycorrhizal associations, and nutrient recycling. It is also common for grass species to thrive in disturbed habitats such as road verges, abandoned fields, and railway tracks. These species often have high seed production and dispersal rates, rapid growth, and a short life cycle.

Grass species provide a range of ecosystem services - soil conservation, carbon sequestration, biodiversity conservation, and livestock feed. Grass has been a significant component of European agriculture for centuries, and it continues to play a crucial role in the region's food production and rural economy. Recently grass has also become an important source of protein, increasingly being used as a feedstock for protein extraction. The extracted protein can be used for example as a source of protein for animal feed and as a base material to produce other protein products. Furthermore, the remaining pulp after protein extraction can also be used as feed for cows.

Several grass species have an increased ability to remove pollutants and contaminants from soil through

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phytoremediation. Tall Fescue has high tolerance for heavy metals such as zinc, cadmium, and lead, and it has been used to remediate contaminated soils in several studies. Ryegrass is effective at removing polycyclic aromatic hydrocarbons (PAHs) from contaminated soils. Rough Meadow grass removes heavy metals and pesticides from soil effectively, while Velvet Bentgrass can remove cadmium and copper. Research on the capabilities of grasses in this area is still on-going but it is clear that grass used in phytoremediation is not suitable as feed to animals.

Climate and environmental goals in the Baltic Sea Region

The Common Agricultural Policy is the main policy instrument of the European Union (EU) for supporting agriculture and rural development. It includes a range of measures aimed at promoting sustainable land use and biodiversity conservation, including support for agri-environmental measures, payments for areas with natural constraints, and support for organic farming. Several targets are set to protect grasslands: at least 5% of agricultural land in each member state should be maintained as permanent grassland, grassland diversity is encouraged, limitation of grassland conversion to other land uses to 175,000 hectares per year, maintain or increase the amount of carbon stored in EU grasslands by at least 10 million tons per year.

Like the European Union's aims for climate neutrality, the Baltic Sea region's goal is to be a climate neutral region by 2050, according to the European Union Strategy for the Baltic Sea Region (BSR). The region should aim for clear water in the sea, rich and healthy wildlife, climate change adaptation, risk prevention and management. The emphasis of needed actions is on the reduction of nutrient emissions, recycling of nutrients, prevention of pollution and strengthening of a sustainable and circular bioeconomy.

The Baltic Sea Action Plan (BSAP) adopted by the Helsinki Convention (HELCOM) is the central framework for implementation of the EU Strategy for the BSR with overall objective of reaching good environmental status for the Baltic Sea by 2030. Actions and measures are designed to strengthen the overall resilience of the Baltic Sea, thus improving its ability to respond to the effects of climate change. The management objective of the BSAP with respect to eutrophication is to minimize inputs of nutrients from human activities, including agriculture. These actions should help to reach the desired state of the marine environment regarding eutrophication with concentrations of nutrients close to natural levels, clear water, algal blooms at natural levels, natural occurrences and distribution of plants and animals, and natural oxygen levels.

The HELCOM Baltic Sea Regional strategy for Nutrient Recycling is another tool for improving nutrient use and reduction of leakages to the Baltic Sea environment from agriculture. The Nutrient Recycling Strategy aims to close nutrient cycles, reduce greenhouse gas emissions, improve soil quality, and enhance carbon sequestration. The circular use of nutrients should be safe and secure, based on the best available knowledge and should encourage new business models together with improved policy coherence. The Strategy has a list of possible measures in the form of a tool box with ideas for nutrient recycling development in the region. The emphasis is on the use of organic fertilizers and nature-based solutions for achieving objectives.

Climate and environmental goals for Skive Municipality and Zemgale Planning Region

This section looks at the translation of goals at the Baltic Sea level to the local scale, through the objectives and actions of two project partner regions of the Blue Green Lab project.

Skive Municipality adopted a new climate action plan in 2022 with the goal of a 70% reduction in CO_2 emissions by 2030 and climate neutrality by 2050. These climate targets are in accordance with international agreements and with national targets established for greenhouse gas reduction formulated in the Danish Climate Act. To reach the 70% reduction target by 2030, Skive Municipality must halve their CO_2 emissions per year by 2030, i.e. by 314,000 tonnes CO_2/year. The large reduction in CO_2 emissions by 2030 in Skive Municipality is expected largely due to the development of the Power-to-X industry (PtX) and the transition of the agricultural sector, especially in terms of land use.

The national agreement on the green transition of Danish agriculture sets a binding reduction target for the agricultural and forestry sector's greenhouse gas emissions of 55-65% compared to 1990 emissions. This agreement is particularly important in Skive Municipality, as approximately 74% of the land use in the municipality is dedicated to agriculture. Skive Municipality's climate goals aim for significant CO2 reductions from land use and plant cultivation by 2030. For example, the use of biochar (produced from straw) for soil improvement of 4% of the cultivated areas would bring a reduction of 35,000 tonnes CO2/year in 2030. Additionally, conversion of 9% of cultivated areas from annual crops to perennial protein grass would result in a reduction of 4.500 tonnes CO2/year by 2030 and 18% of the cultivated areas by 2050, a reduction of 8,700 tonnes CO2/year in 2050. This conversion of large areas to the cultivation of perennial grass is also expected to have a positive effect on the aquatic environment of the Limfjord, as grass requires less fertiliser and therefore reduces nitrogen discharges to groundwater, rivers and the fjord.

Zemgale Planning Region has adopted a development programme for its region until 2027. Sustainable development is a horizontal priority in the programme to achieve climate, environmental and biodiversity goals in accordance with the European Union's Green Deal policy. "Environment, nature and climate change" is one of the development priorities until 2027. The programme emphasizes that the region's development requires smart and sustainable governance, the introduction of green development principles into management and everyday life, and adaptation to climate change. The reduction goal for CO2 emissions in the region is 190,000 tons CO2 by 2027, compared to 230,229 tons in 2020. Activities in the local development programme include increasing energy efficiency of buildings and larger share of renewable energy sources but without any specific numerical goals mentioned. Protection of biodiversity is emphasized by enlarging protected areas, and extended management measures for wetlands as a type of grasslands. The region anticipates adaptation to climate change through the establishment of green and blue infrastructure and improving the environmental status of water ecosystems. The use of locally produced agricultural biomass is foreseen as an input for the development of sustainable bioeconomy.

Options of biomass use for achieving the climate and environmental goals

In general, the use of grass as a biomass can contribute to the reduction of greenhouse gas emissions in several ways. Grass species absorb CO2 during photosynthesis and store it in their roots and soil (Illustration 1).

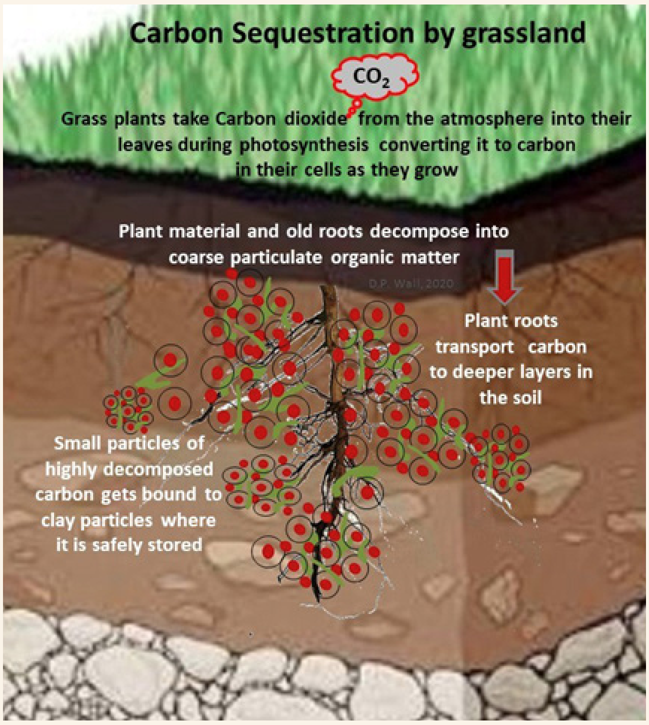

Illustration 1. Scheme of carbon sequestration by grassland, from D. Wall & G. Lanigan, Teagasc.

Grass can be used to produce biofuels (ethanol) replacing some fossil fuels. The use of grasses for grazing and as a feedstock for livestock can reduce emissions from agriculture. By promoting sustainable grazing practices and reducing the amount of feed imported from distant locations, grasslands can also help reduce emissions associated with transportation and fertili zer use (Picture 2). Lastly, the use of grasslands for biomass production can maintain the natural state of the land and avoid the release of emissions associated with land-use change.

Carbon sequestration rates in grassland soils typically range from 1.5 to 4 tonnes CO2 per hectare per year.

Picture 2. Grassland after mowing, with hay. Photo by Aivars Gulbis, www.redzet.eu.

Grazed grasslands sequester carbon at higher rates than grasslands which are cut for silage or hay.
The protein content in annual grasses may be lower compared to perennial grasses, so the option to cultivate perennial grass species like ryegrass (contains 15-25% protein) will be more likely to help achieve climate and environmental goals. Besides carbon sequestration and protein production, perennial species with longer life spans also store more nutrients in their roots and stems, which can be used for regrowth and reproduction in subsequent years.

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Blue Green Bio Lab Associated Partners:

Step 2: Engaging Stakeholders
Facilitating the blue-green circular economy

What we did

After identifying relevant local biomasses, it was time to look at how to design industrial symbioses based on these biomasses. In order to do so, we assessed the need for involvement of local stakeholders and created a workshop design based on participatory principles. The use of a common workshop design made it possible to transnationally compare the outputs and results from the local workshops.

We then assessed the workshop design elements needed to ensure successful workshop outcomes – for participants and the project. During this assessment the following elements were identified:

- Inspirational speech on bio-industrial symbiosis to support a common understanding of basic information and facts among workshop participants.
- Presentation of the selected types of biomasses and ongoing initiatives related to bio-industrial symbiosis.
- An interactive design session outlining local industrial symbiosis based on:
  - Biomass volumes and qualities, and
  - Important resource flows' characteristics and estimates (including excess resources to be accounted for e.g., by adding more companies to the symbiosis).
- Identification by workshop participants of the most significant challenges for initiating local industrial symbiosis with the selected biomasses.

Based on these design elements the project partners created the workshop program. To ensure the ideas from the group discussions were recorded, a template / large poster was made to support facilitators in gathering and organizing inputs from the group discussions. More information on the workshop design can be found in the Participatory Workshop Design brief.

Key Learnings and recommendations

- A point of departure for planning a workshop could be a generic design, but it will inevitably need to be adjusted to the local context.
- It is important to reflect on the choice of inspirational speaker in light of the different needs among invitees and their knowledge/experience level with symbioses and biomasses. Furthermore, ask yourself whether the participants in this workshop will be capable of creating industrial symbioses, or will the task be too large?
- Concerning whom to invite, the partners chose different approaches.
  - With an open invitation, you have to be aware of the level of trust within a group of potentially very diverse participants, as well as between you (the organizer) and the participants.
  - With a more select group of participants, consider carefully whom you select and what point of view each participant will represent and communicate (not just during the workshop but also after the workshop).
- In asking businesses to participate and share information trust issues can also arise. Some businesses may hesitate to share production data with participants they don't know. This challenge could be addressed by inviting the companies to 1:1 meetings prior to a workshop.
- It is important to follow up and inform participants about the results of the workshop to keep them in the loop and engaged. Sharing information is also a sign of respect for the time participants used in attending the workshop. Furthermore, the result can be used to disseminate the project to a larger audience. At the very least, information on next steps is important to share.

For more information on our cases and reflections on workshops held in the project, please take a look at these briefs:

- Participatory Workshop design
  - Annex 1: Art of participatory leadership
  - Annex 2: 3D tool for participatory workshop design
- Design of bio-industrial symbiosis based on blue biomasses – Denmark
- Design of bio-industrial symbiosis with blue biomasses – Sweden
- Design of bio-industrial symbiosis with green biomasses – Latvia

Interreg Baltic Sea Region | Co-funded by the European Union

CIRCULAR ECONOMY Blue-Green Bio Lab

Bio-industrial symbiosis

Policy Brief

Participatory Workshop Design

This brief is a part of the Blue Green Bio Lab Tool Kit, that represents the findings in the Blue Green Bio Lab project. The project targets the urgent challenges of reducing nutrients to waters of the Baltic Sea Region, limiting greenhouse gas emissions, and enhancing European self-supply with food, feed, and energy. Together, aquaculture, agriculture and industry can provide solutions to these challenges through industrial symbiosis based on the sustainable exploitation of local blue and green biomasses initially grown and/or harvested with the objective to produce positive ecosystem services. The Blue Green Bio Lab project is co-financed by Inter-Reg Baltic Sea Region with partners in Denmark, Latvia, and Sweden.

Tine Hahnbak, innovation consultant, Climate Foundation Skive.

This brief provides a description of methodological approach of the Blue-Green Bio Lab project to designing and conducting local stakeholder workshops with the aim of starting discussions about local bio-industrial symbiosis based on selected biomasses.

Purpose of the workshops are to:

- Enhance the capacity of authorities to facilitate bio-industrial symbiosis design processes
- Enable cross-sectoral industrial stakeholders to expand their potential for exploring one type of biomass for multiple products.

Early on in the project, the project partners agreed that best practice would be to have one common participatory workshop design – given the aims of the project to compare output and results from the local workshops.

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- **Bio-industrial symbiosis design principles**
- **Generic participatory design**
- **Local differences**
- **Transnational reflections and learnings between project partners**
- **Annex 1: Art of Participatory Leadership**
- **Annex 2: 3D Tool**

Bio-industrial symbiosis design principles

The principles that govern design of a bio-industrial symbiosis, focus on its distinctive aspects related to primary production and utilization of biomass that yields favorable climate and environmental outcomes within the local ecosystem and landscape. The integration of various industries through symbiotic relationships has proven to be an innovative approach towards achieving sustainable development goals. In this context, the emphasis on utilizing specific types of biomasses to generate positive impacts on both the climate and local environment remains a key priority. The participatory workshop design aims to back the essential considerations and strategies that underpin a successful implementation of a bio-industrial symbiosis.

Generic participatory design

The initial **intention** for the workshops was to create an opportunity for engagement and begin building a mutual foundation for developing bio-industrial symbiosis. The primary **goals** were to involve a range of participants through a participatory process, develop possibilities for industrial symbiosis with participants, and form the basis for future activities in the project. To meet the participatory element, the workshop is designed on the principles of Art of Participatory Leadership; the Climate Foundation partner is an experienced facilitator of this approach. For more information on Art of Participatory Leadership see Annex 1.

Having identified the intention and goals, Climate Foundation Skive assessed the needed elements to secure successful workshop outcomes – for participants and the project. During this assessment the following elements were identified:

- Inspirational speech on bio-industrial symbiosis to support a common understanding of basic infor-

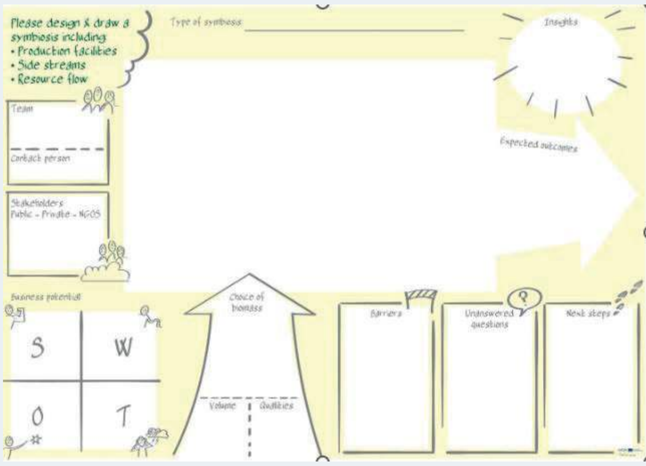
mation and facts among workshop participants
- Presentation of the selected types of biomasses and ongoing initiatives related to an industrial symbiosis
- An interactive design session outlining local industrial symbiosis based on
  - Biomass volumes and qualities
  - Important resource flows' characteristics and estimates (including excess resources to be accounted for e.g., by adding more companies to the symbiosis)
- Identification by workshop participants of the types of challenges with initiating local industrial symbiosis with selected types of biomasses.

Following this assessment, the project partners created the following workshop program:

Program with proposed timing

12.00-12.30 Arrival and standing lunch
12.30-12.45 Welcome, context, purpose, and framing
12.45-12.55 Quick check-in: Who's in the room
12.55-13.30 Inspirational speech on industrial symbiosis (optional: and ongoing initiatives related to an industrial symbiosis)
13.30-13.40 Re-organize in groups (either pre-defined or random)
13.40-15.00 Outlining local industrial symbiosis on selected biomass(es)
15.00-15.15 Break
15.15-15.40 Peer coaching
15.40-16.00 Integration of feedback in original groups and preparation of presentation
16.00-16.30 Presentation from groups outlining 3 most important challenges/barriers and if possible, how to overcome the challenges/barriers
– challenges/barriers recorded in a mind map
16.30-16.40 Voting on what participants believe will move the most if overcome (measure the temperature)
16.40-16.55 Reflections/open mic/check out
16.55-17.00 Next step and thank you.

To ensure the ideas from the group discussion were recorded, a template / large poster was made to support facilitators to gather and organize inputs from the group discussions.



To help organizers with facilitating the different steps in the generic program, a thorough process action plan was developed and discussed among the partners.

Local differences

As time progressed and each project partner began to get a deeper understanding of local knowledge level and stakeholder engagement, a completely identical and common workshop design did not seem to be the best way forward. For example

- Partners in Lysekil Municipality are working with non-native species and there is a limited knowledge of circularity & symbiosis.
- Partners in the Zemgale Planning Region are focusing on a known biomass, but it is not currently in production.
- Partners in Skive Municipality have a known biomass in production, but there are potential opportunities for new symbioses. Furthermore, there is some local knowledge and experience with symbiosis among some of the key actors.

The partners were aware from the start that there would be differences and therefore need for local adjustments in the workshop design.

Due to local level discussions before and at the start of the project, the project partners were also working on slightly different timelines. For example, discussions with stakeholders in Sweden started much earlier than with the Danish and Latvian partners, and therefore the workshop in Lysekil was held a couple of months before the other local workshops. This ended up being a good thing for the project in supporting discussions of how the common workshop design could be used and modified early on.

Workshop and adjustments in Lysekil, Sweden
In Lysekil, Sweden there was a broad invitation to participate – not only did they want to discuss the specific biomasses, but they also wanted to raise the general awareness about circularity and industrial symbioses – to see "what could be the outcome". In the end, 23 people representing 12 businesses/organisations participated in the workshop which was moderated by Innovatum Science Park in close collaboration with the neighboring municipality Sotenäs, who also facilitates Sotenäs Symbiosis center. Based on their knowledge and experience the Sotenäs symbiosis center provided the inspirational speech. Prior to the workshop, the participants had been invited to watch three films (YouTube) made by Sotenäs about symbiosis.

When in contact with one of the companies, it became clear that while they were interested in symbiosis but they were not keen on sharing information about their resources openly. This was an issue that also arose in the workshop. During the workshop symbiosis between Red Algae and giant shrimp (Vannamei) as well as symbiosis regarding the wastewater outcome was discussed. Most questions were discussed on a more general level.

Workshop approach in Zemgale Planning Region, Latvia

In Zemgale Planning Region, Latvia, the concept of bio-industrial symbiosis was new, so it was important to find the right way to introduce it to the local stakeholders and decision makers. Before the seminar, we identified the region's situation in the field of extraction, processing and use of blue-green biomass. In the workshop we therefore addressed a wide range of representatives- from scientists and regional development planners to local government specialists and rural entrepreneurs. In total 20 stakeholders participated.

The workshop organized by the Latvian partner of the project- Zemgale Planning Region (ZPR) was held on April 27, 2023, in Jelgava. It was decided to follow the general design proposed by the project, though they went with two inspirational speeches: one on the concept of the establishment of bio-industrial symbioses and the possible types of biomasses and one on the possibilities of biomass extraction.

Workshop approach and organizing in Skive, Denmark
In Skive, Denmark, it was decided to follow the proposed generic design. The region is a lighthouse concerning circular bioeconomy, green biomass and industrial symbioses on energy hence the concept of bio-industrial symbiosis is well known to many local stakeholders. Starting with an inspirational presentation helped set the frame for discussions about blue mussels during the workshop and make sure participants were updated on the latest initiatives and knowledge concerning the environmental state of local water bodies at focus of Skive's workshop.

The workshop was held on April 27th, 2023. In late February, we held a first meeting with associated partner Food & Bio Cluster Denmark, to define stakeholders to be invited. An invitation was drafted and sent in the middle of March to a mailing list of stakeholders representing fishermen, producers, suppliers, business support organisations, NGO's, local politicians, local authorities, civil citizens, and academia. A reminder mail was sent out and we made a follow up by phone. People were also encouraged to share the invitation. The invitation was announced on the websites and LinkedIn of Skive Municipality, Climate Foundation and Food & Bio Cluster Denmark. On the day of the workshop, there were 25 participants.

Transnational reflecions and learnings between project partners

Both in planning and evaluating the workshops, one in-person and several online transnational meetings were held among the partners. The points below summarize the transnational reflections from the project partners:

1. An identical and common workshop design did not work out as thought in the beginning of the project. As time progressed, each project partner

began to get a deeper understanding of the local knowledge level about biomasses and symbiosis and potentials stakeholder engagement.

2. Due to different local prerequisites, the partners found that it was of great importance to define who should participate in the first discussions? In Lysekil it was mainly businesses, in Zemgale it was mainly municipalities and in Denmark it was a mix.
3. It is also important to reflect on the choice of inspirational speaker because of different needs, depending on the knowledge/experience level with symbiosis and the biomass.
4. Having an inspirational speech during the workshop can also be beneficial to frame how to understand research and research results. And to counter the gap between knowledge and opinion as mentioned earlier.
5. Asking workshop participants to create an industrial symbiosis is simply too large a task during a first encounter workshop. At this stage, it is more important to build trust and level the understanding of the subject to be debated. This is a common learning from all workshops and partners.
6. Asking businesses to participate and share information, leave a chance to meet a trust-issue. Some businesses will hesitate to share production data with participants they don't know. A challenge exposed by the Swedish project partner which they overcame by inviting to 1:1 meetings before the workshop, setting the frame and building trust.
7. It is important to frame the role of a municipality/region at the workshop. That they as a partner in the project participate in the workshop on project terms and not as an authority which they commonly represent.

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Blue Green Bio Lab Associated Partners:

Participatory Workshop Design

To ensure gathering of comparable results from the local workshops and having a participatory, co-creative workshop design, we have used guidelines and templates / posters based on Art of Participatory Leadership (AoPL) principles. AoPL is well-known and often preferred by the EU Commission to co-create, enable commitment, and produce good results.

What is the Art of Participatory Leadership?

The Art of Participatory Leadership (AoPL) is an approach to scale up from personal to systemic usage of dialogue, facilitation, collaboration and co-creation of new solutions needed to address complex challenges in our work and in our world.

AoPL integrates methodologies, models and practices for collaborative dialogues and designing processes to engage large and small groups in conversations that matter. This systemic approach helps in empowering individuals and teams to learn together, work with collective intelligence, co-create new solutions and move to actions fast. Connecting individual perspectives into collective wisdom is particularly important in times of high complexity and disruption where ”copy/paste” solutions do not work. AoPL is based on how to host and harvest meaningful conversations.

Methodologies

AoPL conveys a set of powerful practices applicable for small and large groups:

- Circle
- World café
- Appreciative inquiry
- Open space technology
- ProAction café
- Design for wiser action
- Four-fold practice
- Chaordic path
- Collective story harvesting
- Collective mind-mapping
- Graphic facilitation

Each of the practices or methodologies uses a powerful question at its core. Crafting a good question is a challenge and creating a great one is an art. It’s worth spending time on framing questions because they open the door to whatever comes next.

More information

The AoPL is a network and has no formal, legal structure, no appointed leader, no accreditation program and no controlling body. It is based on a practitioner network, with local communities of practice; it is committed to learning and generous with its sharing and support. The first step to become a practitioner is to follow a 3-day-training; these can be found on the internet googling Art of Participatory Leadership trainings.

You can also find more information here: https://artofhosting.org/

Participatory Workshop Design

As part of the preparation process for the local workshops in the Blue Green Bio Lab project, a simple and dynamic digital tool with building blocks for designing bio-industrial symbioses was developed.

In developing the tool, the partners identified approximately 30 types of production units, plants, different types of stock, and several resource-flows (liquids, gas, fuel, electricity, water, etc. – all color coded). All elements are placed in local folders, which are easily accessible and connected on a dashboard. The resource-flows can be visualized through arrows and lines of various thickness, to differentiate between heavier and lighter resource flows. The tool can also be used in various languages.

From the platform, users can

- share with one another,
- export results/drawings as pictures or pdf's,
- create text boxes for commenting and explanation,
- continuously add new elements (scaling has no limits) and
- save work done in local folders.

The 3D Tool is web-based, open-source, and accessible at: www.bluegreenbiolab.com.

Initially, the 3D Tool was to be used to combine information from different companies (workshop participants) regarding their flows of e.g., electricity, heat, water, dry matter as well as possible prices between companies within the symbioses.

At an in-person partner meeting in Lysekil, Sweden in spring 2023, the partners tried out the tool and discussed the best way to integrate it into the project. At this point the partners decided, not to use the digital 3D Tool in the workshops directly, due to the risk of using too much time and focus on technology. Furthermore, the partners assessed that the limited time with workshop participants should primarily focus on dialogue, trust-building and exchanging knowledge and perspectives.

The partners have however found value in using the 3D Tool to think through, organize and share the key results and learning from discussions with workshop participants. The results of this learning are shared in diagrams included in the bio-industrial symbiosis briefs.

The partners anticipate the continued use of the 3D tool beyond the Blue Green Bio Lab project to further discussions with key stakeholders in developing bio-industrial symbioses based on blue and green biomasses.

We believe the 3D tool can support facilitators in bio-industrial symbiosis development through supporting a common understanding among partners regarding important resource flows, inputs and production units.

Short explainer videos are available to help new users to understand and use the tool:

- How to move an icon: https://www.youtube.com/watch?v=k53iegCRI00
-
- How to make an arrow: https://www.youtube.com/watch?v=R2AK9-yM2Ak
-
- How to make a larger text box: https://www.youtube.com/watch?v=GZ2mrY5o0IE
-
- How to load and/or save: https://www.youtube.com/watch?v=mPUeNCA2fa0

Design of bio-industrial symbiosis based on blue biomasses – Danish workshop

This brief is a part of the Blue Green Bio Lab Tool Kit, that represents the findings in the Blue Green Bio Lab project. The project targets the urgent challenges of reducing nutrients to waters of the Baltic Sea Region, limiting greenhouse gas emissions, and enhancing European self-supply with food, feed, and energy. Together, aquaculture, agriculture and industry can provide solutions to these challenges through industrial symbiosis based on the sustainable exploitation of local blue and green biomasses initially grown and/or harvested with the objective to produce positive ecosystem services. The Blue Green Bio Lab project is co-financed by Inter-Reg Baltic Sea Region with partners in Denmark, Latvia, and Sweden.

Tine Hahnbak, innovation consultant, Climate Foundation Skive.

This brief contains the findings from the Danish workshop on designing bio-industrial symbiosis based on blue biomasses as part of the Blue Green Bio Lab Project. The purpose of the workshop was to identify challenges and barriers and how to move forward. The workshop was held by Climate Foundation Skive and Skive Municipality in April 2023.

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Resume

The Danish workshop was held April 27th, 2023, with 25 participants representing fishermen, aquaculture interests, suppliers, business support organisations, local politicians, citizens, and academics. The workshop began with an informal lunch and then an inspirational speech by a researcher with extensive practical experience on projects related to blue mussels. The speech set the context for the workshop and had the purpose of ensuring all participants were updated on the latest initiatives and knowledge regarding the local fjord's environmental conditions, where poor water quality is an urgent factor to be addressed. As the workshop progressed, it became evident that there were significant differences in participants' understanding and knowledge about blue mussels and mussel farming. Early in the workshop it also became clear that this was the first time the various stakeholders had been gathered to exchange perspectives. The most significant outcome, prioritized by the participants at the end of the workshop, was the desire to meet again and continue the dialogue. It should be noted that there has been and still is notable opposition to the idea of increased mussel farming from citizens in the Skive area.

Below are the findings collected from the template designed for the event to frame group discussions, the template is a large poster with predefined topics and space for notes (please go to "Participatory workshop design brief" for details); no additional information is added below. The template was placed on tables for each group where a facilitator from the project was responsible for gathering the essence of the discussions of the various topics.

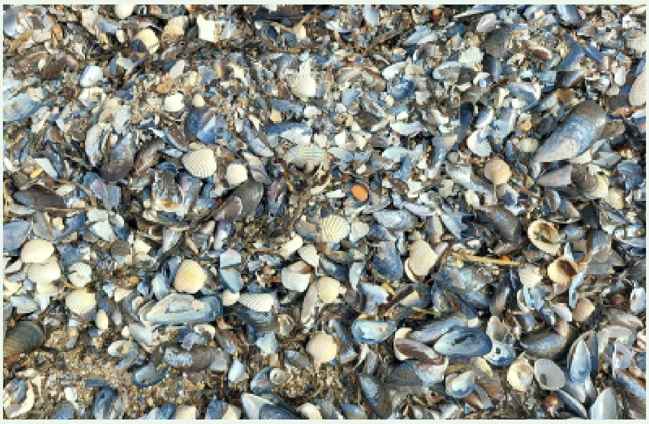
To secure knowledge sharing and cross-pollination, participants were organized into five groups beforehand. After a first round of diving into the topics, they were asked to re-organize into new groups for peer-coaching. And lastly, going back into original groups to build upon their work. The work was then presented in plenary, focusing on strengths and barriers. The workshop concludes with a prioritization of the barriers that need to be addressed to make the greatest positive impact.

Mapping of bio-industrial symbioses

Choice of biomass

The invitation to the workshop was specifically focused on blue mussels as the primary biomass to discuss, because Skive Municipality sees the potential for using blue biomasses in new ways to achieve both climate goals and improve water quality in Skive Fjord (for details on these potentials, please see the brief "Mussels as a potential biomass for symbiosis"). The fjord is today heavily polluted due to current and former agricultural activities, as well as the deposition of sewage from a now closed slaughterhouse.
All groups discussed perspectives on blue mussels, specifically cultivated blue mussels for human consumption. The groups had different approaches and weighting of topics, yet all the group discussions involved the following topics:

• Nature restoration
• Production/cultivation
• New products
• New marketing opportunities.



Not all groups included information on volume and/or quality of blue mussel production. Those that did pointed out that a mussel farm can harvest 300-500 tons, resulting in a total of 3,000-5,000 tons across 10 facilities. One producer mentioned that they produced 3,000 tons on approximately 80 hectares in 2022 but plan to produce around 2,000 tons in 2023; however, they would like to be able to produce 5,000 tons. They also agreed that blue mussels produced in the inner part of the Limfjord are of high quality. Producers can sell them for DKK 10 per kilogram (app. EUR 1,5) with approximately 50 mussels per kilogram for 2-year-old quality mussels.

Nature restoration

It quickly became apparent that neither producers nor citizens were interested in introducing "ecosystem service mussels", what are also called "mitigation mussels", despite scientific evidence highlighting their environmental benefits particularly the ability of mussels to filter nutrients from the water as presented in the inspirational speech.
Existing blue mussel producers opposed the use of mitigation mussels because as they stated, these mussels are small and have thin shells. Harvesting the mussels would be difficult, resulting in significant losses, and it is currently not economically viable to develop solutions for purification or separation of the mussel meat from the shells. The required technology is currently lacking.

Citizens rejected the idea of mitigation mussels because they do not want additional blue mussel "smart farms". The idea behind smart farms is to submerse them under water during winter months, but this idea has not yet been successful. The visibility of the black pipes of smart farms on the surface of the water are the primary reason for citizens' opposition, however the increased amount of fecal matter, sludge, and resulting odor under the facilities are also among citizens' concerns.

The following topics were also discussed:

- The presence of sludge, especially its thickness and the need for permission to remove it.
- Using seaweed fertilization near streams and the fjord as alternative approach to recycle nutrient discharge.
- Planting of eelgrass and use of stone reefs to enhance biodiversity.
- The establishment of private-driven sea gardens connected to professional facilities.

Production / Cultivation

The first and most important point regarding production and cultivation is that the total current supply of mussels can be sold. Furthermore, there the demand for blue mussels, whether "in one piece" or divided into meat and shells, is higher than the current supply. To balance supply and demand, it is necessary to obtain permits to increase the number of facilities for larger-scale production.
There is a desired shift in production (primarily from

mussel producers) from harvesting wild mussels to cultivating mussels. Wild mussels account for 65% of the catch (obtained through dredging), take 2-3 years to mature for harvest and consist of 15-25% meat. Cultivated mussels (grown on lines and smart farms) account for only 35% (moving toward 50%) of the current catch and take 10-12 months to mature for harvest, consisting of 40-50% meat. Cultivated mussels are also better at water filtration due to their faster growth.
Several groups express concerns about issues associated with dredging, which they view as very harsh on the fjord's ecosystem. And they point to the fact, that many mussels die in the process.

New products
With the aim of increasing demand for mussels in the Danish market, some groups discussed ideas related to product development to open up more channels and hopefully cater to the tastes of more Danes.
In addition to boiled and frozen mussels (meat), suggestions were made for producing mussel oil (as a flavor enhancer) and breaded or as "Swedish meatballs" since mussel meat is considered a high-quality ingredient.
Regarding the use of shells for purposes other than construction and riding arenas, participants had ideas for incorporating shells into high-value products. Examples included Caviart (type of caviar), shampoo, lotion, and calcium lactate for nutraceuticals.

New marketing opportunities
There was a particular focus during discussions on marketing blue mussel products to children and tourists.
Several groups saw value in developing mussel products that appeal to children, with the logic that if children enjoy eating mussels, so will their parents. One approach is to create mussel meat in child-friendly designs, drawing inspiration from Sweden and Iceland. Another proposal is the establishment of sea gardens as a potential educational setting promoting an understanding of food production, climate and environment, symbiosis, and circular thinking. Another integrated learning program could combine culinary skills with natural sciences.

Participants thought tourism has great potential as a new marketing channel. The idea is to enhance the understanding of mussel production by offering tours. For example, kayak excursions could be organized, similar to "oyster safaris" or diving trips, and boat tours could include visits to mussel farms and exploration of seaweed.
A third potential marketing channel was selling mussels to public cafeterias, emphasizing their ability to replace meat as a protein source, highlighting the health and economic benefits, as mussels are cheaper than beef and pork.

A diagram produced to summarize the workshop using the 3D visualization tool developed in the Blue Green Bio Lab project can be found at the end of this brief on page 5.

Strengths

During the summing up of each group at the end in plenum, participants talked about the strengths of their ideas. Below is a summary of the strengths identified:

- Mussels can become interesting to a wider audience.
- There are health benefits associated with consuming mussels.
- There is a climate advantage if mussels can serve as a meat substitute.
- Production of edible mussels contributes to clearer water, reduced oxygen depletion, and less bottom disturbance.
- Mussel production offers potentials for business development.
- We have a knowledge cluster in the area with both Technical University of Denmark's Shellfish Center and a relatively large industry.

Barriers

A focal point for the project is that barriers are more diverse than just regulatory ones. They can be social, cultural, business-related, etc., which became evident in the discussions. Two recurring themes throughout the workshop were the differences between knowledge and opinions, and the lack of clarity regarding legal requirements for mussel farming. A demand for greater transparency regarding the types of mussel farming and the selection of site locations raised questions such as:

- Why are there no production and operational requirements for existing facilities?
- Why is the industry not granted permits for additional facilities?
- Why can dredging occur at depths less than 2 meters (a reference to Natura 2000 areas)?
- Why are smart farms permitted when it is not yet proven that they can be submerged?
- Why are small, discarded mussels not allowed to be used as fertilizers?
- How should invasive species like Pacific Oysters, wandering mussels, and signal crayfish be managed?

There is a lack of knowledge about alternative methods for removing nutrients from the fjord other than mussels. And there is a need to dispel misunderstandings since there is conflicting data from various sources, leading to confusion and mistrust. In this context, the possibility of using seaweed fertilizers near fjords and water bodies is a gentle method to recycle nutrient discharge. However, this "fertilizer" is not recognized as such in Denmark, only as soil improvement tool. Similarly, it is currently not permissible to remove sludge from the fjord bed, which accumulates in thick layers in large parts of the fjord. Additionally, there are no economic incentives for cultivating eelgrass, which would have a mutually beneficial effect alongside mussel beds by increasing fish populations, helping to control invasive species.

Lastly, a significant barrier is that Danes, in general, do not consume much and shellfish. There is tremendous potential for more sustainable business in terms of increased sales and reduced transportation, if the consumption of mussels, preferably without shells, could be increased. Increased production separating the meat from the shells would also help with the current scarcity of shells that could be used in other industries such as cosmetics or the pharmaceutical sector.

Addressing barriers with potential for greatest positive impact

The workshop concluded with a prioritization of the barriers that need to be addressed to have the greatest positive impact. The prioritization process in the workshop involved giving all participants two stickers that they could place on notes describing the different challenges. The stickers were then counted once everyone had placed them.

This process revealed the most important barriers/obstacles to be addressed according to participants, in prioritized order – with the top two being clear "winners":

- How do we communicate better across different sectors?
- Lack of communication and involvement among stakeholders.
- What can we do for the fjord, rather than what the fjord can do for us?
- Failure to utilize existing facilities before establishing new ones.
- How do we sell our products locally? (e.g., to children).
- How do we gather more knowledge?
- Mismatch between science and production competition.
- Difficulty in persuading Danes to consume mussels.
- Where and which activities should be chosen (to intervene effectively)

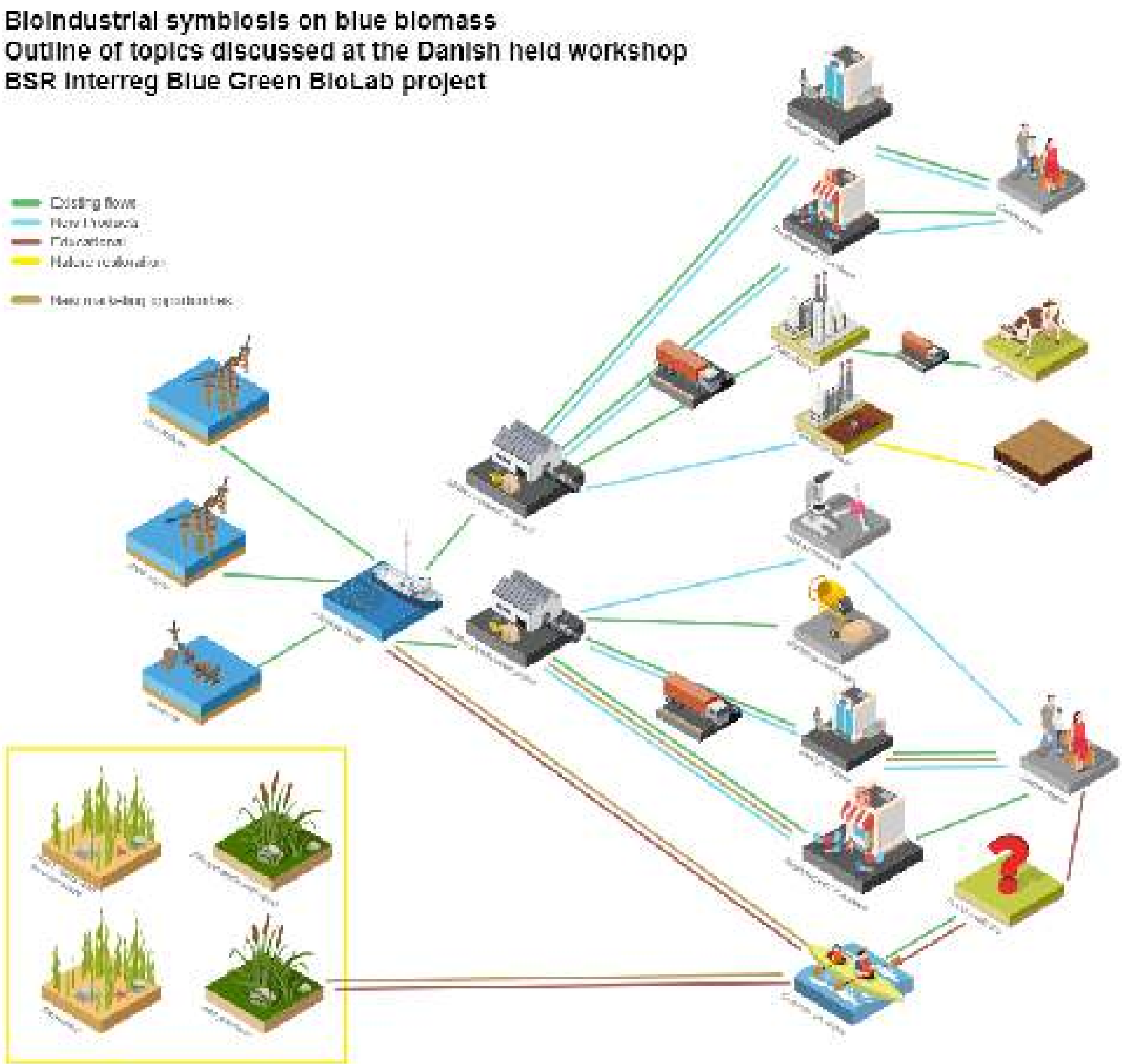
Next steps

On the template, it was possible to write suggestions on how best to move forward in creating future bio-industrial symbiosis using blue biomass. Suggestions were:

- The need for awareness campaigns
- Promoting new dietary habits
- Seeking inspiration from other places to leverage existing technology
- Creating learning programs for students
- Enhancing dialogue and knowledge-sharing across different interests, distinguishing between facts and opinions
- Developing a master plan that ensures a political framework, a democratic process, a possibility to seek funding, and gives a method that can be passed on to the Costal Water Council for the central Limfjord.

Reflections / learnings

- With an open invitation, there will attend participants you do not expect. It requires a thorough frame-setting of the workshop purpose, which is presented at arrival, in the welcome and at the tables with the message that everyone should have time to speak and that the template sets the framework for topics.
- There is a big difference in working with blue biomass compared to green biomass. In green biomass the farmer owns the land, but when we work with blue biomass, the water is a common area. There is thus a great need for marine spatial planning if we are to make full use of blue biomass in the future.



Project facts

The Blue-Green Biolab project is co-financed by Interreg Baltic Sea Region.

Total budget: 499,399.60 Euro.
Project period: October 2022 - March 2024.

Homepage: https://interreg-baltic.eu/project/blue-green-bio-lab/

Lead partner: Energibyen Skive, Skive Municipality.

Contact person: Cathy Brown Stummann, cstu@skivekommune.dk

Blue Green Bio Lab Associated Partners:

Design of bio-industrial symbiosis with blue biomasses - Sweden

This brief is a part of the Blue Green Bio Lab Tool Kit, that represents the findings in the Blue Green Bio Lab project. The project targets the urgent challenges of reducing nutrients to waters of the Baltic Sea Region, limiting greenhouse gas emissions, and enhancing European self-supply with food, feed, and energy. Together, aquaculture, agriculture and industry can provide solutions to these challenges through industrial symbiosis based on the sustainable exploitation of local blue and green biomasses initially grown and/or harvested with the objective to produce positive ecosystem services. The Blue Green Bio Lab project is co-financed by Inter-Reg Baltic Sea Region with partners in Denmark, Latvia, and Sweden.

Anna Gunnäs, maritime business developer Lysekil Municipality.

This brief contains the findings from the Swedish workshop on designing of bio-industrial symbioses on blue biomasses as part of the Blue Green Bio Lab Project. The purpose of the workshop was to identify challenges and barriers and how to move forward. The workshop was held by Lysekil Municipality together with Innovatum Science Park and Sotenäs Municipality in February 2023.

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Resumé

The Swedish workshop was held on February 3rd, 2023, with 23 participants representing various companies, infrastructure providers as well as business support organisations. The workshop was conducted in collaboration with both Innovatum Science Park and the neighboring municipality Sotenäs who has experience in working with circular symbiosis.

The invitation to the workshop was sent out via social media and newsletters as well as via direct mail and telephone calls to companies and organisations identified in collaboration with the Swedish associated partners, Innovatum Science Park and Chalmers Industriteknik. The aim was to identify and address primarily local companies that could possibly be part of the symbiosis starting with the identified warmwater biomasses, the red algae Asparagopsis, Vannamei (giant shrimp) and the fish Clarias.

Before the workshop, the participants were invited to watch three films about industrial symbiosis. The workshop started, as suggested in the general form, with an inspirational introduction to industrial symbiosis in general to ensure common knowledge, but it was also an attempt to frame the day.

Some of the participants knew each other beforehand, but most of the participants had not met each other earlier. Overall, the meeting went very well, the participants were interested in the topic and contributed with their knowledge and expertise. There was, however, one key company who was reluctant to share facts about their resource flows. The company was in a critical stage with regard to raising capital and did not want to be fully open about their resources and potential. The organizers of the workshop learned this when contacting the participants before the workshop and thus took it into account when planning the workshop in detail. This did to some extent affect the workshop, as volumes and quantities from this company could not be fully and openly discussed at the workshop.

Mapping of the bio-industrial symbioses

Choice of biomass

The setting in Lysekil, Sweden differs from the settings in Skive, Denmark and Zemgale Region in Latvia in various ways. In Denmark the local project is based upon available and well-known biomasses with existing value-chains. Skive Municipality also has a history of working with industrial symbiosis and thus has both experience in the subject and trust from society. In the Zemgale Region there is limited experience with bio-industrial symbiosis, however the biomasses at focus in Latvia are well known.

In Lysekil, the topic is new to both the municipality and the local companies even though Lysekil has followed closely developments in the neighboring municipality, Sotenäs. As the project also introduces "new" non-native species, farmed by relatively new companies in a land-based fully controlled setting, the work will naturally be conducted in a slightly different way than in Skive and Zemgale.

As part of the project in Lysekil there is also afeasibility assessment being performed for a climate neutral industrial park very close to the oil refinery producing residual heat. The chosen biomasses in Lysekil in focus are thus tropical: Vannamei and Asperagopsis, based upon two pilot cases in Lysekil, and African catfish (Clarias), as it also is a warm water species and there are existing companies in Sweden with experience with this species.

Vannamei, pilot farm in Lysekil:

The environmentally friendly land-based methods for farming tropical shrimp in cold climates is built upon the use of residual heat from nearby industries. The cultivation method is based on Biof-lock, which provides a probiotic environment and is the basis of the feed. The cultivation system is closed, which minimizes nutrient leakage to the environment. In other words, it is possible to farm tropical giant shrimps completely without antibiotics, mangrove destruction or adverse socioeconomic conditions.

Asperagopsis, pilot farm in Lysekil:

"If cattle were a country, they would rank third in greenhouse emissions". The methane emissions from cattle can be decreased by 70–90% per day when dried red macroalgae (Asperagopsis) is included in their feed (0.6%). A land-based factory enables optimization of temperature, light, and nutrients to maximize the red algae's growth rate while ensuring a high and standardized quality of the feed supplement. To ensure a sustainable production footprint and viable production economics, the algae produced needs renewable electricity, waste heat, and CO2 from nearby industries.

Clarias

African catfish (Claria) is a common food fish around the globe. It is a wild freshwater fish found in Africa and Asia. In a land-based system water quality, energy could be controlled and the eutrophication that a fish farm usually contributes could be effectively handled. Clarias is a semi-fatty cutlet fish, rich in omega 3, with firm meat reminiscent of chicken, monkfish and pork tenderloin.

Industrial circularity

Before the workshop Lysekil Municipality, Innovatum Science Park, Sotenäs Symbiosiscenter discussed the structure of the workshop to encourage participants to start thinking about possible symbioses / industrial circularity within their organisations, as the organizers assessed that it would be most beneficial to work organizationally with the following questions:

1. What flows are available in your businesses

today?

2. What intangible flows exists? Competence, knowledge, and information? (Social symbiosis).

Furthermore there was focus on additional questions related to company inputs and outputs to help participants get their thinking process started.

- INPUTS: What is expensive to buy today? What large quantities do you buy?
- OUTPUTS: What is expensive to get rid of? What large amounts do you want/need to get rid of?

Here are some of the findings from participants in the workshop:

- Seafood processing company (mainly herring): uses lots of water, district heating, electricity, transport in and out. Organic material as output – large quantities of nutritious sludge. Today transported more than 230 km before ending up as biogas.

Intangible assets: Product developing, seafood expertise, existing supply chain, free capacity in premises.

- Oil refinery: 75 MW of residual heat is not being used today. The hot water has an outbound temperature of 120-120 C and 60 C on return. A lot of untreated water, and carbon dioxide.
  Shipping, the refinery operates classified harbours. 7,6 million sqm of land.

Searching for new and green input biomasses as they are stopping processing crude oil.

- Aquaculture and food processing company: work with sea squirt (tunicate) biomass all the way from cultivation to product with zero waste. Aims at a capacity to harvest 1400 tons per year within 2 years. Have just started to investigate the possibility to produce another product – fish feed. Getting access to residual heat is interesting.

Strengths and opportunities

In Sweden 72% of the consumed seafood is imported, presenting a national food security challenge but also a sustainability challenge due to transportation and eventual climate harsh farming conditions. The development of sustainable aquaculture in controlled environment based upon local opportunities such as residual heat would target both challenges.

The realization of the circular business park could have a considerable impact for the local society. An important indirect effect of an expanding aquaculture industry and seafood sector is that new jobs are created in both primary production and the wider seafood industry and could also affect the tourism sector.

Each biomass has its own substantial market, naturally within the food sector, both for more or less direct consumption, but also as ingredients in, for example materials and fodder. In Sweden the research and innovation process for utilizing and using whole fish and shellfish is just in its infancy and will surely result in climate smart products.

The discussions showed that there are potentials for various kinds of symbiosis: even though the water outside Lysekil is rather salty compared to the rest of Sweden, extra salt is need when farming Asperagopsis – which could be supplied by a company processing herring.

Asperagopsis could clean the water for the Vannamei farm – and the reverse is also beneficiary: the water during the breeding of Vanname is nutritient rich and would act as fertilizer for the Asperagopsis farm.

And finally, the residual heat from the oil refinery could be used for both farming and drying biomasses.
(See a 3D model diagram of possible resource flows at the end of this brief.)

Barriers and obstacles

There is potential, but this work is easier said than done. Farming non-native species, outdated regulations, and long permit processes are just a few of the barriers before successful bio-industrial symbiosis will be a reality.

The transition to a circular society requires a transition on several levels. Today not only do we work mainly sector wise, the legal framework and the way our government is structured is also organized in silos. But climate and environmental challenges require a totally different set up – focused on systems rather than silos. In Sweden different authorities need to handle and are responsible for similarly challenging questions. In the worst cases some authorities end up counteracting each other. This in turn gives companies unpredictable development conditions. Furthermore, experience shows that regional authorities sometimes assess cases differently and when it comes to new non-native species this is particularly noticeable. The company farming Vannamei contacted four different regions in Sweden asking for legal advice and got four totally different answers.

One example discussed during the workshop: A land-based RAS (recirculating aquaculture system) salmon farm, who is planning to build a symbiosis system where the plant primarily will produce salmon, but the purification process also includes algae cultivation, from which silicon is extracted. In addition, the salmon and algae farming are linked to a biogas plant. The result from the symbiosis is almost no leftover waste. Despite this, the permit process is now entering its sixth year! The algae farm and the biogas plant are up and running. However, the legal system handling aquaculture in Sweden is just considering how much fodder should being used in the fish farm, and not how much nitrogen and phosphorus which is actually leaving the plant. In short, the road to the permit is long and bumpy.

Additionally, there are questions with regard to a future circular symbiosis with regard to water sharing for the farming of red algae and Vannamei shrimp. The definition of where one business process starts and where the next business process takes over could directly affect the permit process.

One of the companies also introduced waste regulations as a question to be further investigated. When a resource, in a process, has been defined as a waste product – there is a lot of work to have that waste defined as a resource again. This kind of set up is not beneficiary for a circular society.

Next steps

There are several opportunities to be taken care of. Even though there are some considerable obstacles the upside is substantial, both for the environment, climate, and the local society.

The barriers identified are well known and are hardly solvable within the Blue Green biolab project. The next step will therefore be to investigate and analyze what initiatives are already ongoing and to see how we could join forces with them.

In the municipality we will also continue to work with the feasibility study for the business park and will continue to work with the organisations participating in the participatory workshop as their input is valuable in the planning process.

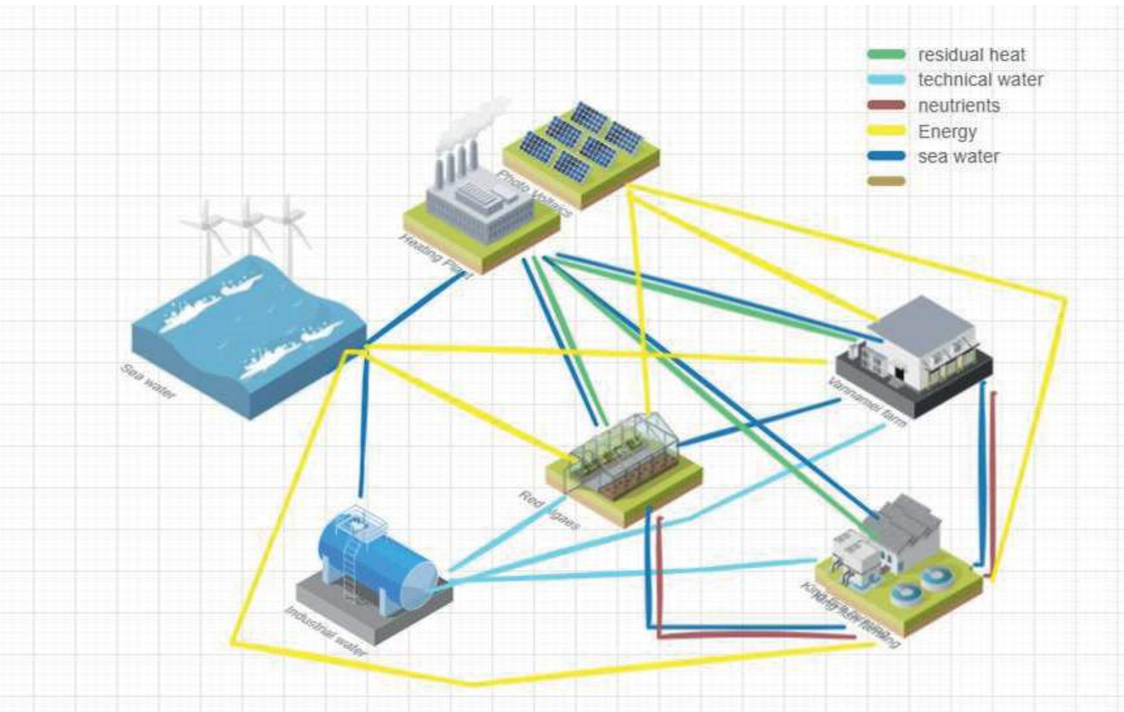
On the basis of the positive feedback from workshop participants, it is also evident that the workshop was valuable for the organisations' internal processes. The organizers and participants left the workshop meeting room with smiles on their faces and looking forward to further collaborations. It was a good day.

Reflections / learning

The workshop, and the process before the workshop, proved to be valuable for the organizers, who have now taken some, even though fairly small, steps towards industrial symbiosis in Lysekil. The businesses have their business models and as the permits are based upon their own products and biomasses it requires guts, trust and courage to take the first steps towards industrial symbiosis as the legal setting is not built on circular models. From a "good society point of view" it is easy to see all the benefits; saving resources, limiting residuals etc., and thus we would all like circular revolution to happen overnight. There is a need for long-term strategies and commitments.
The set up in Lysekil is both introducing a new way of operating and non-native species at the same time. The non-native species will be bred and farmed on land, in closed systems, but how this will be handled in the legal context is very unclear and will be further investigated in the next part of the project.

It will be of utmost importance to be very clear about what the goals are and to communicate them effectively. The focus on the potential for farming non-native species needs to be based on a knowledgeable discussion, not driven by emotions. It is important for everyone to understand that these aquaculture systems are closed and are fully controlled.

The workshop made it clear that the set up in Lysekil will be an interesting journey, and there is a lot to be learned along the way.



Mapping of resource flows based on knowledge developed in the Blue Green Bio Lab workshop in Lysekil, Sweden.

Bio-industrial symbiosis

Policy Brief

Project facts

The Blue-Green Biolab project is co-financed by Interreg Baltic Sea Region.

Total budget: 499,399.60 Euro.
Project period: October 2022 - March 2024.

[Homepage: https://interreg-baltic.eu/project/blue-green-bio-lab/](https://interreg-baltic.eu/project/blue-green-bio-lab/)

Lead partner: Energibyen Skive, Skive Municipality.
Contact person: Cathy Brown Stummann, cstu@skivekommune.dk

Blue Green Bio Lab Associated Partners:

Design of bio-industrial symbiosis with green biomasses - Latvia

This brief is a part of the Blue Green Bio Lab Tool Kit, that represents the findings in the Blue Green Bio Lab project. The project targets the urgent challenges of reducing nutrients to waters of the Baltic Sea Region, limiting greenhouse gas emissions, and enhancing European self-supply with food, feed, and energy. Together, aquaculture, agriculture and industry can provide solutions to these challenges through industrial symbiosis based on the sustainable exploitation of local blue and green biomasses initially grown and/or harvested with the objective to produce positive ecosystem services. The Blue Green Bio Lab project is co-financed by Inter-Reg Baltic Sea Region with partners in Denmark, Latvia, and Sweden.

Evija Ērkšķe, Zemgale Planning Region.

This brief contains the findings from the Latvian workshop on designing of bio-industrial symbioses on green biomasses as part of the Blue Green Bio Lab Project. The purpose of the workshop was to identify challenges and barriers and how to move forward. The workshop was held by Zemgale Planning Region and Latvian Institute of Aquatic Ecology in April 2023.

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Resumé

The seminar of representatives of interested institutions organized by the Latvian partners of the project- Zemgale Planning Region (ZPR) was held on April 27, 2023 in Jelgava with 21 participants representing local municipalities, academics, farmers, small and medium enterprises and non-governmental organizations.

It was decided to follow the general design proposed by the project. The Zemgale region in Latvia is well known as an agricultural and energy development area. Cereals are the main agro crops grown here, forestry and timber industry are also developed. The region does not have direct access to external waters, that is, an outlet to the Baltic Sea or the Gulf of Riga, which determines that the use of marine plant or animal biomass cannot be counted on. In the Zemgale region, there are quite a lot of lowlands, wetlands, meadows and inland waters, where there is a good potential for grass or reeds extraction, further processing and energy producing. At the time however, these potentials are not developed.

Before the seminar, the region's situation in the field of extraction, processing and use of green biomasses was identified. In this process a wide range of representatives were involved - from scientists and regional development planners to local government specialists and rural entrepreneurs. As an introduction, the types of biomasses included in the biomass briefs were presented and the options to include those into bio-industrial symbioses.

The workshop began with a speech by the executive director of Zemgale Planning Region. Afterward followed the presentation by project partner Latvian Institute of Aquatic Ecology on several possible biomass types for creation of bio-industrial symbioses. Later the floor was given to two enterprises. The first was "Mežacīruļi"

Bio-industrial symbiosis

Policy Brief

drawing the experience on biomass extraction and use for energy production purposes as well as "EGG ENERGY" on energy processing for energy production. The presentation was by the professor of Latvia University of Life Sciences and Technologies and focused on the opportunities on biomass processing and use from industrial hemp and oriental galega.

During the group discussion part of the seminar, participants talked about possible bio-industrial collaborations in the Zemgale region, about existing and necessary production facilities, biomass processing capacities, various possibilities of additional use of wild and cultivated plants, as well as the flow of resources in our region. Furthermore, a SWOT analysis was carried out regarding business cooperation potential and determined the priority of challenges and their solutions.

Thus, the workshop was the first step for participants' understanding of the seriousness of the issue. It was also an encouragement to the project team to continue communicating about the involvement of various players in the Zemgale region and the creation of a mutual basis for bio-industrial symbiosis.

Mapping of the bio-industrial symbioses

It was not possible to map any bio-industrial symbioses due to missing value chains in Zemgale region. The tendency for biomass use in the region expressed by participants was mostly towards energy (biogas) production, as experience exists in the region. The following section therefore tackles some of the issues related to energy production.
(See also the 3D model diagram at the end of this brief.)

Choice of biomass
All groups choose to focus on green biomass types with the emphasis on extraction and processing. The groups had different approaches and considerations, but the following topics were discussed:

- Nature restoration
- Production/cultivation
- New products
- New market opportunities

Nature restoration
Residues from agricultural crops, grasslands, bushes have great volumes of green biomass in the Zemgale region. The gathering of green biomasses frequently is considered a great way to clear the agricultural areas from the residues and also fight invasive alien plant species, one of the main reasons for soil degradation and reduction of biodiversity nowadays. By regular grass cutting there is no option for the seeds of invasive plant species to ripen and spread the plant further.

Production / Cultivation
Specific production of green biomass is still in question. Zemgale is a region of extensive agricultural production, so there is more likely an option to use the leftovers from the crops, vegetables and other agricultural production as well as timber. The biomass from grasslands is used for the livestock mostly, but part of that could be used also for energy production.
New products
During the workshop some participants discussed the usage of straw, reeds and hemp in the production of construction materials. Hemp also has an option to be used in the production of the food products, such as oil, seed mix and butter. Still, all new options and products have a theoretical potential at this point, given the lack of established value chains.

Marketing opportunities
The idea of bio-industrial symbiosis is quite new in the region, and it was obvious that it is a topic that should be communicated more extensively and explained more between the stakeholders.

Bio-industrial symbiosis

Policy Brief

Strengths

During the groups' presentation of their work, they discuss the strengths of their chosen symbiosis. Many of these strengths have been mentioned above in the review of symbiosis possibilities. In general, these ideas about circular bio-industrial symbiosis are considered to have a great potential in building cooperative networks and value chain creation. Less evaluated but still relevant were the opportunities in new financing programs, regarding development logistics and development of the new technologies.

Barriers

Most barriers for green biomass use for energy production purposes involve the provision of certain volumes of gathered biomass that could be delivered to the energy producers. Businesses are willing to receive regular supplies of biomass. To some extent that is possible, but considering the seasonal changes and the biomass destinations the situation may be different and unpredictable. The stakeholders pointed out the threats starting from the uncoordinated actions in the energy sector, current political situation and existing unpredictable situation in energy and economics sectors.

Addressing barriers with potential for greatest positive impact
There is a need for wider awareness of the many ideas for biomass usage (beyond only energy) and a greater linkage with the improvement of ecological quality and climate impact through the development of circular bio-industrial symbiosis.

Prioritization of Efforts
The workshop concluded with a prioritization of the barriers that need to be addressed to have the greatest positive impact. This prioritization, referred to as a "temperature measurement" in the workshop, involves equipping all participants with two stickers that they could place on notes containing different challenges. The stickers were then counted once everyone has placed them.

The temperature measurement revealed that the most important barriers/obstacles to be addressed, in prioritized order, are as follows – with the top two being clear "winners":

- How do we communicate across different sectors?
- Lack of communication and involvement among stakeholders
- Where and which activities should be chosen (to intervene effectively)?

Other barriers and obstacles mentioned in groups' presentations include:

- Communication.

Next steps

The groups of participants had the opportunity to share their suggestions on how we best can move forward in creating future bio-industrial symbiosis in the biomass sector. The proposed suggestions are as follows:

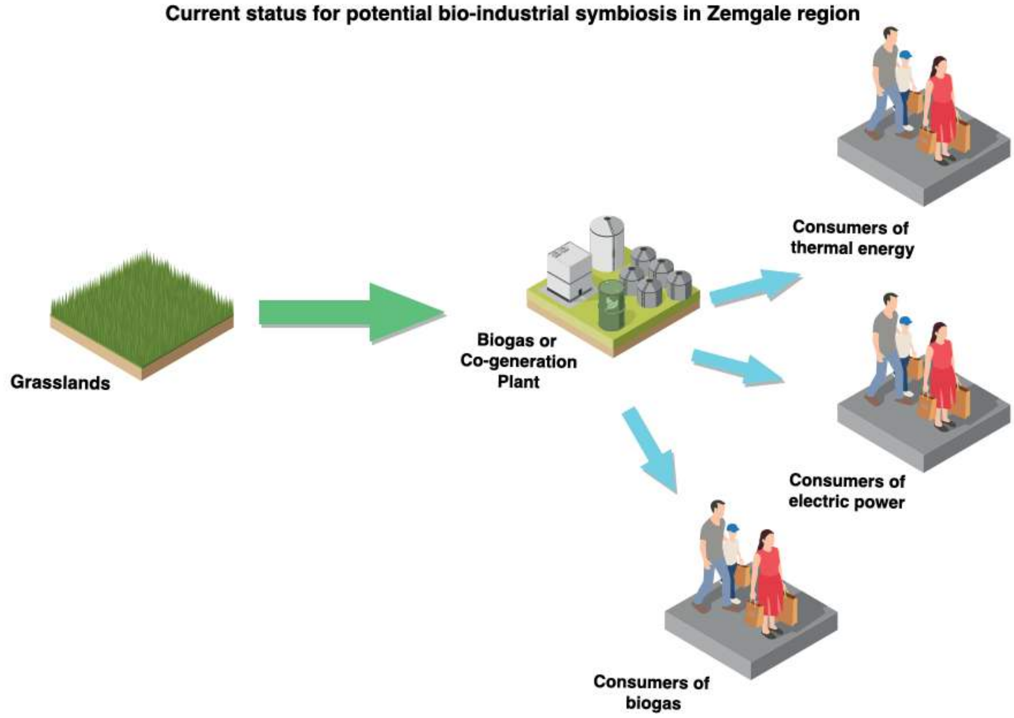
- The need for awareness campaigns on the use of biomass in energy production;

- Developing a master plan that ensures a political framework, a democratic process, the ability to seek funding for the value chains of biomass harvesting, logistics and use in the energy creation.

Reflections / learning

- it was a good opportunity to hear the views of the participant and to be able to see the strenghts and the weaknesses of the current situation from their point of view.
- In the areas of the river protection line it is not allowed to gather the reeds.

Current status for potential bio-industrial symbiosis in Zemgale region



RESOURCES
In Zemgale there is a possibility to use existing resources of biomass as initial feedstock for bioindustrial purposes, grass is considered as most promising. For successful implementation of this approach, a cooperation between municipalities, state and private property owners is needed. Also, the availability and abundance of respective type of resource should be assessed before initiating further use.

USE OF RESOURCES
The most possible current possibility for use of biomass is feedstock for biogas and/or co-generation plant. This option is in line with Energy Action Plan 2018-2025 of Zemgale Planning region. Action Plan also foresees locations of energy facilities to have appropriate regional coverage.

END USERS
Type and distribution of the produced energy will be decided by direct involvement of local inhabitants, mostly via community councils. Community council is a non-governmental body directly representing interests and concerns of local citizens.

Diagram of possibilities for bio-industrial symbiosis based on knowledge developed in the Blue Green Bio Lab workshop in Zemgale Planning Region, Latvia.

Project facts

The Blue-Green Biolab project is co-financed by Interreg Baltic Sea Region.

Total budget: 499,399.60 Euro.
Project period: October 2022 - March 2024.

[Homepage: https://interreg-baltic.eu/project/blue-green-bio-lab/](https://interreg-baltic.eu/project/blue-green-bio-lab/)

Lead partner: Energibyen Skive, Skive Municipality.
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Blue Green Bio Lab Associated Partners:

Step 3: Working with policy
Developing conducive policy environments and practices to spur bio-industrial symbiosis

What we did

Earlier in the Blue Green Bio Lab project workshops were held at each project site where barriers and challenges to bio-industrial symbiosis were identified. After the workshops we transnationally discussed the findings and identified 2 common challenges to further address.

1. **National regulations** that are perceived as barriers for circular bio-industrial symbiosis regarding the biomasses each partner focused on (and to the extent possible the EU level regulations that they relate to).
2. **Communication** about circular bio-industrial symbiosis ideas and potentials with our selected biomasses

At each of the 3 project sites co-creative meetings on developing conducive environmental policies and practices to support the establishment of bio-industrial symbiosis were held. The co-creative meetings were afterwards transnationally evaluated in a partner meeting in Jelgava, Latvia.

Key Learnings and recommendations

- Even though we had different points of departure with regard to technology and innovation-readiness, the challenges were shared. For example: working with fast tempo innovation processes in (slower...) administrative bodies.
- We also gained insights regarding the importance of making space for retrospective learning for ourselves and our stakeholders. We experienced that working goal-oriented *(in a common direction)*, rather than goal-fixed *(toward a specific outcome)* can enhance collaboration and innovation in complex projects.
- In designing the co-creative meetings, we learned to prioritize a point of departure in the pre-understanding among the workshop participants.
- In short, it's about keeping it simple *(despite the complexity!)*, using practical examples to illustrate and create common understanding, and ensuring respect for stakeholders' different "languages" *(for example scientific vs layman's understandings)*.

For further details, the following briefs describe the actions within policy environment in each country:

- Developing Policy Environments and Practices – Knowledge and approaches
- Spurring blue bio-industrial symbiosis in Skive, Denmark
- Spurring blue bio-industrial symbiosis on land in Lysekil, Sweeden
- Spurring green bio-industrial symbiosis in Zemgale Planning Region, Latvia

Developing Policy Environments and Practices – knowledge and approaches

This brief is a part of the Blue-Green Bio Lab Tool Kit, that represents the findings in the Blue Green Bio Lab project. The project targets the urgent challenges of reducing nutrients to waters of the Baltic Sea Region, limiting greenhouse gas emissions, and enhancing European self-supply with food, feed, and energy. Together, aquaculture, agriculture and industry can provide solutions to these challenges through industrial symbiosis based on the sustainable exploitation of local blue and green biomasses initially grown and/or harvested with the objective to produce positive ecosystem services. The Blue-Green Bio Lab project is co-financed by Inter-Reg Baltic Sea Region with partners in Denmark, Latvia, and Sweden.

Anne Bergeld Gunnäs, Lysekil Municipality
Anda Ikauniece, Latvian Institute for Aquatic Ecology

The brief is a result of the work in the project on developing conducive policy environments and policy practices to spur bio-industrial symbioses. The brief provides overviews of existing knowledge, relevant information on the EU legislative framework as well as a description of the different approaches of developing the policy environment from partners in Latvia, Sweden and Denmark participating in this project.

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- Existing knowledge from similar projects
- The EU legislative framework
- Related research findings
- Co-creating conversations
- Transnational evaluation

Existing knowledge from similar projects

With the rise of climate and environmental problems during the last ten years, effective and sustainable use of resources has become a topic also in the Baltic Sea region. Several projects (*Urban Baltic Industrial Symbiosis, Baltic Industrial Symbiosis, BSR Stars 3, Baltic Biomass 4 Value, Green VALLeys, LIFE_PHIPP*) have been devoted to looking for efficient ways of energy and resource use, including biomasses in the region. Below is a short overview of the key results in these projects.

The projects Baltic Industrial Symbiosis and BSR Stars 3 have identified several relevant factors for successfully establishing and implementing (bio)industrial symbiosis. The presence of **appropriate policies** was one of the most important factors. As most of the Baltic Sea region's countries have not explicitly addressed bio-industrial symbiosis in planning documents, the following steps are suggested:

- to communicate the potential of industrial symbiosis to include it in the national political agenda, emphasizing its relevance for circular economy; and
- to include industrial symbiosis in national circular economy strategies.

Given that existing industrial symbiosis activities have mostly started as mutual initiatives between businesses, foundations, and municipalities without specific policy support, it is also important to improve **national legal competencies** for developing and supporting of symbiosis initiatives. The projects suggest countries establish one national governmental agency responsible for symbiosis activities to ensure long-term development and competence.

Appropriate funding opportunities is another set of relevant factors for expanding industrial symbiosis. Direct national support of bio-industrial symbiosis via dedicated funding programmes is not typical (BB4Value, 2021). Fiscal support tends to occur through the help of for example: national CO2 tax regulations, missing subsidies for fossil fuels and providing more favourable environments for innovative startups. There are several EU funding initiatives for development of the circular bio-economy (European Circular Bioeconomy Fund, Bio-based Industries Joint Undertaking) although the requirements for applications may not match the current potential of symbiosis partners.

Therefore, an increase in **regional and local level capacity** to support symbiosis is crucial. This can be done with a help of training programmes on circular bioeconomy for national authorities of various levels (Baltic Biomass 4 Value), creation of national networks for (bio)industrial symbiosis, regional information events for local businesses and match-making events for potential symbiosis partners.

Consequently, much of the success in creating and developing (bio)industrial symbiosis lies in the **communication of the idea**. Provision of easily accessible information, promotion of the best practice cases and networking are mentioned as useful communication tools.

The EU legislative framework

This section looks at the current landscape of the European Union legislative framework for environmental protection, including waste management and circular economy, with an emphasis on (bio)industrial symbiosis. Baltic Sea regional policies are also shortly characterized.

In general, European environment policy is governed by the principles of precaution, prevention, rectifying pollution at the source, and on the 'polluter pays' principle. The forthcoming legislative proposals and goals are summarised in multi-annual Environment Action Programmes (EAPs), with the 8th EAP currently in force. It sets the EU's legally agreed upon common agenda for environment policy until the end of 2030 and has six priority objectives:

- Achieving the 2030 greenhouse gas emission reduction target and climate neutrality by 2050,
- Enhancing adaptive capacity, strengthening resilience, and reducing vulnerability to climate change,
- Advancing towards a regenerative growth model, decoupling economic growth from resource use and environmental degradation, and accelerating the transition to a circular economy,
- Pursuing a zero-pollution ambition for air, water and soil and protecting the health and well-being of Europeans,
- Protecting, preserving, and restoring biodiversity, and enhancing natural capital (notably air, water, soil, and forest, freshwater, wetlands, and marine ecosystems),
- Reducing environmental and climate pressures related to production and consumption (particularly in the areas of energy, industrial development, buildings and infrastructure, mobility, and the food system).

The European Green Deal (effective December 2019) is the European umbrella policy framework which should help to focus EU policies on making Europe the first climate-neutral continent in the world. Thus, the current EAP is also targeted towards enhancement of Green Deal's goals.

EU horizontal strategies support the objectives of EAPs and at present these are the most significant:

- Sustainable development strategy and related documents, outlining how to integrate the Sustainable Development Goals (SDGs) into EU policy priorities;
- Biodiversity strategy for 2030 as a comprehensive, ambitious and long-term plan to protect nature and reverse the degradation of ecosystems; and
- Farm to fork strategy, which aims to make food systems fair, healthy and environmentally friendly.

The binding directives and regulations for environmental protection are issued according to the type of threat, pollution, or habitat in need of being protected (water, air, soil). The general 'polluter pays' principle is implemented by the Environmental Liability Directive, which aims to prevent or otherwise remedy environmental damage to protected species or to natural habitats, water, and soil. The scope of the directive has been broadened three times to include the management of extractive waste, the operation of geological storage sites and the safety of offshore oil and gas operations respectively.

European waste management policy is part of the environmental policy framework, as it aims to protect the environment, human health, and help the tran-

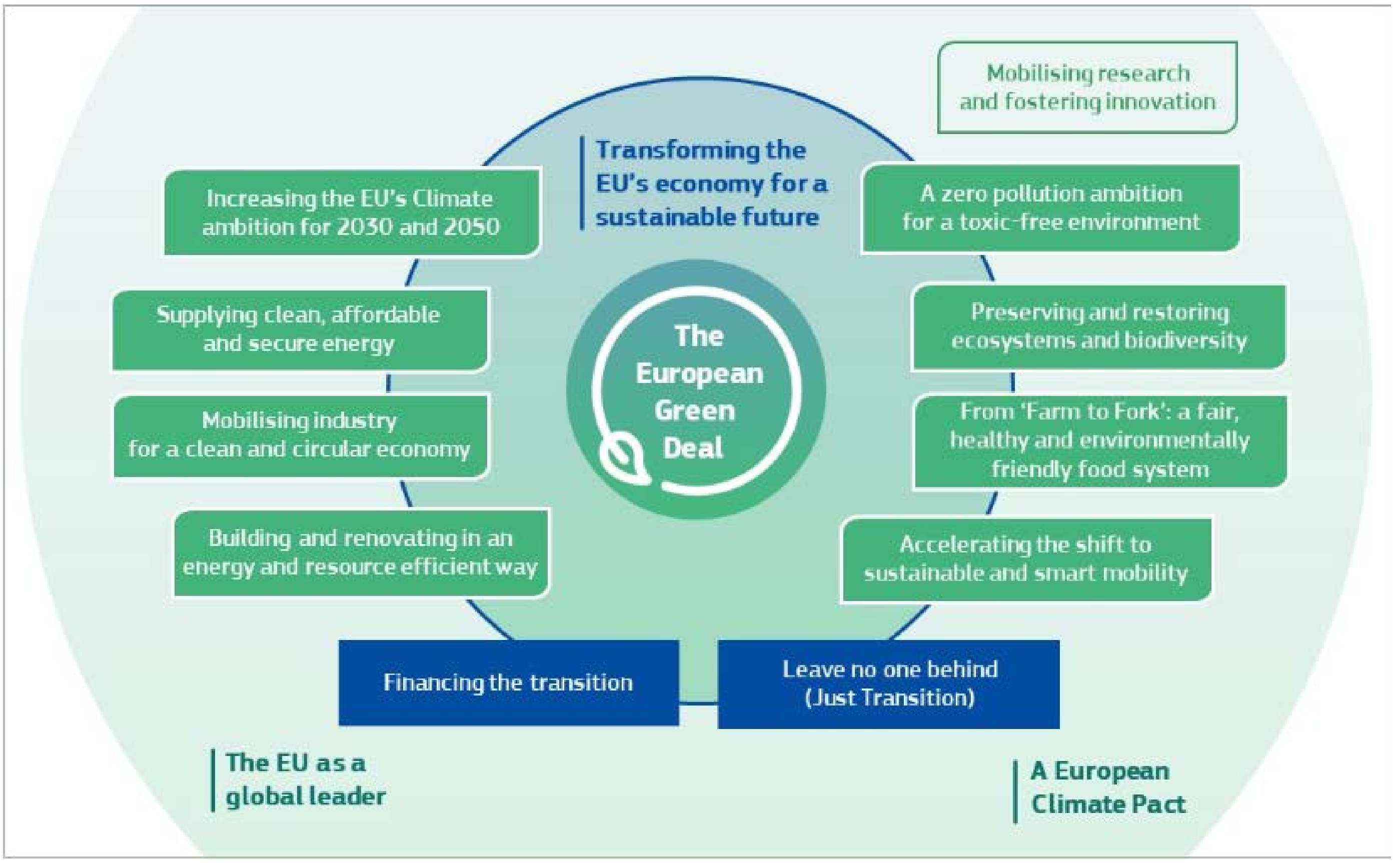

Fig 1. The European Green Deal Structure. The figure shows the areas of focus for transforming the EU's economy for a sustainable future. Source: Communication from the Commission, The European Green Deal, Brussels, 11.12.2019.

sition to a circular economy by extracting as many high-quality resources from waste as possible. The Waste Framework Directive is the EU's legal framework for treating and managing waste in the EU. Certain categories of waste require specific approaches (such as batteries, building materials, and biodegradable waste). Therefore the EU has many laws to address different types of waste. The waste is seen as a resource in the circular economy although the EU Circular Economy action plan does not explicitly connect the waste with industrial symbiosis.
On the regional level the European Union Strategy for the Baltic Sea Region (EUSBSR) is the overarching policy planning agenda in regional development and incentives. The Strategy's three main pillars are to save the Baltic Sea, to connect the region and to increase prosperity. The latest 2021 Action Plan stresses the importance of climate change and therefore horizontally includes it in all 14 Actions. Development of circular economy, specifically in the form of industrial symbiosis, is included in the "Bioeconomy" Policy Area.

Although there is a strong linkage between EUSBSR and the Baltic Sea Action Plan of Helsinki Commission (BSAP), the focus of the BSAP is on protection measures for the marine environment. It should be noted that there are no other overarching governance documents on regional issues, other than the BSAP. However, the holistic approach and wide coverage of the BSAP, with four action segments and almost 100 actions in more than 10 sectors, is in line with efforts toward an EU-wide circular and sustainable (bio) economy.

Related research findings

As research on bio-industrial symbiosis in the context of our project is not available, this section focuses on findings from studies of industrial symbiosis in the Baltic Sea Region and beyond. The concepts of circular bio-economy or the bio-economy innovation ecosystem also to large extent represent idea of bio-industrial symbiosis. A review by OECD (2019) has stated that *"building regional and national bio-economies is proving to be difficult. Joining them to make an international (circular) bio-economy will require a major transition for society, away from fossil dependence and towards a more sustainable economy and future. The mix of policies that is required reflects both the complexity and the importance of this transition. (..) Far more difficult, however, is enabling an ecosystem of stakeholders, from the feedstock owners and producers, to the customers for bio-based products and on towards end-of-life/recycling."*

A recent wide review (Lybæk et al., 2021) on policy frameworks for the deployment of industrial symbiosis has identified a set of factors together with proposed solutions.

- **A lack of policy interventions.** Here a suggested solution is to have firm regulation as a policy intervention together with more incentive-based initiatives, especially at the local level.
- **Direct and indirect policies** influencing the development of industrial symbiosis systems. Indirect policies are related to waste management practices (taxes on landfill, bans on organic waste landfilling); direct policies are incentives to companies by e.g. government programs, co-operation platforms and other interventions formulated within the frame of an overall national Industrial symbiosis strategy, providing a clearer governmental policy.
- **Greater cooperation between companies** within devoted platforms for information exchange on side streams and by-products.
- **A knowledge gap on the concept of industrial symbiosis**, technologies, options, and funding opportunities. This gap could be overcome by the facilitation of a learning environment, e.g., via online platforms with information resources.
- **Need for more flexible funding schemes.**
- **Local political and public support** by municipalities and administration is crucial, as well as by local inhabitants.

Results from a case study on the facilitation of local biogas system development in Norrköping focuses on interventions with public and private actors through a workshop series (Lindfors et al., 2020). These interventions generated knowledge of Norrköping's significant potential for producing and using biogas, and its potential as a location for a transport hub. The workshop series created a shared understanding that cooperation and coordination to distribute resources and knowledge about biogas was critical for realizing these potentials. Furthermore, the municipal organization was identified as an important actor for coordinating these efforts.

Institutional capacity and involvement, regarding the role of sectoral actors and need for mutual trust is emphasized in several studies (Bacudio et al., 2016, d. Abreu&Ceglia, 2018, Patala et al., 2020). It has been identified that government, or other respective authorities, is vital in building and maintaining an industrial symbiosis coordination network, but that ultimately other actors and driving forces are necessary to ensure the cyclical flow of materials and energy. A change in thinking from linear towards systemic is also essential for successful implementation of industrial symbiosis.

Co-creating conversations

Earlier in the Blue Green Bio Lab project workshops were held by each of the public authority partners in the project, where barriers and challenges to bio-industrial symbiosis were identified. These workshops used a common approach (see project brief "Participatory Workshop Design for the Blue Green Bio Lab Project").
After the workshops a transnational dialogue between the partners ended with identifying 2 themes to work with further.

1. **National regulations** that are perceived barriers for circular bio-industrial symbiosis regarding the biomasses we are focused on in each country (and to the extent possible the EU level regulations that they relate to).
2. **Communication** about circular bio-industrial symbiosis ideas and potentials with our selected biomasses

The transnational dialogue revealed the importance of delving more into communication issues. The partners discussed how easy implementations of bio-industrial symbiosis plans could be if not obstructed by communication that takes on a life of its own, which tends to be based upon feelings and personal opinions rather than knowledge-based facts. The partners agreed to focus on better understanding the role of communication and its role in enhancing understanding and development of bio-industrial symbiosis and the transformation to a sustainable future.

After the transnational dialogue each of the 3 project sites held co-creative meetings on developing conducive environmental policies and practices to support the establishment of bio-industrial symbiosis.

Skive, Denmark

After the first workshop in Skive focusing on bio-industrial symbiosis of blue biomasses, the partners took a step back and really looked at what the stakeholders wanted – more options for dialogue. Therefore, their needs and interests were in the center of 2nd workshop. The invitation was crafted around a collaborative question: What is needed to achieve a cleaner fjord, and what can each of us contribute to support this?

The result was constructive conversations between participants that before the workshop likely saw themselves as opponents. The mixing of entrepreneurs and business development interests stimulated discussions about innovation, which are essential to reach climate, environmental and business goals. More information on this workshop can be found in the project brief "Spurring blue bio-industrial symbiosis in Skive, Denmark".

Zemgale Planning Region, Latvia

A co-creative online meeting was held and attended by 21 participants. The attendees represented the Ministry of Climate and Energy, local municipalities (environmental and energy specialists), energy producers and respective professional associations. The participants were chosen based on an assessment of stakeholders that might have key importance for the development of bio-industrial symbioses in Zemgale region.

The online meeting was well attended, however knowledge about and options for using green biomasses in bio-industrial symbiosis are currently limited

Fig. 2 Participatory workshop held in Skive, Denmark in April 2023.

in Latvia. More communication is needed to shine light on and better understand the availability of green biomasses, new value chain actors, logistics, and innovation around final products and sustainability issues. More information on this workshop can be found in the project brief "Spurring green bio-industrial symbiosis in Zemgale Planning Region, Latvia".

Lysekil, Sweden

In Lysekil two co-creative meetings in the format of roundtable discussions were held in the fall of 2023. The first meeting focused on societal engagement and how to communicate with different stakeholders in transforming society. The workshop was in cooperation with Linköpings University, Lysekil, Luleå and Slite municipalities. The topic, the transformation to sustainable societies, echoed the challenges identified in the previous workshop related to communication and trust.

The second roundtable discussion had a more "hands-on" approach to the environmental policy – how do we create a land-based aquaculture system in harmony with environmental regulations? Lysekil municipality, LEVA in Lysekil (municipal electricity and wastewater company), Smögenlax (aquaculture company), Rena Hav (wastewater and biogasplant) and IVL (Swedish environmental institute) participated.

The outcomes of the meetings were positive in different ways. The broad representation of stakeholders and perspectives added dynamism and value in the first meeting. The second meeting had a similar roundtable setup, but with a more practical approach in problem-solving. These conversations added significant value to developing the wastewater treatment concept design for a bio-industrial symbiosis park. The meeting also became a starting point for closer collaboration between the businesses. Read more on activities in Lysekil in project brief "Spurring blue bio-industrial symbiosis in Lysekil, Sweden".

Transnational evaluation – what did we learn together?

The co-creative meetings at each project sites were transnationally evaluated in November 2023. The part-

Fig 3. Transnational workshop in Jelgava, Latvia.

ners concluded that even though we are starting from different points of departure with regard to technology and innovation-readiness, we still have a lot of issues in common. We all have the challenge of working with fast tempo innovation processes in an administrative body – where policy development occurs at a slower pace.

We also gained further insights regarding the importance of making space for retrospective learning for ourselves and our stakeholders. We experienced that working goal-oriented (in a common direction), rather than goal-fixed (toward a specific outcome) can enhance collaboration and innovation in complex projects.

Regarding the designing of co-creative meetings, we learned to prioritize a point of departure in the pre-understanding among the workshop participants. Allowing participants to form both content and process (open space) is one approach.

In short, it's about keeping it simple (despite the complexity!), using practical examples to illustrate and create common understanding, and ensuring respect for stakeholders' different "languages" (for example scientific vs layman's understandings). At the end of the day this work requires flexibility on the spot and a willingness to learn along the way. You might have to change how to proceed based upon where the participants are – and you don´t know that until you´ve met them in the workshop.

Relevant Sources

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Project facts

- The Blue-Green Biolab project is co-financed by Interreg Baltic Sea Region.
- Total budget: 499,399.60 Euro.
- Project period: October 2022- March 2024.
- Homepage: https://interreg-baltic.eu/project/blue-green-bio-lab/
- Lead partner: Energibyen Skive, Skive Municipality.
- Contact person: Cathy Brown

Blue Green Bio Lab Associated Partners:

Food & Bio Cluster Denmark
KURZEME PLANNING REGION
innovatum science park
CHALMERS INDUSTRITEKNIK
CBIO AARHUS UNIVERSITY CENTRE FOR CIRCULAR BIOECONOMY

Spurring blue bio-industrial symbiosis in Skive, Denmark

This brief is a part of the Blue-Green Bio Lab Tool Kit, that represents the findings in the Blue Green Bio Lab project. The project targets the urgent challenges of reducing nutrients to waters of the Baltic Sea Region, limiting greenhouse gas emissions, and enhancing European self-supply with food, feed, and energy. Together, aquaculture, agriculture and industry can provide solutions to these challenges through industrial symbiosis based on the sustainable exploitation of local blue and green biomasses initially grown and/or harvested with the objective to produce positive ecosystem services. The Blue-Green Bio Lab project is co-financed by Inter-Reg Baltic Sea Region with partners in Denmark, Latvia, and Sweden.

Cathy Brown Stummann, Project leader, Skive Municipality

Thine Hahnbak, Innovation consultant, Climate Foundation Skive

This brief focuses on developing conducive policy environments and policy practices to spur bio-industrial symbioses in the area around Skive, Denmark. The activities discussed in the brief build upon challenges and opportunities for bio-industrial symbiosis identified earlier in the Blue Green Bio Lab project via workshops and discussions with local stakeholders.

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- **Choice of biomass**
- **Co-creative workshop**
- **Challenges and opportunities**
- **Next steps**
- **Reflections and learning**
- **Relevant sources**

Choice of biomass

The inner part of the Limfjord is heavily polluted due to nutrient run-off from current and former agricultural activities and deposition of sewage from a now closed slaughterhouse. Eutrophication has been a repeated challenge in the area, reaching the most expansive and serious occurrence in the fall of 2023. These serious challenges with eutrophication have also affected marine life, as evident in the latest Key Fish Report in the fall of 2023, showing drastic decreases in the local fish population.

The Danish partners in the Blue Green Bio Lab project have focused on the possibility of increasing production of blue mussels to help with climate and environmental goals, particularly around Skive Fjord, Risgårde Bredning and Lovns Bredning (see Figure 1). It is anticipated that the filtration capacity of mussels will contribute to improved water quality enabling over time production of other blue biomasses for bio-industrial symbiosis such as seaweed and eel grass. Skive Municipality and the Climate Foundation Skive see opportunities for the development of new products using blue mussels.

Figure 1 – Map of the Inner Limfjord

Co-creative workshop

On November 27th the Climate Foundation and Skive Municipality together with Food and Bio Cluster Denmark held a second Blue Green Bio Lab workshop.

The workshop was organized based on results from the first project workshop in April 2023, where a prioritization of important next steps among participants revealed that they primarily wanted to meet again and share perspectives. To the partners' surprise, it turned out to be the first time that such a diverse group of stakeholders had gathered in the same room. Another important result was the desire to focus on "not what the fjord can do for us, but what we can do for the fjord." These prioritized wishes became the starting point for the second workshop.

The workshop was crafted around a collaborative question: What is needed to achieve a cleaner fjord, and what can each of us contribute to support this? The participants from the first workshop were invited and those who couldn't attend the first workshop but wanted to stay informed. Members of the Coastal Water Council and the Green Council in Skive Municipality were invited to involve more local NGO interests and politicians. Several researchers / universities were also invited to ensure knowledge about the latest research was present at the workshop.

The workshop was designed in a co-creative format using the Open Space Technology method, allowing participants to discuss what matters to them and engage with like-minded individuals. This method was chosen with the purpose of creating an idea catalog that could be used in a potential future project on the restoration of the Inner Limfjord. The participants produced 9 topics for the idea catalog on improving the Inner Limfjord:

- Mussels as an additional method to reach the goals for the EU Water Framework Directive
- How to reduce nitrogen discharge in the fjord
- Thyborøn canal development
- Re-establishment of the seabed- No scraping, fewer nets
- Limfjord Council's (Limfjordsrådet) further narrative
- Restoration of the fjord's natural state – crab removal
- Retrieval of eelgrass from the beach for building materials
- Reduce nutrient loading from livestock farming
- Preserve coastal stone reefs by halting dredging from shipping lanes

During the workshop, we also opened up the possibility of continuing these dialogue-based workshops, and many participants expressed their interest in doing so.

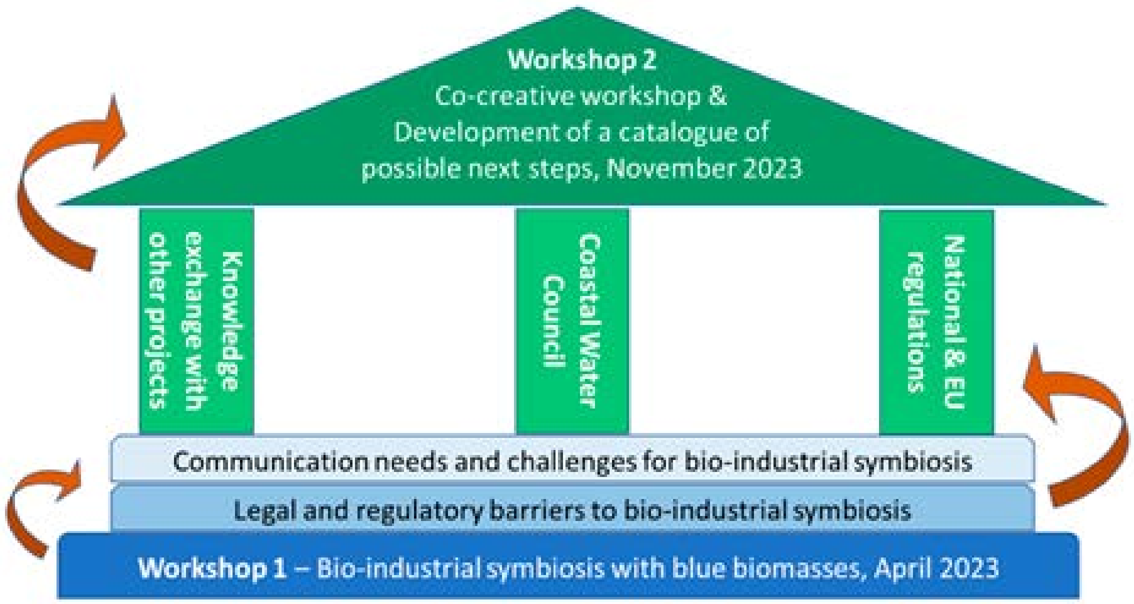

Figure 2. Activities in Denmark and discussed in this brief

Challenges and opportunities

The diagram in Figure 2. shows the activities of the Climate Foundation Skive and Skive Municipality prior to the co-creative workshop held on November 2023. Blue Green Bio Lab workshops in Sweden, Denmark and Latvia in spring 2023, the partners focused on the themes of communication and legal barriers to work with further.

Legal barriers - National and EU regulations

In Denmark the production of mussels and biorefining of mussel extracts for high-value products are subject to regulations from various areas of legislation primarily related to aquaculture, environmental protection, and water management. Below is a short summation of these regulations.

- Fisheries and marine environment legislation falls under the Danish Environmental Protection Agency, which regulates the protection of the Danish marine environment regarding permits for mussel farms, fishing methods, water quality and environmental protection.
    - The Danish Environmental Protection Agency also prepares the Water Area Plans in accordance with the EU Water Framework Directive, while municipalities have a role in ensuring that the goals and measures of the water area plans are incorporated into local administration.
- Food safety regulations fall under the auspices of the Danish Veterinary and Food Administration, which regulates safety, quality and hygiene with regard to mussels and high-value products derived from mussels.
- Cosmetics and pharmaceutical legislation: If mussel lactate is to be used in cosmetic products or pharmaceutical production, then the following EU legislation applies Novel Food Regulation, EU Regulations on Animal By-products, EU's Cosmetic Products Regulations, REACH requirements (chemical regulations), EU's Active Pharmaceutical Ingredients and Good Manufacturing Practice.

Mussel Committee

Skive Municipality represents several municipalities on the Mussel Committee, an advisory group to the Danish Fisheries Agency. The permitting process for new mussel farming has been on hold since July 2021, due to delays with the development of a new Danish Maritime Spatial Plan and uncertainties regarding how the plan will impact permitting for mussel farming. Over the years there has also been rising opposition to mussel farming, particularly regarding Smart Farms. During a meeting in September 2023 Skive Municipality discussed the permitting process with Mussel Committee members, specifically about improving transparency in the permitting process. Skive Municipality shared experiences with the Committee from

Figure 3. Example of a SmartFarm, photograph by Lars Skytt Nielsen

the Blue Green Bio Lab workshop held in April 2023. A key learning from this workshop was the need for greater communication between stakeholders and a better understanding about the mussel farming industry, how it operates and the positive environmental effects from mussel farming for water quality. Skive Municipality is continuing this dialogue with the Danish Fisheries Agency, which is preparing a new permitting process, after the adoption of a new Danish Martime Spatial Plan, possibly in the fall of 2024.

Communiation and engagement in various fora

The Danish partners have been deeply involved in Coastal Water Council's discussions at a local level, but have also reached out to projects with a similar focus to gain a better understanding of how to support improved communication.

Coastal Waters Council (Kystvandråd):

In spring 2023 a local Coastal Water Council was established with financing from the Danish Ministry of Environment. The Coastal Water Council brings together researchers, agricultural interests, mussel farmers, politicians, NGOs and representatives from 3 municipalities with catchment areas to the inner part of the Limfjord. The Coastal Water Council discusses ways to improve water quality to fulfill the EU Water Framework Directive, while considering the array of stakeholders in the area.

The Climate Foundation Skive and Skive Municipality are both involved in the work of the Coastal Water Council and are supportive of the idea of new regulatory options for mussel farming including the possibility for 'mitigation mussels', whose primary function is to provide positive ecosystem services through filtering and removing nutrients that cause eutrophication. This type of mussel farming is currently not permitted in Denmark. Mitigation mussels are unlikely to be of high enough quality for human consumption, but have potential uses in new value chains. It should be noted however, that mussel farming cannot alone solve eutrophication challenges in the Inner Limfjord.

The concluding technical report from the Coastal Waters Council will be presented in early 2024 with recommendations from the Council to the Ministry of Environment. The Climate Foundation and Skive Municipality are continuing this dialogue with the policy level locally and nationally.

Knowledge exchange with other projects:

In the fall 2023 the Danish partners reached out to several organizations and projects to better understand communication issues and approaches about bio-industrial symbiosis.

- Submariner Network – Skive Municipality's met with SUBMARINER to gather best practices for communicating about blue economy development, which made clear the importance of mutual knowledge sharing with local society, particularly around mussel farming.
- Danish Bio-economy Conference – At this yearly conference the partners met with:

- TETRAS project- Discussions about the project's involvement of local students in the development of a demonstration facility for recirculatory aquaculture systems (RAS).
- Baltic Muppets project – Discussions about the project's testing of how to sink Smart-Farms fully underwater, which could improve public acceptance of increased mussel farming by reducing the impact of mussel farming in the seascape.
- Kalundborg Symbiosis – Discussions about network's structure for ensuring communication between symbiosis partners at strategic and practice levels.

- Blue Mission BANOS 1st Mission Arena- Workshops and discussions at the Ocean Arena gave the partners further insights into the basis for public views toward mussel farming and suggestions on addressing these sentiments through authentic stakeholder involvement, knowledge sharing (regulations and science) and developing trust.

Next steps

The partners anticipate the following next steps:

- Following up with participants to the workshop held on November 2023
- Working with the results from the Coastal Water Commission
- Continuing dialogue about a new mussel farm permitting system
- Continuing dialogue with companies interested in working with blue biomasses
- Securing funding to keep the dialogue going with a point of departure in our idea catalogue

Reflections and learning

After the first workshop in Skive focusing on bio-industrial symbiosis of blue biomasses, the partners took a step back and really looked at what the stakeholders wanted – more options for dialogue. We therefore put their needs and interests at the center of 2nd workshop. The result was constructive conversations between participants that before the workshop likely saw themselves as opponents. Some of these participants remained after the workshop or walked out together to keep the conversation going. Furthermore, the mixing of various entrepreneurs and business development people stimulated interesting discussions about innovation, which we are in acute need of to reach climate, environmental and business goals.

Using the Open Space Technology approach is not a typical way of doing things for the municipality, but trusting the participants created meaningful results that the partners can work with in the future, knowing that there is already support for these ideas.

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Project facts

The Blue-Green Biolab project is co-financed by Interreg Baltic Sea Region.

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Project period: October 2022- March 2024.

Homepage: https://interreg-baltic.eu/project/blue-green-bio-lab/

Lead partner: Energibyen Skive, Skive Municipality.
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Blue Green Bio Lab Associated Partners:

Spurring blue bio-industrial symbiosis on land in Lysekil, Sweden

This brief is a part of the Blue-Green Bio Lab Tool Kit, that represents the findings in the Blue Green Bio Lab project. The project targets the urgent challenges of reducing nutrients to waters of the Baltic Sea Region, limiting greenhouse gas emissions, and enhancing European self-supply with food, feed, and energy. Together, aquaculture, agriculture and industry can provide solutions to these challenges through industrial symbiosis based on the sustainable exploitation of local blue and green biomasses initially grown and/or harvested with the objective to produce positive ecosystem services. The Blue-Green Bio Lab project is co-financed by Inter-Reg Baltic Sea Region with partners in Denmark, Latvia, and Sweden.

Anne Gunnäs, Maritime business developer, Lysekil Municipality

This brief focusses on developing conducive policy environments and policy practices to spur bio-industrial symbioses in the area around Lysekil, Sweden. The activities discussed in the brief build upon challenges and opportunities for bio-industrial symbiosis identified earlier in the Blue Green Bio Lab project via workshops and discussions with local stakeholders.

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- **Resumé**
- **Co-creative meetings**
- **Challenges and opportunities**
- **Next steps**
- **Reflections and learning**

Resumé

Lysekil is as many places around the world facing major challenges in terms of energy and food supply as well as the impact of climate change on people and society. Based on local conditions the municipality aims to increase access to locally produced food, electricity and energy – while at the same time acting climate-smart. Thus, the municipality, LEVA in Lysekil and the PREEM refinery are working jointly on a feasibility study: developing an area near Brofjorden into a climate-positive and circular industrial park for companies with high sustainability ambitions.

The planned circular industrial park has via Preem unlimited access to residual heat and is located about 1000 meters from the seaside with the possibility to have salty water on land. In the feasibility study we are trying to do the utmost with the uniqueness of the site. The chosen biomasses to work with in the project are therefore all tropical marine species, the red algae Aperagopsis, giant shrimp Vannamei and Kingfish/ catfish.

Co-creative meetings

In Lysekil two co-creative meetings in the format of roundtable discussions were conducted. The first one was on October 6, 2023, and the second on November 22, 2023. The first meeting focused on societal engagement and how to communicate with different stakeholders in transforming society. The planning of the workshop was in cooperation with Linköpings University, focusing on Preem in Lysekil Municipality, LKAB a mining company in Luleå Municipality and Cementa a cement company in Slite Municipality in the transformation to sustainable societies. These companies are the top 3 emitters of carbon dioxide in Sweden. The main topic discussed by participants, echoed the challenge identified earlier in the Blue Green Bio Lab project related to communication and trust.

Figure 1 Happy participants at workshop in October 2023

Twelve participants represented a broad range of stakeholders. Fossil Free Sweden (a governmental initiative), Swedish Climate Policy Council, LO- Swedish Trade Union Confederation, Tenant Alliance for Fair Climate Change, Stockholm University, Linköping University, the 3 municipalities in transition as well as the study organization (see Figure 1). Worth mentioning is also that the municipal representatives came from very different development sectors: Lysekil – business, Slite – cultural and Lule – social. Before the event all the participants received a brief and the below 3 themes/questions to reflect upon. At the meeting the 3 questions were presented, one at a time, to the municipalities who shared reflections. After each question all participants were invited to comment, followed by a joint discussion.

1. Does climate change need to be fair and if so, what does that mean from your perspective?
2. How do we make a fair transition in practice? What is required for a policy of rapid and extensive emission reduction (and societal change) to be anchored in a wider population?
3. What future society do you hope for? What needs to be changed to get there?

Figure 2. Main points from discussions, October. 6, 2023.

The second roundtable discussion had a more "hands-on" approach to the environmental policy topic – how do we create a land-based aquaculture system in harmony with environmental regulations? Besides Lysekils municipality, LEVA in Lysekil (municipal electricity and wastewater company), Smögenlax (aquaculture company), Rena Hav (wastewater and biogas plant) and IVL (Swedish environmental institute) participated. LEVA and Lysekils municipality planned the meeting together. Smögenlax and Rena Hav participated at the previous Blue Green Bio Lab workshop, and this meeting was a continuation of the workshop held in spring. The meeting had the following agenda:

- Conceptual design circular industry park (LEVA)
- Learnings in Sotenäs – Smögenlax & Rena Hav (Rena Hav)
- Environmental status in Brofjorden water body (IVL)
- Possibilities and challenges (All)
- Summary and next steps (Lysekil municipality)

Challenges and opportunities

Communication with society and among businesses
The challenges addressed in October were mainly about how to achieve a societal understanding and acceptance to the rather new set up of a circular bio-industrial symbiosis industry. From Lysekil's perspective – a tool for achieving a fair societal transformation to a sustainable future. The need for change is urgent, and we must be able to focus on the right questions. But, as many people are reluctant to change, we have at the same time a need to spend time to inform and act transparently in order to build trust.

As we learned from the report How can municipalities support the development of industrial symbiosis (Baltic Industrial Symbiosis) one of the key findings for seeding, developing and expanding industrial symbiosis is the importance of creating an entrepreneurial and collaborative culture of trust and innovation.

Not only is there a need for trust and acceptance in the society towards a symbiosis industry park. Even more important is the need for trust and understanding between the companies involved in the symbiosis setting. If the foundation is not solid and transparent and the businesses do not or will not rely on each other, there is simply no possibility to create a symbiotic relationship or enhance business opportunities in this way.

Furthermore, developing acceptance for producing different species (mainly discussed in the November meeting) highlights the need for transparency. The breeding and farming will take place in fully controlled processes in a RAS setting (recirculating aquaculture systems). Nevertheless, as there will be access to tropical conditions the species farmed will likely be non-native and if not communicated in a planned and transparent way – there might be a communication failure – giving room for rumors that could delay and in worst cases stop this development, for example with misunderstandings ending in thoughts like 'They are going to farm invasive species that will ruin the whole ecosystem!'

National regulations perceived as barriers for circular bio-industrial symbiosis
In the November meeting LEVAS concept work around wastewater was in focus (Figure 3). The main question addressed was designing a land-based circular aquaculture industrial park to meet the requirements in national environmental regulations.

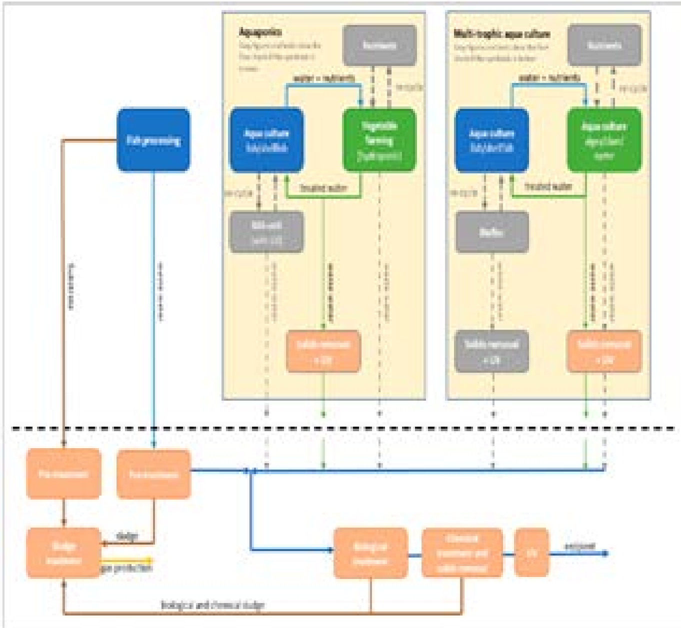

Figure 3. Levas concept design

National environmental water regulations in short- In Sweden, the EU Water Framework Directive is largely implemented in the Environmental Code, the Water Management Ordinance, and the county administrative boards' instructions. Five water authorities are responsible for water management in their respective districts. The Swedish Agency for Marine and Water Management supports the water authorities through guidance and issues binding rules, regulations, for how work is to be carried out.

The environmental quality standards are a legal instrument for authorities and municipalities when applying laws and regulations in the environmental area and the norms also govern the physical planning in the municipalities. Water organizations, such as water councils, are important in their role as associations of stakeholders with regional or local support.

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WISS (Water Information System Sweden) is a database developed by the Swedish Water Districts, the County Administrative Boards and the Swedish Agency for Marine and Water Management. All lakes, rivers, groundwater, and coastal waters are classified and given an ecological, quantitative and chemical status. The data fed into WISS is used to report the Swedish work within the EU Water Framework Directive.
In WISS, the waterbodies are fairly small compared to other countries. For example, are there two just outside the refinery and one on the inside (Figure 4). The ecological status for all three waterbodies are "moderate" and the chemical status are "poor". When designing the bio- industrial park's wastewater system and locating a possible emission point at sea, the carrying capacity of the waterbody is crucial and directly affects the permit process. This could in turn directly affect the type of biomasses/businesses valid for the circular bio-industrial park and how the symbiosis should be planned.

Figure 4. Waterbodies around the refinery from WISS

Next steps

Closing the roundtable conversation some activities were planned to continue these discussions:

- As there is still much to learn from Rena Hav, a follow up meeting will take place between Lysekil Municpality, Leva and Rena Hav
- A critical question found during the discussions was about energy and electricity supply. Some years ago, energy and electricity were nearly an unlimited source in Sweden and available at relatively unexpensive rates. This situation has changed, and as energy and electricity supply is central in the circular setup, we aim to further address the question.
- The environmental quality standards in the waterbodies outside the refinery will also be further examined to determine a feasible emission point fulfilling the EU Water Framework Directive.
- The communication aspects will be further investigated and addressed in 2024 as there is much more to do here. One of the most critical aspects of the continuing work is developing commitment and acceptance to the needed sustainability transition.

Reflections and learning

The outcomes of both meetings were very positive, but in different ways. The best thing about the first meeting was without question the broad representation of stakeholders. Starting the meeting we did not really know what to expect and what value it would give. The take-home message is don't be afraid to mix perspectives! It added so much dynamism to the conversation and is an approach worth doing again.

The second meeting had in a way the same setup for the conversation, but with a much more practical approach in trying to solve a problem. The conversations added much value to the wastewater treatment concept development and was perhaps also a starting point for a much closer collaboration between the businesses.

Project facts

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Lead partner: Energibyen Skive, Skive Municipality.
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Blue Green Bio Lab Associated Partners:

Spurring green bio-industrial symbiosis in Zemgale Planning Region, Latvia

This brief is a part of the Blue-Green Bio Lab Tool Kit, that represents the findings in the Blue Green Bio Lab project. The project targets the urgent challenges of reducing nutrients to waters of the Baltic Sea Region, limiting greenhouse gas emissions, and enhancing European self-supply with food, feed, and energy. Together, aquaculture, agriculture and industry can provide solutions to these challenges through industrial symbiosis based on the sustainable exploitation of local blue and green biomasses initially grown and/or harvested with the objective to produce positive ecosystem services. The Blue-Green Bio Lab project is co-financed by Inter-Reg Baltic Sea Region with partners in Denmark, Latvia, and Sweden.

Evija Ērkšķe, Project Manager, Zemgale Planning Region

This brief focuses on developing conducive policy environments and policy practices to spur bio-industrial symbioses in the Zemgale Planning Region of Latvia. The activities discussed in the brief build upon challenges and opportunities for bio-industrial symbiosis identified earlier in the Blue Green Bio Lab project via workshops and discussions with local stakeholders.

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- **Choice of Biomass**
- **Co-creative workshop**
- **Challenges and opportunities**
- **Next Steps**

Choice of biomass

Zemgale region is the central agricultural production area in Latvia. Due to intensive land use and fertilization the impact of nutrient loads on water bodies of Zemgale is considerable. About 20 % of water bodies in Lielupe River basin have unfavorable or bad ecological status, mostly due to eutrophication. Therefore, the region is searching ways to improve the quality of the marine environment and develop business approaches through green solutions. Increasing the share of grassland in the total pool of agricultural land could be one approach. Bio-industrial symbiosis requires selecting a biomass, and in a scoping meeting for symbiosis the grass was chosen as a potential biomass for Zemgale. The initial idea was to use grass mostly as a resource for biogas production.

Co-creative workshop

A co-creative online meeting was held on November 24th, 2023, via ZOOM (see Figure 1). The meeting was attended by 21 participants and organized as part of the Zemgale regional climate, energy and environment issues coordination working group meeting. The attendees represented the Ministry of Climate and Energy, local municipalities (environmental and energy specialists), energy producers and respective professional associations. The participants were chosen based on an assessment of stakeholders that might have key importance for the development of bio-industrial symbioses in Zemgale region.

At the beginning of the meeting, the participants were introduced to the project and the concept of bio-industrial symbiosis. The country's climate and energy goals and progress towards them were then presented. These presentations were followed by a summary of status of European Union industrial symbiosis policies (see Figure 2) and a discussion on national regulations for green biomasses and bio-industrial symbiosis and their development possibilities in Latvia, moderated by the Latvian Institute of Aquatic Ecology, a Blue Green Bio Lab project partner.

The Ministry of Climate and Energy is the leading institution in the management of climate and energy policy areas and the director of the department was an active participant in the Zemgale meeting. The director discussed with participants that Latvia, like all member states, needs to fulfill the European Union goals for climate policy. In the discussion with participants, the director Indicated that he believes the goals for climate policy can be fulfilled by all member states and there should be no concerns on the part of Latvia.

During the discussion opinions differed on topic of energy and climate. State representatives emphasized the importance of current laws and common European conditions. In general, legally following EU conditions does not limit practical actions in Latvia, because people and society in general want to live more in harmony with nature.
Local government specialists asked the Ministry of Climate and Energy about the renewable electricity produced in the country that is not fully utilized and

Figure 1. Screenshot of online meeting in November 2023

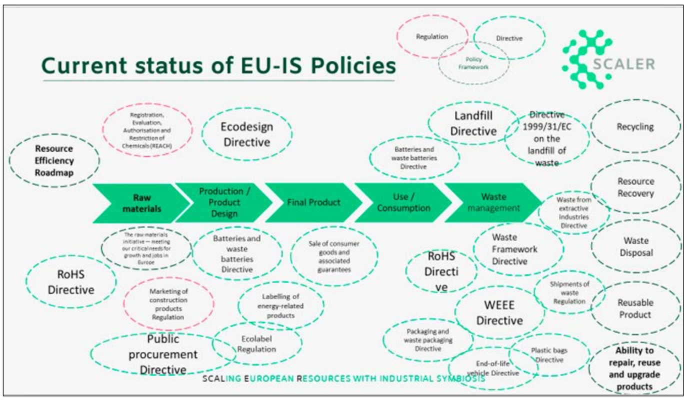

Figure 2. Diagram used to explain EU industrial symbiosis policies

why we should continue to use Nord Pool AS, a European scale electricity stock exchange. Energy prices are a big concern in Latvia, and it is difficult to say whether this market works for consumers and businesses or more for electricity producers, who want to sell electricity as expensively as possible. The ministry explained that renewable electricity production (from hydro, solar and wind) in Latvia is not stable enough year-round and that as we still lack solutions for advanced electricity storage, there is a need to continue using Nord Pool.

On the topic of the use of green biomasses for some form of energy the representatives of the local municipalities maintained a skeptical and pragmatic point of view- until there are working plants for processing green biomass, even if they are small by Latvian or European standards, our hay, bushes, reeds will not be used cost-effectively and energy-efficiently.

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Challenges and opportunities

Legal barriers at the national level

National regulations do not specifically target bio-industrial symbiosis although achievement of climate goals together with economic development in environmentally friendly way are acknowledged in policy documents and Cabinet of Ministers decrees. Particular attention is devoted to industrial symbiosis as a part of waste management policy when framing the circular economy. Biomass is treated as biowaste and for municipalities composting is the dominant way of handling it.

Climate policy has been recently developed in Latvia and the ultimate goal is reduce greenhouse gas emissions. Two new climate acts are now in the process of adoption in Latvia with the expectation to achieve the European climate objective of zero emissions in 2050. However, the sectoral responsibility in Latvia is a barrier to the necessary holistic approach needed to implement circular policies.

Environment protection regulations could also be the challenge if wildly growing biomass is used for symbiosis. Certain types of vegetation (like common reed) are regarded as habitat forming species and not allowed for harvest. Danish Fisheries Agency, which is preparing a new permitting process, after the adoption of a new Danish Martime Spatial Plan, possibly in the fall of 2024.

Communication and outreach

The need for communication about circular bio-industrial symbiosis ideas and potentials is without a doubt important. Outreach to specialists in local municipalities with information and knowledge about bio-industrial symbiosis can play an important role in the future development of the circular economy strategy of the local areas. The proven best practices of other regions make clear the possible ways of collaboration among various stakeholders and the products that might be developed during the bio-industrial symbiosis processes. Currently Latvia is in the very early stage of green biomass usage in bio-industrial symbiosis. Furthermore, at the moment some biomasses cultivated for energy production are not in harmony with sustainability goals.

Next steps

The Zemgale Planning Region sees a need for additional education and training on concepts about bio-industrial symbiosis for stakeholders. The concept still is new in Latvia, and it requires a longer process than the Blue Green Bio Lab project to begin using biomass differently than traditional uses, moving beyond that grass only as a hay for cattle.

Reflections and learning

The online meeting was well attended, and participants were genuinely interested in the topic. However, the knowledge and options for using green biomass in bio-industrial symbiosis is currently limited. Thus, more communication is needed with relevant parties with various knowledge and perspectives on for example: the availability of green biomasses, new value chain actors, logistics, innovation around final products and sustainability issues.

Policy Environment and Practice

Policy Brief

Project facts

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Blue Green Bio Lab Associated Partners:

Additional materials

Water and wastewater supply for a bio-industrial symbiosis park

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Summary

There is a joint declaration of intent between Lysekil municipality, LEVA and Preem to investigate the possibility of developing an area near Brofjorden into a climate-positive and circular industrial park for companies with high sustainability ambitions. The intent is that one person's waste can be another's raw material.

Such an industrial park needs to be provided with various types of infrastructure. This report focuses on the water services needed by the park. A pipe network with several separate pipes is needed to transport water of different quality to, from and possibly between different industries. Permits are required for the construction of pipelines, especially inlet and outlet pipelines in the sea, which requires a permit under Chapter 11 of the Environmental Code for water activities. Production industries need industrial wastewater treatment plants with associated environmental permits under the Environmental Code Chapter 9 Environmentally Hazardous Activities. According to initial soundings with the county administrative board, the prerequisite for obtaining a permit is realistic.

The purpose of an industrial symbiosis park is that the industries should be able to cooperate and offer each other different types of media where the residual product of one could become the raw material of the other. However, this is not something that has been investigated in connection with this report; it is left to future industries to plan. The outset in this project report has been that some sort of industrial wastewater treatment will be needed for the area.

LEVA has a municipal mission according to its owner's directive to be an enabler of development within the municipality of Lysekil. The company could be an active partner in this type of project. For more detailed project planning to begin, funding must be secured, and a clear plan of responsibilities must be developed.

Background

The growing challenges of climate change together with the increasingly urgent need in recent years to ensure national self-sufficiency in food, feed, biomaterials, and carbonaceous biofuels have pointed to the potential of circular bio-industrial symbiosis plants based on blue and green biomasses. Against this background, a transnational and interregional (Interegg) project has been launched in the Baltic Sea Region (BSR).

Lysekil municipality, in Västra Götaland County in Southwest Sweden facing the Skagerak Sea to the west and Gullmarsfjorden to the east aims to explore circular business park concepts in collaboration with other BSR-countries. Lysekil investigates a piece of land which has the potential to become a circular business park. Dialogues have been initiated with a couple of aquaculture businesses.

Objective

The purpose is to obtain positive ecosystem services by combining agriculture and aquaculture in land-based industrial parks. However, this type of bio-industrial symbiosis park requires environmental permits with associated wastewater treatment plants to comply with the permits. The project aims to focus on closing nutrient cycles, reducing greenhouse gas emissions and improving soil quality and carbon sequestration.

Lysekil municipality together with LEVA which is the public water, wastewater, electricity, and district heating company, will draw the first outline for the infrastructure serving the park concerning both energy and water. This leads to subsequent identification of what type of wastewater plant would best serve the business park.

LEVA´s role in the project has been to investigate which type of wastewater treatment that would be suitable. LEVA has also investigated the conditions for how the technical supply can be managed to meet the needs and conditions for the construction of a bio-industrial symbiosis park.

Mission

LEVA's mission has been to investigate what type of treatment plant that could support a bio-industrial symbiosis park. In addition to providing infrastructure and services in energy and water, LEVA's mission according to the owner directive is to be active in the work of developing Lysekil municipality as a sustainable and attractive municipality in terms of housing, education, business, and quality of life.

LEVA is investigating the possibilities to:

Provide seawater and lake water and treat industrial wastewater in a way that enables resource reuse within and outside the area.

Provide renewable production and storage.

Provide district heating (develop the possibility of increased access to waste heat).

Creating conditions for sustainable transport.

Creating conditions for sustainable energy solutions.

This report focuses on water management and supply.

Water management

An area with many actors where space must be provided for the expansion of existing activities at the same time as more space must be created for new activities poses major challenges for the infrastructural facilities. One example of this is Rena Hav AB in the neighbour municipality Sotenäs, which currently has problems expanding its operations because the water recipient is already heavily loaded, which means difficulties in obtaining environmental permits.

The challenge is thus to create an infrastructure with flexibility to meet needs that change over time. Oversizing facilities is not only costly but also results in less efficient operation. While striving for flexibility in the infrastructure, assumptions must be made and a dimensioning factor for design must be set. In this study, assumptions will be made regarding to this reasoning.

Distribution system

Water of different qualities will need to be distributed via pipes to and from the area. Since reliable deliveries of different media are a prerequisite for industries to achieve efficient production in their operations, it is important to minimize the risk of supply failure. This can be done in different ways depending on the type of water distributed and a plan for operational reliability should be developed early in the process. Taking measures for the entire symbiosis park creates cost-effectiveness for the various stakeholders.

Since several industries are planning to use the various pipelines, it is of great importance that a structure is developed for operation and maintenance plans.

To further reduce the consequences of possible delivery failures, it is necessary that a contingency function is set up with the necessary resources in the form of both competence and materials, to be able to rectify faults quickly. An emergency response organization could also serve several actors in the industrial area which means lower costs.

Opportunities for coordination

Within the industrial area, it is possible to coordinate the laying of different types of pipelines and create an infrastructure that facilitates access when necessary. It is equally important that facilities outside the industrial area are constructed in a way that facilitates access and that the necessary permits for construction and maintenance are obtained to ensure availability.

In simple terms, the distribution system can be constructed in three different ways: conventional shafts, above-ground piping or in so-called infra-culverts. Depending on the media to be transported, different methods may be more or less advantageous. Equipment subject to inspection is often laid above ground to allow for supervision. Co-location of many pipelines requires large areas to enable access and for this reason other solutions may be advantageous, such as laying the pipelines in an underground culvert.

Figure 1. Infrastructure culvert

Figure 2 Underground pipelines

Figure 3. Above-ground pipe installation

Seawater collection facility

At present, there is no infrastructure for bringing seawater to the planned area. To meet the need, a new facility needs to be built. The operational area is located at a level of approximately +30 m above sea level, which in addition to a pipeline from the sea also requires a booster station for the collection of seawater. In addition, a pipeline is needed to return saltwater effluent back to the sea.

A general study shows that a suitable route for new seawater pipelines follows the valley that extends from the area in a westerly direction towards the bay at Fiskebäcksvik. The route broadly follows the gully that runs in the same direction. There is also a public road parallel to the stream. This leads to the beach and the pilot station located in the bay. The proposed pipeline route and location of the booster station are shown below in Figure 4.

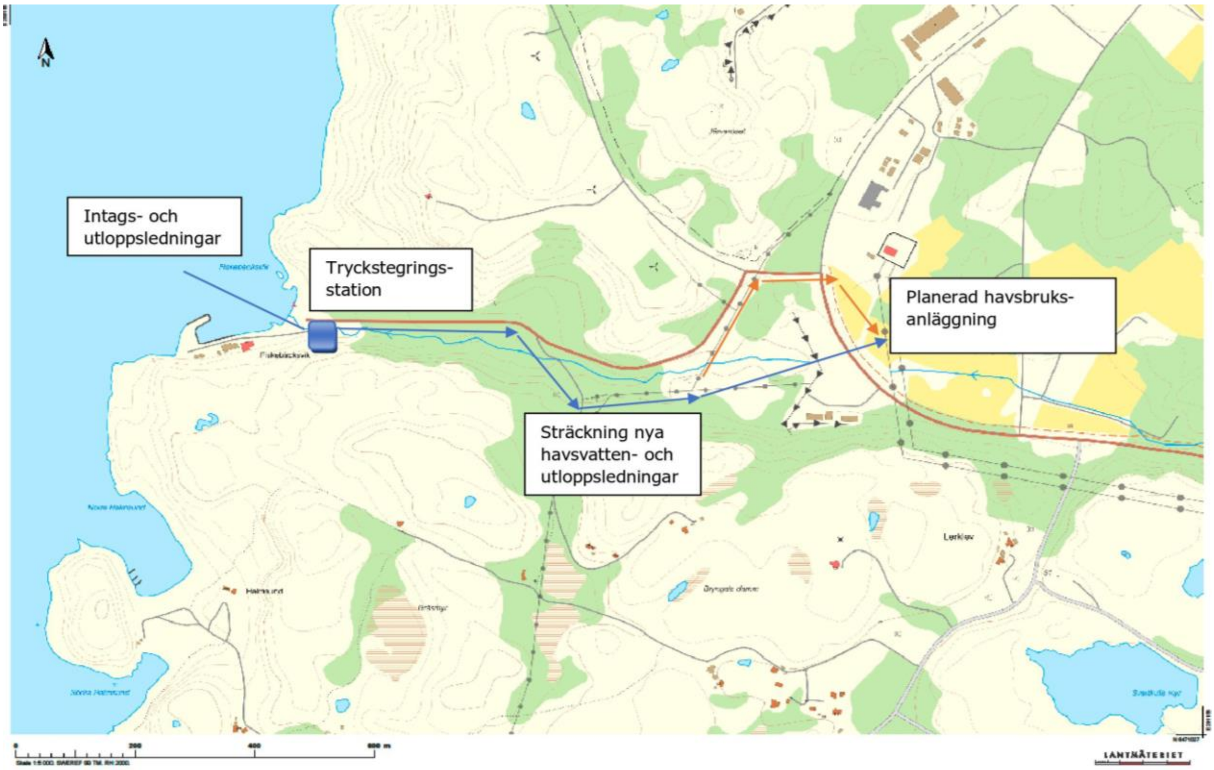

Figure 4. Overview of the proposed pipeline route for the inlet and outlet pipes to the industrial park.

Technical design

In the absence of more detailed information on the required capacity, this has instead been assessed based on similar facilities that are being planned. However, the need for seawater is largely dependent on both the choice of focus and size of the aquaculture facility and the extent of water recirculation.

The "Smögen salmon" facility planned in Sotenäs municipality states that the need for seawater can amount to a maximum of about 5 000 m^3/day (about 58 l/s based on 24 hours of operation). However, as there is considerable uncertainty about the required capacity, two alternative capacities have been used in the following. In alternative a) the capacity is set at 58 l/s and in alternative b) at 20 l/s.

Dimensioning of pipelines

As previously mentioned, double onshore pipelines are required on the current route between the site and Fiskebäck bay. The pipeline length is estimated to be approximately 1 100 m.

Two sea-based pipelines are needed from the shore to a location in the sea suitable for seawater intake and discharge. In this study, a suitable sea depth for this has been estimated to be about 20 m. The length of the offshore pipelines would then be about 200 m each.

With the intention of reducing the hydraulic losses, preferably on the seawater intake and discharge pipelines, the pipeline dimensions are chosen so that the total pressure losses are less than 5 m water column from the sea to the new area.

This means that for option a (58 l/s) the seawater conveyance pipe dimension is PE (polyethylene) 315x18.7 mm, while for option b (20 l/s) the dimension is chosen to be PE 200x11.9 mm. The pipe dimension for seawater drainage from the area to the sea is chosen in both cases as PP (polypropylene) 200 mm.

The seawater pipelines are selected in the same material and dimension as the land-based pipelines.

Pressure boosting unit

The booster station should be located close to the shore so that seawater can be obtained by gravity in the intake pipe from the sea. The station should be constructed with an underground intake chamber. The seawater intake pipe is connected to this. The technical design of the station should be carefully investigated since seawater with a high chloride content is to be handled. The conditions for the installation of submerged pumps for the collection of seawater should be studied, as submerged pumps are operationally preferable. Above the intake chamber, a superstructure is constructed to house electrical and control functions.

The station should be equipped with two separate pumps where each pump has the capacity to deliver the amount of water required by the operation (options a and b respectively).

The power requirement of the pumps for option a (58 l/s) is about 30 kW/each and for option b (20 l/s) about 22 kW/each. With a capacity corresponding to option a, the energy consumption is estimated to be about 75 000 kWh/year and for option a about 25 000 kWh/year.

Permit management

The planned facility for feeding seawater affects both private and public interests. Below is an assessment of what these interests are and what permits may be required.

Ground facilities

The proposed pipeline route extends over private and public land. Affected landowners are mainly PREEM and Lysekil municipality. Depending on how the pipeline route is chosen in detail, an environmental permit may be required for construction in the stream ravine down towards Fiskebäcksvik, in addition to utility assessment. The pipeline route probably requires passage of PREEM's pipeline route at Aspedalen.

Submerged pipelines

The cables closest to the shore extend over sea areas belonging to the Swedish Maritime Administration. A hearing in the Environmental Court may be required before permission for construction is obtained.

Pressure boosting unit

The booster station will be located on land belonging to Lysekil municipality. The construction of this requires not only a building permit but also that the issue of shoreline protection is handled.

Time frame

The time required to set up a facility as described above is based on the following estimates of licensing processes and utility assessment:

Preliminary design:	1 year
Permit management:	2 years
Project design	1 year
Procurement and construction	2 years

Preliminary budget
Below are the estimated costs (in SEK) for the construction of underground and undersea pipelines and the booster station. The costs are highly preliminary and should only be seen as an indication of the level of investment in the cost situation in 2023.

Facility	***Extent***	***Cost alt. A***	***Cost alt. B***
Underground pipelines	ca 1100m		
Alternative A, PE315 + PP200		10Mkr	7 Mkr
Alternative B, PE200 + PP 200			
Submerged pipelines	ca 200m		
Alternative A, PE315 + PP200		4mkr	3 Mkr
Alternative B, PE200 + PP 200			
Pressure boosting unit			
Alternative A, Qdim 58 l/s		8Mkr	7 Mkr
Alternative B 20 l/s			
Total		**22Mkr SEK**	**17Mkr SEK**

Water supply

Raw water from Kärnsjön

Raw water is available from Kärnsjön, a lake located in Munkedal municipality. The character of the water is typical of lake water, it is of relatively high color and some organic material but not in any way poor in quality. The availability of water from the lake is good according to current abstraction rights and water judgments, but the pipeline capacity to transport the water to Lysekil is limited. This means that an agreement will need to regulate withdrawals and any buffering within the park may be needed depending on water withdrawals. Since the water demand is not known at this stage, assumptions need to be made to propose measures that need to be arranged to ensure access to lake water.

Raw water – sea water

The supply of seawater is infinite. The limiting factors are pipelines and the dimensioning of water treatment facilities. As pipelines are costly to construct, assumptions need to be made about demand.

Potable water

The availability of drinking water is good and infrastructure is already in place to supply the area with drinking water. Since the water is of high quality and has been treated to the point of being an approved drinking water, it is environmentally correct to work to minimize the consumption of drinking water for the symbiosis park. The ambition should be to try to use other water sources and possibly treat them for this purpose.

Process water

Stormwater can be reused for many purposes, such as irrigation during dry periods. It can also be used to mix with seawater before desalination to be used as a non-salinated process water to reduce salinity and thus reduce energy requirements.

Desalination of seawater provides a concentrated residual product with a higher salinity that can be used, for example, for the cultivation of fish or algae that require different salinities than those from Skagerrak and Kattegat. There will probably be an industrial need for highly concentrated saltwater, but energy consumption increases exponentially when the salinity is concentrated.

Potential circular flows and wastewater treatment

The overall concept of a bio-industrial symbiosis park is based on circularity. The design philosophy is to recycle as many residual flows as possible. If possible - one industry's waste is another's raw material.

If the industrial wastewater from the different industries is similar, it opens the door for several actors to collaborate on wastewater treatment. This is the case for Rena Hav's concept in Sotenäs. In this project, it has been acknowledged that actors probably have different types of wastewaters. This means that different technical treatment solutions may be needed. It is not obvious that it is possible to cooperate on all the actual treatment steps, but there may still be coordination benefits if treatment plants are owned and operated by the one operator.

Stormwater

It is important to bear in mind that developing industrial land changes the permeability of large areas that lead to increased stormwater runoff, resulting in significantly higher flows. A plan for how water will be retained and how runoff will be discharged to the recipient is developed early in the physical planning process. Any retention of stormwater could provide opportunities to also use stormwater for the various industries.

Smart designing of stormwater facilities enables that the water can be used as a resource. The construction of stormwater ponds and greenways in the area can promote biodiversity while slowing down and purifying stormwater before it reaches the recipient.

Separating black and grey water and collecting stormwater facilitates the reuse of fresh water. For example, recycled grey and storm water can be used for irrigation, flushing toilets, or as technical water.

Wastewater treatment

It is much more efficient to build a treatment plant for the whole park than a smaller plant for each industry.

There is an industrial wastewater treatment plant at Preem, which handles wastewater from their operations. In Lysekil there is a municipal wastewater treatment plant, which mainly handles municipal wastewater from the municipality's residents.

In some situations, it is possible to use municipal wastewater treatment plants for the treatment of industrial wastewater, but often there are both technical and legal limitations. In the case of the Långeviksverket in Lysekil, there is also no capacity to handle this type of industrial wastewater, even if such fractions could be handled.

A possible future connection of an industrial park would probably require extensive reconstruction and expansion of the Långevik plant, including the time and cost of a new permit application. Since significantly stricter limit values would also most likely be obtained in a new permit, the cost of the new plant would increase even more than the cost of today's reconstruction. Since there is no municipal need for an expanded facility, the entire cost (before connection is even possible) would fall to the industrial park. This is probably not a realistic solution for this type of industrial park in terms of both time and cost.

There are different ways of designing a treatment process, mainly depending on the type of parameters to be handled. Often some form of pre-treatment is needed. For example, it can be a mechanical treatment in the form of a sedimentation process to handle a larger number of solid particles. The mechanical treatment can also be supplemented by chemical precipitation to achieve a higher degree of separation. Organic material is often best handled in a biological treatment where microorganisms decompose the pollutants.

The risk of any presence of non-native species that can be released to the sea, such as non-indigenous ones, may require disinfection steps such as UV light. There is always the possibility of using membrane technology to achieve a high level of treatment. However, this is often associated with high costs. In this case, the volumes involved would be relatively small, making it a realistic solution.

Below is a brief description of the type of treatment that different types of industrial wastewater are likely to require. The final need for treatment is determined in a permit process; the reasoning is based only on assumptions based on input data for the industrial park.

The following section distinguishes between two main types of wastewaters: wastewater from aquaculture, aquaponics and vegetable production and wastewater and substrates from fish processing. The different types of industries could potentially cooperate if their residual fractions match the need for raw materials for another industry. The input data to investigate the task presented in the report is based on fictitious industries, so the reasoning is only theoretical. The need for treatment that could be relevant for each type of industry is described below. Any collaboration beyond this can be seen as a bonus. Ultimately, the need for treatment is decided in court through a permit application.

Wastewater from aqua culture, aquaponic culture and hydro culture

- Wastewater from the cultivation of algae, mussels or oysters would probably be allowed to be discharged to the receiving water without further treatment other than solids removal and UV treatment (if the species is non-native).
- Wastewater from aquaponics may possibly be allowed to be discharged to the receiving water without further treatment than solids removal and UV treatment if the wastewater is removed from the recycling process as wastewater from the hydroponic culture.
- Wastewater from multi-trophic aquaculture (fish/shellfish + algae/mussel/oyster) may be allowed to be discharged to the receiving water without further treatment than solids removal and UV treatment if the wastewater is removed from the recovery process as wastewater from the algae/mussel/oyster farm.
- Wastewater from bio-flock fish/shellfish farms may be allowed to be discharged to the receiving water without further treatment than solids removal and UV treatment.
- Wastewater from fish/shellfish farms may be allowed to be discharged to the receiving water without further treatment than RAS treatment (provided it includes UV treatment).
- Solids removal and UV treatment are necessary to ensure that non-native species are not released to the recipient.
- Further treatment (i.e. biological and chemical treatment) of the above wastewater will be required if the discharge after internal treatment is deemed to have a negative impact on the ability to achieve the environmental quality standards (EQS) of the receiving water.

Wastewater and substrate from fish processing

-Wastewater and substrates from fish processing have a significantly higher content of nutrients, organic matter, fat, and salt, which affects the need for treatment. This is primarily a matter of biological treatment, but it also places high demands on grease removal because grease can cause problems for other treatment processes. This type of wastewater can also cause odour problems, which can disturb the surroundings and be an influential factor in the possibility of obtaining a permit. High levels of salt can also interfere with other treatment processes. For these reasons, this type of wastewater is not easy to reconcile with other industrial wastewater.

Figure 5 shows a possible design of a treatment plant that can meet the requirements based on the assumptions that formed the input to the report and the concept for the industrial park. The figure should only be seen as a proposal and a detailed design needs to be made in connection with a possible

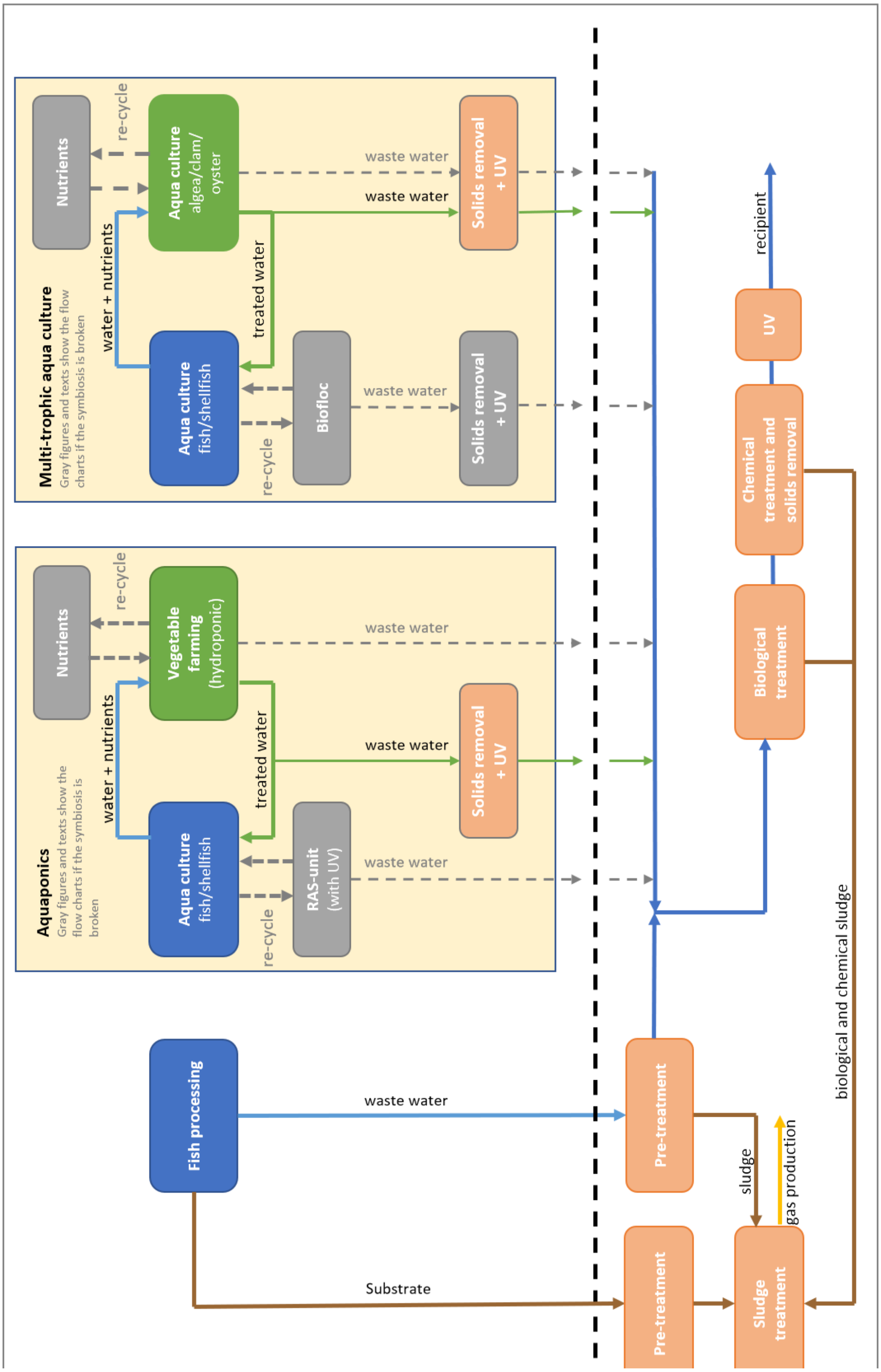

Figure 5. Example of design of a treatment plant

future permit process.

Permit management

There are several different types of permits that need to be managed. The largest and most important in Sweden are dealt with in the Environmental Code, Chapter 9 Environmental hazardous activities, and Chapter 11 Water activities. In addition, there is also a need for several other types of permits, such as utility assessment for pipeline laying and any shoreline protection permits and similar permits.

The Environmental Code, chapter 9 Environmental hazardous activities

It is not until work on the application for an environmental permit starts that the final design of a treatment plant can be determined. The application needs to describe the quality and quantity of input parameters. The application work can therefore not start until it has been decided which types of industry will be established in the industrial park. The application needs to contain information on process design that includes the necessary design parameters that need to be handled in the wastewater treatment plant along with hydraulic and nutrient loads. Technically and legally, the industries may change in the future, but the composition of the industrial wastewater must still fit within the scope of the application. The application must also demonstrate that the receiving water body will not be adversely affected.
From the day work on the application starts, it takes at least a few years until a treatment plant can be completed. The most critical step in obtaining an environmental permit for this type of treatment plant is not the design of the plant but the environmental quality standards for the water recipient.

The Environmental Code, chapter 11 Water activities

The construction of pipelines in water (both inlet and outlet pipelines) requires a permit under Chapter 11. This does not really concern the type of sewage discharged and how it affects the recipient, but rather the physical impact of the pipeline itself. The aim is to show that the measure can be implemented without damaging natural values in water. However, all other required permits must also be reported in the application.

Emissions from the Symbiosis Park to the sea

The closest recipient to which the wastewater can be discharged is Yttre Brofjorden, which has the following status classifications:

Ecological status: Good

Chemical status: Does not reach good

Occurrence: Natural.

Based on the recipient's documented conditions and consultation with the County Administrative Board, the assessment is made that permission can probably be given for a symbiosis park where assumptions have been made that future industries are of a medium-sized nature and its wastewater composition is consistent with other equivalent industries. However, account must be taken of the fact that Preem discharges its industrial wastewater to the same recipient. After a complete environmental application, the County Administrative Board estimates that the processing time is between two and three years. The conditions of the recipient can be decisive for whether an environmental permit can be obtained, and a more in-depth analysis of its conditions is recommended for further work. The conditions of the recipient may be decisive for the type of business that can be established.

LEVA:s role in a bio-industrial symbiosis park

LEVA, which is both VA principal and responsible for the electricity and district heating network in Lysekil municipality, works daily with similar infrastructure needed to serve an industrial symbiosis park. With respect to this background, LEVA is investigating how the company could assist with the creation of a symbiosis park and whether it would be of interest to be a participating party in the future. Within the framework of being an enabler for development within the municipality, the company has chosen to collaborate with the municipality of Lysekil and Preem on how an industrial park could be designed.

Challenges

Work with the environmental application and detailed process design is costly. Before that kind of work can begin, the financing of the project must be made clear. On the one hand, the activities regarding preliminary planning, permit management, etc. that LEVA would possibly run must be financed, on the other hand the connection model for the industrial park must be investigated, including which actors run the project and who takes the financial risks.

Opportunities

What speaks for LEVA's involvement is that the company is organized in a way that would make it relatively easy to solve the various tasks while also enabling LEVA to expand its operations. In the long term, the competence development that this entails could also bring back experience and knowledge that can be used for LEVA's regular tasks. Leva is investigating the possibility of producing drinking water for the municipality's residents from desalinated seawater, it could possibly be coordinated with various needs for technical water for the industrial park. LEVA already operates sewage treatment plants today, an industrial treatment plant could be operated in a similar way, which means coordination gains.

Conclusion

It is technically possible to build an industrial park in the intended area. After initial soundings with the county administrative board, it is also likely to be possible to obtain the required permits for water management. This refers to both the construction of intake and outlet pipes as well as an environmental permit for wastewater treatment. What needs to be investigated further is which actors are to be involved, conditions in outer Brofjorden which is the recipient and how the financing is to be handled.

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Additional report on biomass types

by Anda Ikauniece, Latvian Institute of Aquatic Ecology

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Introduction

During the mapping of information and knowledge of biomasses in the Blue Green Bio Lab project for the creation of biomass briefs (Step 1), the amount of collected knowledge extended the need for short and concise briefs. However, local experiences are highly relevant for development and growth of bio-industrial symbioses, as they contain detailed descriptions of local conditions and possibilities. Therefore, it was decided to create an additional report for the Toolkit containing more comprehensive information, knowledge and experiences.

The report is structured by 3 of the biomass types shortly described in the 'biomass briefs' from Step 1 in the toolkit: mussels, seaweed and grass. Here we have concentrated on several aspects of these biomass types – the related ecosystem services, cultivation techniques, current challenges and ways forward. We have included information on low-trophic marine aquaculture species like mussels and seaweed, and grass. These types of biomasses are also of the current major concern for the project partners and the Baltic Sea region countries in general.

1. Cultivation of mussels

1.1. General status

Mussels are organisms regarded as low-trophic aquaculture subject. Low-trophic aquaculture is defined as the cultivation of organisms that do not require feeding for most of their life cycle.

Large parts of the inland Danish waters are suitable for low-trophic aquaculture because they are nutrient-rich, due to the significant runoff of nutrients from the land. The runoff of nutrients from land not only represent a loss of valuable nutrients, but also causes environmental problems due to the high availability of nutrients in Danish waters. By cultivating seaweed and mussels, nutrients are bound in valuable biological material that can be use for example in high-value, healthy foods or as a source of valuable ingredients. The Danish coastal waters also have a remarkably high hygienic standard, making them ideal for low-trophic aquaculture.

The greatest potential currently lies in the inland waters, but with the technological development of cultivation techniques, increased demand for products, and, for example, fiscal incentive structures promoting low carbon footprint products, open waters could also be utilized. Thus, the possibilities of utilizing even very large marine areas for the production of blue biomass are increasing. In this context, co-location between offshore energy facilities and low-trophic aquaculture would be an obvious opportunity, which is currently neither profitable nor technologically fully developed.

Cultivation of blue mussels (*Mytilus edulis*) can take place at salinities greater than 10-12 PSU (Practical Salinity Units), with the highest efficiency observed at salinities 16-20 PSU. The majority of the coastal waters in Denmark are generally highly suitable for mussel cultivation, as they are not excessively exposed to waves and wind. The overall high nutrient levels in coastal waters provide favourable biological conditions for cultivation. Simultaneously, the hygienic standards of the coastal waters are very high due to advanced sewage systems and wastewater treatment. Thus, high-quality mussels can be cultivated quickly in the coastal waters of Denmark.

Mussel cultivation is a relatively new form of production in Danish waters, which truly began around 2002 with the establishment of the Danish Shellfish Center (DSC) in Nykøbing Mors and its associated series of development projects. In 2020, there were four major companies, but more are on the way. However, production has steadily increased, reaching approximately 8,800 tons per year in 2019.

In recent years, there has been diversification in the industry. While earlier practices exclusively used longlines and socks for production, more and more producers are choosing to expand with pipe+net cultivation or engage in combination cultivation. In the latter, cultivators either apply for culture banks or collaborate with fishermen, conducting cultivation where larval capture and initial growth occur in the water column (mainly on nets), and final growth takes place on the seabed.

1.2. Use and environmental impact of mussel cultivation

The mussels produced are primarily utilized for fresh consumption or as boiled organic mussel meat. The majority (>80%) of the production in Denmark is exported, but the domestic market for fresh mussels is growing. Danish mussel cultivation is generally a profitable business.

Mussel cultivation can also serve as a marine measure to achieve better environmental conditions in water areas under the Water Framework Directive. It has been assumed that, through production alone as a measure, production efficiency per standard facility (approximately 19 hectares) could reach up to a maximum of 1,500 tons for longline systems and approximately 2,500 tons for pipe+net systems when harvested in the most productive areas before Christmas of the same year the facilities are deployed. These values apply to production with the aim of nutrient removal. For production intended for human consumption, the production capacity would be considerably smaller. It has been previously estimated that the total production potential for blue mussels in inland Danish waters is 300,000 tons annually. By including areas in open waters, such as in offshore wind farms, production could be significantly increased, but it would require technological development to make offshore production economically viable. The extent to which the potential in inland waters can be realized will depend on several factors, including available area.

Another important factor is whether mussel cultivation will be used as a marine measure and, in that context, whether there is a model for payment for the ecosystem services that cultivation provides in terms of nutrient binding and removal. If mussel production is implemented as a marine measure to achieve 4.5% of the nitrogen reduction target, and 5% of areas designated for wind energy production in inland Danish waters are simultaneously designated for mussel production, the annual production potential could increase to 275,000 tons (Gylling et al., 2021). If the production is solely to be marketed on commercial terms, it is unlikely that the potential can be realized within the coming decade. Including combination forms and all forms of cultivation, mussel cultivation without payment models for ecosystem services could increase to 20-70,000 tons within a period of 4-7 years.

1.3. Utilization of cultivated mussels and barriers to mussel farming

The use of cultivated mussels for human consumption is known in the form of fresh or boiled mussel meat. The application of mussels cultivated as a marine measure will result in products for consumption on a smaller scale, around 10-30% – the rest will need to be used for e.g. feed ingredients. The optimal method for the production of mussel meal has not yet been developed and will depend on the intended use of the final product. For poultry feed, a higher degree of shell fractions can be tolerated in the final product, which is not the case for use in pig or fish feed. Methods for complete separation of shell and meat before drying exist, but currently, they are not competitive with other marine protein sources as feed ingredients, not even for organic animal feed. Methods are close to development, and there is industrial willingness to invest in processing facilities, as long as there can be a guarantee of a sufficient supply of mussels.

However, there are several barriers to mussel farming identified in Denmark:

- An increasing local resistance to aquaculture facilities, especially pipe+net systems, primarily because they are perceived as ugly and attract seagulls. However, local resistance can be mitigated through better communication and aesthetic design of the facilities. Public awareness campaigns highlighting the environmental benefits of mussel farming as a marine measure could also play a crucial role in overcoming resistance.
- The limited availability of suitable areas for mussel farming. Identifying and securing appropriate locations, especially in open waters or offshore areas, is a significant challenge. The coexistence of mussel cultivation with other marine activities, such as shipping lanes and fishing grounds, needs careful consideration to avoid conflicts.
- Environmental factors, including water quality, temperature, and potential disease outbreaks, can impact mussel farming. Monitoring and managing these factors are essential to ensure the health and quality of the cultivated mussels.
- The development of cost-effective and environmentally friendly harvesting methods is crucial. Efficient harvesting techniques are essential to maximize yields and minimize the environmental footprint of mussel farming operations.
- Market demand and consumer acceptance play a pivotal role in the success of mussel cultivation. Developing diverse and attractive mussel products for consumers, coupled with effective marketing strategies, can enhance market penetration and profitability.

While there are challenges and barriers to mussel farming, ongoing research, technological advancements, and strategic planning can contribute to the sustainable growth of the industry. Overcoming these obstacles will not only foster economic development but also promote the environmental benefits associated with mussel cultivation as a marine measure.

1.4. Cultivation of other mussel species in Danish waters

Among other mussel species, the cultivation of the European flat oyster (*Ostrea edulis*) has particularly advanced to a stage where practical production can be established, and there are active businesses engaged in this activity. The common cockle (*Cerastoderma edule*) has the potential for cultivation development. Cultivation of the Pacific oyster (*Crassostrea gigas*) is not addressed here because this species is invasive, and there are doubts about the possibility of establishing cultivation, even with triploid (expectedly sterile) versions, in Danish waters.

1.4.1. European oyster

There is one company in Denmark that primarily focuses on the cultivation of the European oyster (*Ostrea edulis*), and there are several smaller aquaculture companies looking to expand their operations by including oyster cultivation or have already initiated oyster farming.

To start the cultivation of oysters, attempts have been made to collect animals from spat-catching areas, like Limfjorden. However, as a business model, it has not proven to yield sufficient production material for profitable operations. Oyster production, therefore, relies on the supply of spat from a hatchery. Spat from hatcheries is delivered in various sizes, ranging from around 5 mm to 2-3 cm. The smallest ones come directly from the hatchery, while larger sizes require access to nurseries or other intermediate stages before the spat reaches its final growth phase in the marine environment.

European oysters exhibit optimal growth at salinities greater than 20 PSU, but they can tolerate salinities as low as approximately 15 PSU. The final growth phase takes between 2-3 years depending on the salinity of the production environment, water temperature, and food concentration. Various systems for the final growth phase in the sea (grow-out) are currently being explored, and ongoing development work aims to identify optimal systems that are both gentle on the spat and do not require extensive manual labor.

It is estimated that there is currently a market for up to 3,000 tons of European oysters annually in Europe alone, with additional untapped markets primarily in Eastern Europe. With an annual harvest of less than 1,000 tons, there is considered to be significant market potential that could generate revenue and local employment opportunities.

Barriers to European oyster production include:

- Insufficient hatchery capacity for spat production (a new hatchery in Nykøbing Mors is expected to be operational by mid-2021).
- Development of cost-effective methods for the final growth phase in the sea.
- Further spread of the Bonamia sp. parasite.
- Viable production companies, although mussel farmers could potentially expand their production to include oysters since their infrastructure would be suitable for oyster production.

1.4.2. Common cockle

Common cockles have been a significant and growing export commodity, especially from Limfjorden but also from the Wadden Sea, with production reaching approximately 7,000 tons in 2019. In Denmark, common cockles are currently produced solely through fishing with mussel dredges (Limfjorden) or suction dredges (Wadden Sea). However, in other countries, initial versions of common cockle cultivation have been developed.

Common cockle spat is produced in hatcheries and subsequently planted in intertidal areas, where they are later manually handled and harvested during low tide. Such a production method is, for various reasons, not yet feasible in Danish waters.

It would be possible to develop techniques for spat production in hatcheries in Denmark, although this has not been tested yet. An option for the final growth phase in Danish waters is on culture banks, where the cockles are harvested after reaching maturity on the banks. Cultivation of common cockles on culture banks could become an alternative to harvesting from wild stocks, which, based on experience from other European countries, can be highly fluctuating. There is expected to be a market for a minimum of 15,000 tons annually.

1.5. Ecosystem services of blue mussels

1.5.1. Nutrient removal through mussel cultivation

Mussel cultivation is considered the most effective marine measure against eutrophication and is closest to implementation. In 2020, Aarhus University compiled a catalog of marine measures (Bruhn et al., 2020), providing a thorough overview of mussel cultivation as a measure to remove nitrogen and phosphorus from coastal areas. Blue mussels can be produced in various ways, both on floating systems and on the seabed.

According to the 2020 Measure Catalog (Bruhn et al., 2020), the maximum production in a 250x750 m production area on longlines is 1800 tons with harvesting in November. This corresponds to the removal of 0.7-1.4 tons of N per hectare and 0.06-0.09 tons of P per hectare. For production on nets, the corresponding values are a maximum production of 4,000 tons per facility, with the removal of 1.6-3.0 tons of N per hectare and 0.10-0.17 tons of P per hectare. The cost of N removal with mussel cultivation on nets in Skive Fjord would amount to 48-64 DKK/kg N.

The Measure Catalog also models spatial variation in the potential of mussel production (Holbach et al., 2020). Danish waters are classified based on production potential, with the most productive areas in Denmark found in Limfjorden, including Skive Fjord. With 9 existing permits for longline mussel farming in Skive Fjord, an annual removal of 226 tons of N can be achieved if mussel farming is conducted as compensatory cultivation on longlines, with maximum biomass production. If 4 additional mussel farms are permitted, and SmartFarm technology is used, or a submerged net system on all 13 mussel farms, an annual removal of 731 tons of N can be achieved. This removal corresponds to the effort needed in the draft of the water plan for 2021-2027 for the coastal waters of Bjørnsholm Bugt, Risgårde Bredning, Skive Fjord, and Lovns Bredning.

Compensatory cultivation on longlines or on smart farm systems could continue for several years, and when the desired environmental condition is achieved, mussel cultivation could gradually shift towards mussels targeted for consumption.

1.5.2. Improved biodiversity – Danish fjord examples

Blue mussel production contributes to increased biodiversity in several ways. In a water area, a fjord, or a bay, mussels remove nutrients and increase water clarity. Both of these effects contribute to improving conditions for marine plants, macroalgae, and eelgrass. These plants are important habitats for various other species - different types of fish and birds. Cultivated mussels, whether on floating farms or bottom cultures, provide habitats for various species that seek shelter or feed between the mussels. Studies in the western part of Limfjorden have shown that in the areas where mussels had settled on the bottom, significantly higher biodiversity was found than in a nearby reference area. The mussels on the bottom offer a habitat for various species, thus increasing biodiversity. However, this situation assumes that the mussels can survive on the bottom, while in many locations in Skive Fjord, fallen mussels may not survive and form mussel beds.

During mussel cultivation, there will be a deposition of feces from the mussels, and therefore, one often observes that immediately under mussel cultivation, there is very low biodiversity and a dominance of opportunistic species adapted to a life in a poor bottom conditions. By choosing a location with good current conditions, fallen mussels may survive and contribute to higher biodiversity on the bottom.

The biodiversity in mussel production is certainly affected by the regular harvests, resetting biodiversity. In Vejle Fjord, a project called "Sund Vejle Fjord" is currently underway, where mussels are cultivated on longlines. The mussels are placed in permanent bottom cultures that do not need to be harvested. Both the mussels on the longlines and on the bottom contribute to clearer water through mussel filtration and increased biodiversity in Vejle Fjord.

1.5.3. Carbon capture

As blue mussels grow, shell formation occurs, leading to the binding and mineralization of CO_2 into calcium carbonate ($CaCO_3$). Mineralizing carbon into solid calcium carbonate is the most stable form of storage, and the carbon will not be released again if the shells are stored appropriately or utilized, such as embedding them in concrete. Approximately one-third of a mussel consists of shell, and with the production of 100,000 tons of mussels, 33,000 tons of mussel shells containing calcium carbonate are harvested, binding about 3,300 tons of carbon, equivalent to 10,000 tons of CO_2. Considering that Denmark needs to achieve additional savings of 24 million tons of CO_2 annually, a large mussel production can contribute a relatively modest amount of CO_2 capture from shell deposition.

Blue mussels are particularly interesting as food in the context of wanting to increase food production with a low carbon footprint. In 2021, CONCITO4 published an overview of the carbon footprint of various foods. Blue mussels rank at the bottom with a load of 0.22 CO_2 equivalents per kilogram of raw mussel. This is the same load as for mineral water, and about one-third of the load from apples and peas. Comparing with other marine proteins, the footprint is 30 times larger for cod fillet and 45 times larger for raw plaice. If we want a good steak from a trimmed tenderloin, the load is nearly 700 times larger than if mussels were chosen. Thus, we can achieve significant carbon savings by changing our eating habits. Such a change is initiated by information, easy access to the right high-quality ingredients, and also by involving citizens, for example, in the production of their own mussels in local sea gardens (www.havhost.dk).

1.6. Blue mussels in bioeconomy

The biomass of blue mussels can be used for food or for feed production. If the mussels are of high quality, the best price can be obtained in a food market, whereas mussels that cannot be sold as food can be allocated to bottom culture, habitat restoration, or as a feed product. In the production of mussels as a marine measure for nutrient removal, producers will adjust production to achieve the maximum possible biomass production. High biomass production will result in the production of mussels of low quality that cannot be directly used as food. Furthermore, the waters in Skive Fjord face the challenge of low salinity, causing the mussels to be small and thin-shelled, making them more suitable for further cultivation or as feed. The small size of blue mussels is typical also in other areas of the Baltic Sea where salinity does not exceed 8-10 PSU. Therefore, from the range of areas in the Baltic mussel biomass can be used mostly for feed.

1.6.1. *Mussels for feed*

Blue mussels with qualities unsuitable for human consumption can be used for bottom culture, habitat restoration, or feed. Blue mussels have a high protein content with the same amino acid composition as fishmeal. Therefore, various development projects have been carried out where blue mussels are processed into a storable meal product. Two projects, MUMIPRO (https://www.mumipro.dk) and InProFeed of Aarhus University (https://pure.au.dk/portal/en/projects/industrial-production-and-processing-of-mussels-to-fish-feed-inpr), concluded in 2021, and both projects have experimented with different processing techniques. The significant challenge is generally to separate the shells from the meat, and once this separation is achieved, the mussel meat needs to be dried until the moisture content is approximately 10%.

For the separation of mussel meat and shells, the following methods have been tested:

1. **Filter Press:** DTU Food has tested a filter press designed for pressing mash. The filter press has a capacity to press 1 ton of mussels per hour, with an investment cost of 1.6 million DKK. Pilot experiments have shown that only about 50% of the proteins are extracted from the mussels. The extraction rate is believed to be significantly improved. After filter pressing, the protein liquid needs to be dried, which was done by spray drying. No report on the experiment has been prepared.
2. **Deboner:** Several experiments have been conducted with a deboner, also known as a separator. Leroy Seafood in Norway and TripleNine have experimented with this processing technology, but there is no publicly available information on the results of pilot experiments.
3. **Screw Press:** Experiments have been conducted several times with a screw press, where the mussels can be separated into a shell fraction and a protein-rich liquid similar to the filter press. Like the filter press, it is difficult to achieve a high utilization of mussel raw material, and much of the protein ends up in the shell fraction, typically used as a fertilizer product.
4. **Cooking Process:** Production of mussel meat for freezing or canning involves a cooking process, and a simplified version of this process can also be used to extract mussel meat for feed production. Mussels are separated on a declumper to prevent clumps of bound individuals. Declumping is done by a machine where many fingers work against each other, gently separating the mussels. Subsequently, there is a shucking of the mussels, removing the byssus threads that mussels attach to the substrate with. After that, the mussels are briefly pressure-cooked, and the mussel meat is separated from the shells on a shaking table. A subsequent process ensures that the produced mussel meat does not contain shell fragments. Unlike mussel production for food, mussel production for feed will not include shucking or a post-inspection of the product, as byssus or shell fractions will not affect a feed product. The finished mussel meat can then be dried into a high-quality meal product. The drying of mussel meat itself is relatively energy-intensive and therefore costly. Fermentation Experts A/S is working on a larger project where mussel meat is not dried, but where the mussels, along with liquid, enter a fermentation process with plant proteins. In this production method, the water normally added to a fermentation process is substituted, and because it is not necessary to dry the mussels, this process provides access to mussels at a lower production cost.

1.6.2. Readiness of the production technology

The mussel production technology is well developed for several Danish areas but poorly tested in areas with low salinity. Before initiating mussel production anywhere, it would be appropriate to assess the production potential at the individual site. Several factors determine whether a location is suitable for mussel production. The production potential depends on the mussel population's growth (shell growth, meat growth). Predation of mussels by particularly eider ducks can cause significant losses.] A single eider duck can eat up to 3 kg of mussels per day, and when mussels are torn off the longline or cultivation net, there will often be mussels falling to the bottom in addition to those eaten by the eider duck. Overall, a flock of eider ducks can quickly clear a mussel farm of mussels. Techniques have been developed to keep eider ducks out of mussel farms by setting up nets, but in relation to mussel production for feed, setting up nets would be so cost-prohibitive that mussel farming cannot be made a profitable business. There is no knowledge to clarify whether increased mussel cultivation in Limfjorden can lead to an increased occurrence of eider ducks in Limfjorden and thus have damaging effects on mussel farming.

1.6.3. Cultivation of mussels on longlines and nets

The cultivation of mussels on longlines is a well-established technology, with numerous experiments conducted using different materials and successful full-scale productions. However, when it comes to cultivating mussels on nets, the knowledge base is more limited. Some experiments have been conducted on the mesh sizes of the nets, and practices involving thinning and harvesting have also been explored to some extent.

There are still two significant challenges associated with cultivating mussels on nets supported in the water column by pipes. These challenges include the visual impact of the structures and issues with drifting ice. Since the PE pipes that keep the nets afloat have a constant buoyancy, the pipes are very visible when the mussels are harvested and throughout the summer. The sight can cause a resistance of local population towards mussel cultivation. Another problem with the pipes is their vulnerability to drifting ice.

With longlines, it is possible to submerge the production by keeping the lines down with concrete blocks, and this is a well-established practice. In the case of a risk of ice formation, the pipes supporting the nets can only be submerged by filling them with water, causing them to sink to the bottom. This will result in mussel losses and is also highly labor-intensive.

The company Wittrup Seafood A/S is leading a GUDP project, SUBMUSSEL, where mussel production on nets is submerged, avoiding conflicts related to visibility and ice. A solution is expected to be developed within 2 years, and a prototype is currently undergoing testing (https://gudp.lbst.dk/nyheder/nyhed/nyhed/miljoemuslinger-skal-fjerne-kvaelstof-fra-fjordene).

1.6.4. Other applications for mussels

Improving water quality and microplastic removal

Mussels have been tested for water purification in areas affected by sewage overflows. They demonstrated the potential to reduce bacterial and microalgal concentrations, providing a cost-effective method for improving water quality. This is true not only for blue mussels, but also for zebra mussels (*Dreissena polymorpha*).

Production of technical water from seawater
Mussel shells could possibly serve as a pre-filter in nanofiltration processes for producing technical water for industrial use. Nanofiltration is effective in removing dissolved nutrients, molecules with poor taste, salts, bacteria, and viruses.

Utilization of mussel shells
Mussel shells have diverse applications, including sustainable construction projects, road filling, and even in climate projects for rainwater reservoirs. They can also be used in the mining industry for acidic water treatment.

Exploiting mussel adhesive for biomedical applications
Mussel adhesive proteins, used by mussels to attach to surfaces, have potential applications in biomedicine, serving as a bio-compatible adhesive for surgical procedures.

2. Cultivation of seaweed

2.1. General status

Seaweed is broadly divided into three groups: brown algae, red algae, and green algae. The macroalgae is another group of organisms for the low-trophic aquaculture and can be cultivated both in sea-based facilities and land-based installations. Denmark is the leading country in the Baltic Sea area in the cultivation of seaweed due to favourable natural conditions. The number of species in the natural seaweed populations around the Baltic Sea is not high. Scarcity of hard substrata together with particularly low macroalgal diversity also characterizes the Baltic Sea coasts of Poland and Latvia, while most other Baltic Sea coasts offer more favorable substrata. Bedrock occurs along Swedish, Finnish and Estonian coasts and on the Danish island of Bornholm, and smaller hard substrata such as pebbles, stones or boulders are frequently encountered mingled with soft bottoms in the remaining areas. However, large parts of the Baltic Sea are characterized by low salinities that limit its suitability as a habitat for seaweeds and marine organisms in general. The mean surface salinity decreases from fully marine conditions at the northern tip of Denmark to 8 at the entrance to the inner Baltic Sea (Darss Sill) and 7 in the central Baltic Sea (Gotland basin; Figure 2.1), and this correlates with a decrease in macroalgal diversity by approximately 50% and 75%, respectively.

Figure 2.1: Types of coastlines, annual average sea surface salinities, and species numbers of algal macrophytes that have been recorded in different sea areas of the Baltic Sea and the German and Danish North Sea (from Weinberger et al., 2020).

2.2. Brown algae

Sugar kelp (*Saccharina latissima*) is the most cultivated and widespread seaweed species in Europe, with a total annual volume of approximately 375 tons of fresh seaweed. Cultivation technologies and protocols have been developed and adapted to different types of water bodies. In Denmark, up to 16 tons have been produced annually in recent years (although 166 tons if production in the Faroe Islands is included).

Sugar kelp can be cultivated at salinities above 16 PSU but grows optimally at salinities above 25 PSU. Sugar kelp thrives in areas with good water exchange but not under excessive wave exposure and can be cultivated in both nutrient-rich and nutrient-poor areas. Hence, large parts of Danish waters are suitable for the cultivation of sugar kelp.

The high hygienic standards in the coastal Danish waters ensure that the microbiological quality of seaweed harvested in Danish waters is generally satisfactory. Commercial cultivation of sugar kelp in Denmark began in 2008, south of Aarhus. Since then, several research and development projects in collaboration with commercial entities have driven the industry forward. Currently, there are two commercial producers in Denmark, with the largest located near Horsens Fjord, having a cultivation area of 100 hectares, though not fully utilized. The production here is organic, yielding up to 16 tons of fresh sugar kelp annually. The second commercial facility is a smaller coastal plant covering 0.4 hectares in Isefjorden, which began production in 2019. Additionally, sugar kelp is cultivated for research purposes in Limfjorden (DTU Aqua, 4 hectares) and in Kattegat off Grenå (Aarhus University, 20 hectares), as well as in sea gardens throughout the country. In the Faroe Islands, one of Europe's leading seaweed producers primarily produces sugar kelp but also finger kelp and winged kelp, totaling around 150 tons of fresh seaweed annually, with a goal of reaching 500 tons annually from 2021.

Cultivation of sugar kelp can serve as a marine measure for nitrogen and phosphorus uptake and removal from the marine environment, contributing to improving the environmental conditions. Based on cultivation experiments since 2011, the yield in Danish waters is estimated to be around 12 tons per hectare per year on average in Horsens Fjord and slightly lower in both Limfjorden and the open Kattegat. Under optimal conditions, the yield can double to up to 25 tons per hectare per year. For comparison, the average area yields for grass and maize for silage are 13.8 and 44.5 tons per hectare per year. The relatively higher efficiency of seaweed production compared to grass can be attributed, among other factors, to the ability to cultivate in three dimensions in the ocean. The technology is still evolving, and mechanization of processes for deployment, harvest, and processing is expected to be developed in the coming years. Seaweed cultivation has been tested in several different Danish marine areas, but there are currently no estimates for the potential total production of sugar kelp in Danish waters.

Danish-cultivated sugar kelp is currently primarily used for food and feed. For food, the market is established for both dried products, fermented products like Nordic seaweed salad, dried seaweed as an ingredient in processed foods such as pesto, mustard, beer, bread, or flour, and to a limited extent as a fresh product for restaurants. Sugar kelp is also used as a bioactive ingredient in probiotic pig feed, where canola and sugar kelp are fermented with specific lactic acid cultures. There is a significant market for several thousand tons of seaweed annually, which cannot currently be met by Danish producers alone. In research and development projects, efforts are underway to utilize sugar kelp for antioxidants, fucoidan, high-quality protein, and energy (bioethanol, butanol). The primary focus here is on cascade utilization to maximize the total value of downstream products.

There is also commercial focus on other brown algae than sugar kelp, such as finger kelp (*Laminaria digitata*) and bladderwrack (*Fucus vesiculosus*). Finger kelp can be cultivated similarly to sugar kelp but grows slower and has yielded very low or no results in cultivation experiments. Bladderwrack and other *Fucus* species are sought after for food, as an ingredient in chip production (SeaMan Chips), and for the extraction of fucoidan, which can be used in the pharmaceutical industry. Bladderwrack and other Fucus species cannot currently be cultivated and are therefore harvested from natural coastal populations. Danish waters host substantial stocks of *Fucus* species, with the Kattegat alone estimated to contain about 82,000 tons of biomass. Harvesting *Fucus* is currently regulated only for the harvest of organic seaweed, which requires approval from the Danish Coastal Authority. This could potentially become problematic for coastal marine ecosystems, where *Fucus* species are crucial keystone species.

Barriers to sugar kelp production:

- Permits for establishing cultivation facilities, primarily due to a lack of knowledge about environmental effects of large-scale cultivation.
- Access to qualified labor. Currently, there are few commercial actors, and knowledge and practical experience are still primarily rooted in research institutions. Several facilities could be managed by central players, reducing operational and installation costs.
- Access to grafted spore lines. A central, specialized hatchery could meet the needs of multiple producers and reduce costs and risks associated with decentralized spore line production.
- Cultivation technology and mechanization of handling during deployment and harvest. Development of mechanically manageable systems with high area efficiency and stability for production in exposed environments needs to be developed.

- Marketing and competition. Handling and processing freshly harvested seaweed for storage stability are challenging due to its high water content. Simultaneously, foreign producers currently supply sugar kelp at prices that are difficult to match for local producers.
- There is growing local resistance to aquaculture facilities at sea, and the visual concerns for sugar kelp are similar to those for blue mussels.
- If production is to increase significantly, seaweed farmers need to be compensated for the ecosystem services the production provides, i.e., seaweed cultivation must be included as a measure in 3rd generation water plans or as an instrument for Carbon Capture and Utilization. This could provide an incentive for a significant increase in production.

2.3. Red algae

Currently, there are no red algae in commercial production in Baltic Sea area. Intensive efforts are being made to optimize the cultivation of the red algae dulse (*Palmaria palmata*). Research and development activities focus on optimizing both the early stages of dulse's life cycle and grow-out either in the sea or in connection with land-based aquaculture. One Danish company is starting production of dulse from sea-based facilities, and another company currently harvests and sells red algae from natural occurrences on a small scale, including dulse, carrageen seaweed (*Chondrus crispus*), red seaweed (*Delesseria sanguinea*), and gracilaria seaweed (*Gracilaria vermiculophylla*). The latter is an invasive species. A significant barrier to expanded production is the development of methods for the production of spore lines or capacity in hatcheries.

There is a growing market for dulse as food. The species is sold dried and fermented/rehydrated and marketed as 'sea bacon.' A Nordic seaweed salad based on gracilaria seaweed is under development by a Danish company.

Furcellaria lumbricalis up to the present has remained the only seaweed species in the Baltic Sea that is harvested on a commercial scale. *Furcellaria lumbricalis* has attached and unattached (loose-lying) thallus forms, which represent two distinctive ecotypes. The attached *F. lumbricalis* is widely distributed on hard substrata in the Baltic Sea and can be found at salinities down to 3.6 PSU. The commercial utilization of the loose-lying *F. lumbricalis* and in West Estonian archipelago was started in 1966 by the local company ESTAGAR and until now it has been mostly based on the extraction of furcellaran, that is widely used as a stabilizing, thickening and gelling agent in the food, pharmaceutical, cosmetics and agriculture industries. At present, there is an increasing interest in a new potential biotechnological application of unattached *F. lumbricalis* biomass as a raw material for extraction of the red pigment R-phycoerythrin. Due to its different bioactive properties, R-phycoerythrin can be used not only in the food industry as a natural food colorant, but also in medicine and cosmetics. To assure environmentally sustainable and long-lasting utilization of the unique loose-lying red algal community, its ecological status has been monitored regularly, and official regulations of harvesting were introduced since the start of its commercial exploitation. Currently harvesting by bottom trawling is limited to 2000 t ww per year. In addition, beach deposits of both loose-lying and attached communities of furcellaria are collected for commercial utilisation of carrageenans.

2.4. Green algae

Sea lettuce (*Ulva* sp.) is the most widely used group of species of green algae, tested for industrial production worldwide. It is a rapidly growing green macroalgae. Many species of sea lettuce exist in Denmark, and they cannot always be distinguished without the use of DNA methods. Sea lettuce is not currently in commercial production in the Baltic Sea area, but a Danish company is working on developing systems for cost-effective production in land-based facilities, and another Danish company harvests and sells to a limited extent from natural occurrences.

Due to high growth rates and tolerance to varying salinity, sea lettuce is suitable for cultivation in nutrient-rich wastewater sources from, e.g., fish farming. In Portugal, sea lettuce is commercially cultivated in land-based facilities for Integrated Multitrophic Aquaculture (IMTA), where sea lettuce utilizes nutrients in nutrient-rich wastewater from fish farming. On a European scale, approximately 50 tons are produced annually in land-based facilities, while over 200 tons are harvested from nature, including from eutrophication-induced mass occurrences, the so-called 'green tides'. Green tides also occur at Danish coasts, and the possibilities of harvesting and using sea lettuce from eutrophication-induced mass occurrences are currently being investigated. High-quality sea lettuce is primarily used for food and marketed as both a salted and dried product. Other existing uses include animal feed or biostimulants for plant production.

2.5. Ecosystem services provided by seaweed

Nutrient removal: Experiments in Denmark with cultivating sugar kelp in different areas have shown that it can remove nitrogen (N) and phosphorus (P) from the water. The removal rates varied between the locations, with different costs associated. The price for removing 1 kg of N ranged from 3,241 to 7,718 DKK, with the lowest cost for cultivation near Horsens and the highest near Grenå.

Improved bodiversity: DNA samples from the water column and sediment revealed greater biodiversity in the sediment beneath the seaweed structure compared to reference areas. The seaweed cultivation was found to enhance biodiversity by functioning as suspended reefs. However, the overall effect on sediment and water column biodiversity was considered not significant.

Carbon sequestration: Macroalgae, unlike plants with permanent root systems, do not establish a permanent biomass structure. The majority of their biomass is shed in the fall, leading to a temporary carbon binding. The cultivation of sugar kelp, however, has a mitigating effect on climate change. As macroalgae grow, they absorb CO_2 through photosynthesis, contributing to carbon sequestration. When the algae are harvested and processed into food or feed, the absorbed CO_2 is released again. If seaweed is used for purposes where it is not incinerated, a permanent removal of CO_2 from the atmosphere can occur. Establishing stone reefs with a sustainable seaweed population could have a climate impact, but it's crucial to note that many seaweed species shed a significant portion of their carbon during the fall.

Ocean Acidification Mitigation: Macroalgae cultivation, particularly sugar kelp, helps counteract ocean acidification caused by increased atmospheric CO_2. The absorption of CO_2 during sugar kelp growth contributes to an increase in pH in seawater.

2.6. Seaweed in bioeconomy

In recent years, there has been significant focus on seaweed as a versatile food source with potential positive effects on marine environments. The utilization of macroalgae for feed, biorefining, and isolation of specific chemical compounds is also being explored. Macroalgae contain valuable substances, including bioactive compounds, with various health benefits such as anti-tumor effects, antibacterial effects, cholesterol reduction, blood pressure regulation, anti-diabetic properties, and antiviral effects.

2.6.1. Macroalgae as food ingredients

Macroalgae serve as food ingredients in various forms, contributing to stabilizers and thickeners used in food and beverages, cosmetics, and pharmaceutical products. There are three main classes of ingredients extracted from macroalgae: alginates, carrageenans, and agar—all of which are polysaccharides utilized to bind water, forming hydrogels, and are primarily employed for thickening.

Alginates:

- Derived from brown algae through an acid treatment process.
- Historically, alginates were produced in Denmark, based on harvesting bladderwrack in the Kattegat and south of Lolland.
- Used primarily in dessert gels and especially in ice cream. Also employed in cosmetic products.

Carrageenans:

- Extracted from red algae, mainly produced through cultivation in the Philippines and now also in Indonesia and Tanzania.
- The extraction involves precipitation with potassium chloride.
- Carrageenans are cost-effective and function as stabilizers in the food industry.
- Effective in binding proteins, used in products like ice cream, meat products, and bread. Also utilized for stabilizing paint, cosmetics, etc.

Agar:

- Extracted from cell walls of various red algae species, including Gelidium, Gracilaria, Pterocladia, and hornwrack.
- Mainly composed of agarose and agaropectin.
- Used as a thickening agent and stabilizer in food, cosmetics, and pharmaceuticals.

2.6.2. Macroalgae in animal feed

Macroalgae are recognized as a feed ingredient for ruminants, providing both nutritional value and an anti-methanogenic effect. This feed can contribute to reducing the climate impact of livestock farming. Experiments conducted by the University of Copenhagen involved adding brown algae *Ascophyllum nodosum* and a mixed product of different seaweed species to cattle feed. Both products resulted in approximately a 20% reduction in methane production from the digestion of cows fed with corn silage.

The addition of seaweeds *Ascophyllum nodosum* and *Saccharina latissima* to lacto-fermented rapeseed feed for piglets altered the piglets' gut flora, potentially exhibiting an anti-inflammatory effect. However, the addition of *Ascophyllum nodosum* alone to the feed did not affect piglet growth and production.

These findings highlight the potential of macroalgae not only as a valuable ingredient in human food but also as a sustainable and beneficial component in animal feed with potential climate impact reductions.

These developments indicate the potential for business growth in the seaweed industry in Denmark, especially if challenges related to production costs and competition with imports are addressed. The interest from both cosmetic and food industries suggests a diverse range of opportunities for seaweed-based products.

2.7. Ecosystem services from eelgrass

Eelgrass (*Zostera marina*) is not a seaweed but belongs to the family of higher plants having the respectives features – leaves and roots. It forms important habitats for marine coastal ecosystem and can substantially contribute towards improvement of water quality, if cultivated in addition. Therefore the most relevant ecosystem services the eelgrass is providing, are listed below.

Nutrient removal

The establishment of eelgrass beds provides ecosystem services by permanently immobilizing nutrients. Each hectare of eelgrass bed immobilizes 146 kg of nitrogen and 32 kg of phosphorus annually. During the eelgrass growth season, an additional binding of 294 kg of nitrogen and 60 kg of phosphorus per hectare occurs. The cost for establishing 1 hectare of eelgrass bed, including planting 47,000 shoots, is estimated at 25 000 EUR. If this investment is depreciated within a Water Plan period (until 2027), the annual cost for nutrient removal would be around 5000 EUR, equivalent to a price of 35 EUR/kg N and 150 EUR/kg P.

Biodiversity improvement

Eelgrass provides habitat for fish larvae and supports a diverse range of marine organisms, contributing to increased biodiversity, including commercially valuable fish species.

Carbon sequestration

Eelgrass beds play a crucial role in carbon sequestration. The root system, accumulation in sediments, and enhanced denitrification in the sediment contribute to permanent carbon immobilization. Studies indicate that eelgrass beds can sequester approximately 822 kg C/ha per year, with 527 kg in the root system and 355 kg in the sediment. This represents an immobilization of about 3 tons of CO_2 per hectare per year.

Economic potential - carbon credits
Given the increased focus on reducing carbon emissions, there is potential to develop a system where the establishment of eelgrass areas compensates for CO_2 emissions. The market price for CO_2 carbon credits has increased significantly, reaching approximately 85 EUR/ton. Establishing eelgrass beds could contribute to carbon sequestration, creating economic value through the sale of carbon credits. It's important to note that carbon sequestration in sediments is considered more effective than on land, as carbon stored in sediments remains stable for millennia, while carbon in soil is less stable and bound for decades. The potential for creating economic value through eelgrass carbon sequestration emphasizes the multifaceted benefits of eelgrass ecosystems.

2.8. Eelgrass in bioeconomy

The eelgrass holds several potentials for use in various sectors, currently mostly under investigation and testing, or used in pilot applications. The widest utilization of eelgrass has been explored for construction and insulation.

Historical use and sustainability. Eelgrass has been historically used for construction purposes and as a filling material in items like mattresses. Its utilization for generations demonstrates its availability and sustainability as a natural resource.

Potential for fishing industry. Here is potential to develop an industry in specific areas to harvest eelgrass, providing a high-quality raw material. This could involve sustainable practices to ensure the long-term health of eelgrass ecosystems.

Dansk Tang's innovative application. Company Dansk Tang is innovatively using dried eelgrass as a substitute for bubble wrap in packaging. This demonstrates the versatility of eelgrass as a renewable and eco-friendly material in various industries.

Building insulation. The study in 2018 explored the use of eelgrass in the production of insulation mats for construction. Eelgrass insulation mats, known as "tang-batts," achieved a fire class E rating without fire impregnation due to the natural salt content in eelgrass. Impregnation with the Firestop flame retardant was expected to result in a fire class B rating. The insulation value was comparable to mineral wool, and tang-batts exhibited good acoustic and sound-absorbing properties.

Eelgrass in experimental construction on Læsø. Company RealDania supported an experimental construction project on Læsø, where eelgrass was used for insulation and both interior and exterior cladding. The house was built using prefabricated wooden cassettes for floors, facades, and the roof. Eelgrass was incorporated as insulation within the cassettes, as padding in an acoustically dampening ceiling covered with linen fabric, and as cladding for facades and the roof.

In conclusion, the utilization of eelgrass in construction, insulation, and packaging demonstrates its potential as a renewable and versatile resource in the bioeconomy. These innovative applications contribute to sustainability, circular economy principles, and the development of eco-friendly alternatives in various industries.

3. Grass

3.1. General status

Grass is the most common and easily accessible type of biomass with centuries long use and applications. Species of grass plants provide a variety of ecosystem services, relevant also for climate change mitigation and adoption.

Soil erosion prevention. Grasses, with their extensive root systems, play a crucial role in preventing soil erosion. The dense network of roots binds soil particles together, reducing the risk of erosion caused by wind and water.

Water filtration and regulation. Grasses help regulate water flow by promoting infiltration and reducing surface runoff. The root systems act as filters, trapping sediments and pollutants, which helps maintain water quality in rivers, lakes, and aquifers.

Carbon sequestration. Grass ecosystems contribute to carbon sequestration by capturing and storing carbon dioxide through photosynthesis. The organic matter in grasses adds carbon to the soil, contributing to carbon sequestration and mitigating climate change.

Biodiversity support. Grasslands support diverse ecosystems with a variety of plant and animal species. The structure of grass ecosystems provides habitat and food resources for insects, birds, mammals, and other wildlife, contributing to overall biodiversity.

Water storage and flood prevention. The root systems of grasses enhance water retention in the soil, acting as a natural sponge during periods of heavy rainfall. This helps prevent flooding by slowing down water runoff.

Erosion control on riverbanks. Grasses are often planted along riverbanks and water bodies to control erosion. The root systems stabilize soil, preventing riverbank erosion and protecting aquatic habitats.

Around 17% of the EU's total surface area was covered by grassland in 2018 but this abundant resource is often left unused, creating costs for society and for rural areas. By valorising grass and grasslands, Europe can generate new opportunities for farmers and rural businesses. Thus, innovative approaches for processing, using, and marketing grass-based products and grasslands ecosystem services could become central to the revitalisation of rural areas.

Unfortunately, permanent grasslands are decreasing in the last decades in Europe. According to the European Environmental Agency (2021), in the last period measured (2012-2018), more than 2,600 km^2 of land was converted into urban area in the EU27+UK. Though small in relative terms, this loss is large in absolute terms, particularly for grassland ecosystems (-1,887 km^2).

Valorisation of grassland is important because otherwise grassland can be taken over for „higher yielding" alternatives use such as intensive croplands. Ploughing permanent grasslands or converting them to intensive croplands, favours soil aeration and microbiological activity that mineralizes the organic matter and releases carbon and nitrous oxide to the atmosphere. In addition, nitrates risk leaching into surrounding waters may cause eutrophication and extra greenhouse gas emissions to the atmosphere.

The decrease in permanent grasslands has important ecological threats such as an increased nutrient leaching due to the intense fertilisation or the increase in fire intensity by the uncontrolled biomass growth in abandoned areas.

3.2. Danish example of innovative application for grass

In the framework of Horizon 2020 project "Go-GRASS" (www.go-grass.eu) the Danish demonstrational pilot to produce protein locally from the grass species was built on the concept of green biorefining. Here cultivated, fresh green crops such as grasses, but also legumes, are used. The varieties of grasses, clovers and lucerne that are usually used for forage production in Denmark can be used for the biorefinery. It is therefore expected possible to use grasses that are more productive and hardy than the usually produced perennial ryegrass. Tall fescue, and Festulolium varieties can produce 1-5 tonnes more DM/ha than can perennial ryegrass, and total crude protein yield can be proportionally higher as well. The first experiences with Festulolium on the biorefinery have shown high extractability of protein, which is very promising.

The grass is expected grown on intensive farmland, and can substitute some of the annual crops, which today makes out some 80% of total farmland in Denmark. Such a substitution can improve agricultural sustainability by reducing soil erosion, nitrate leaching, GHG emission and pesticide use. Another aim is to substitute some of the large import of 1.6-1.7 mio. tonnes of soy cake for feed purposes to Denmark annually. A recent policy note sets up scenarios for the area requirement to substitute the whole import for Denmark, which will vary between approx. 0.5 and 1 mio. ha, dependent on the maturity of the grass production and biorefinery technology.

The green grass and/or legumes are processed by wet fractionation, producing a green juice and a fibrous press cake. This is followed by protein precipitation and separation from the green juice to give protein concentrate and brown juice. The protein concentrate is used for monogastric animal feed, as a replacement for soy meal, while the two side-streams (press cake and residual (brown) juice) are used for ruminant animal feed and biogas production, respectively. In order to maintain high yield and quality of the protein concentrate, the process requires the grass to be harvested and processed within the same day and preferably with as little storage and biomass damage as possible, thereby avoiding protein degradation and enzymatic alterations to protein. This places great demands on grassland management and forage handling logistics. Full utilisation of process capacity at the biorefinery requires harvest to be continuous from May to October, delivering fresh green biomass on a daily basis. In addition, the forage harvesting method needs to prevent or reduce contamination with sand and soil particles and to handle the biomass in a gentle manner to avoid unnecessary damage. For cultivation on wetlands, tall fescue is also one option. If very wet, reed Canary grass and cattail are other options for cultivation, which are currently being investigated. Machinery for harvesting grass on wet lowlands (paludiculture) has to some extent been developed already, with the best examples in the Netherlands. Until now, paludiculture grass quality for green biorefining has only been tested at laboratory scale.

3.3. Swedish example of reed canary grass application

In the Swedish case of Go-GRASS project at two facilities in northern Sweden, a reed canary grass (*Phalaris arundinacea* L) is suitable for production. Reed canary grass (RCG) is appropriate for cultivation in most agricultural regions and a suitable crop for cold climates. It can be grown on most soils, but grows best on moist, humus-rich and light soils. Reed canary grass can provide a good return on most soil types throughout Sweden, and grows better than many other crops on peat and mire soils. In the year before sowing RCG, perennial weeds must be controlled. If the land is overgrown, more extensive restoration is needed. RCG is sown early in the spring, to allow it to develop before autumn. The grass reaches a height of about 2 m in autumn and is harvested in early spring of the following year, using similar techniques to those in conventional forage harvesting. The delayed harvest gives a dry matter content of 85% and a storable material that can be directly briquetted without any artificial drying. Reed canary grass has been studied previously as a fodder crop, but the delayed harvest makes it interesting as an energy crop. However, the raw material cannot compete economically with wood-based biomass fuels, so today it is primarily used as animal bedding. The pilot case in Sweden were developing low-cost, low-impact technology to make biofuel briquettes using reed canary grass.

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