Nordic Innovation

Marine Biobased Building Materials

Technical Playbook

Report by Arup

Nordic Blue Building Alliance

Acknowledgements

We would like to express our sincere appreciation to all respondents from research, public authorities and companies who have provided input to this report.

Disclaimer

Disclaimer: This report is part of the Nordic Innovation program; Sustainable Construction. Arup and the Blue Building Alliance are responsible for all its content.

The front cover is showing harvest of eelgrass from the shore of Møn and the image was kindly provided by Tobias Øhrstrøm, © Søuld

About Nordic Innovation

Nordic Innovation is an organisation under the Nordic Council of Ministers. Nordic Innovation aims to make the Nordics a pioneering region for sustainable growth and works to promote entrepreneurship, innovation, and competitiveness in Nordic business.

ARUP

Nordic Innovation

Preface

The Nordic Prime Ministers' vision for the Nordic cooperation is that the region is to become the most integrated and sustainable region by 2030.

The Nordic Ministers for Industry and Innovation have launched eight programs which are to contribute to realizing this vision. Nordic Innovation is responsible for carrying out the programs and one of the programs is the Sustainable Construction program. Nordic Innovation has entered into a partnership with the Nordic Blue Building Alliance, led by Arup, to create this report.

The report is a part of the Nordic Sustainable Construction programme which contributes to the Nordic Vision 2030 by supporting the Nordics in becoming the leading region in sustainable and competitive construction and housing with minimised environmental and climate impact.

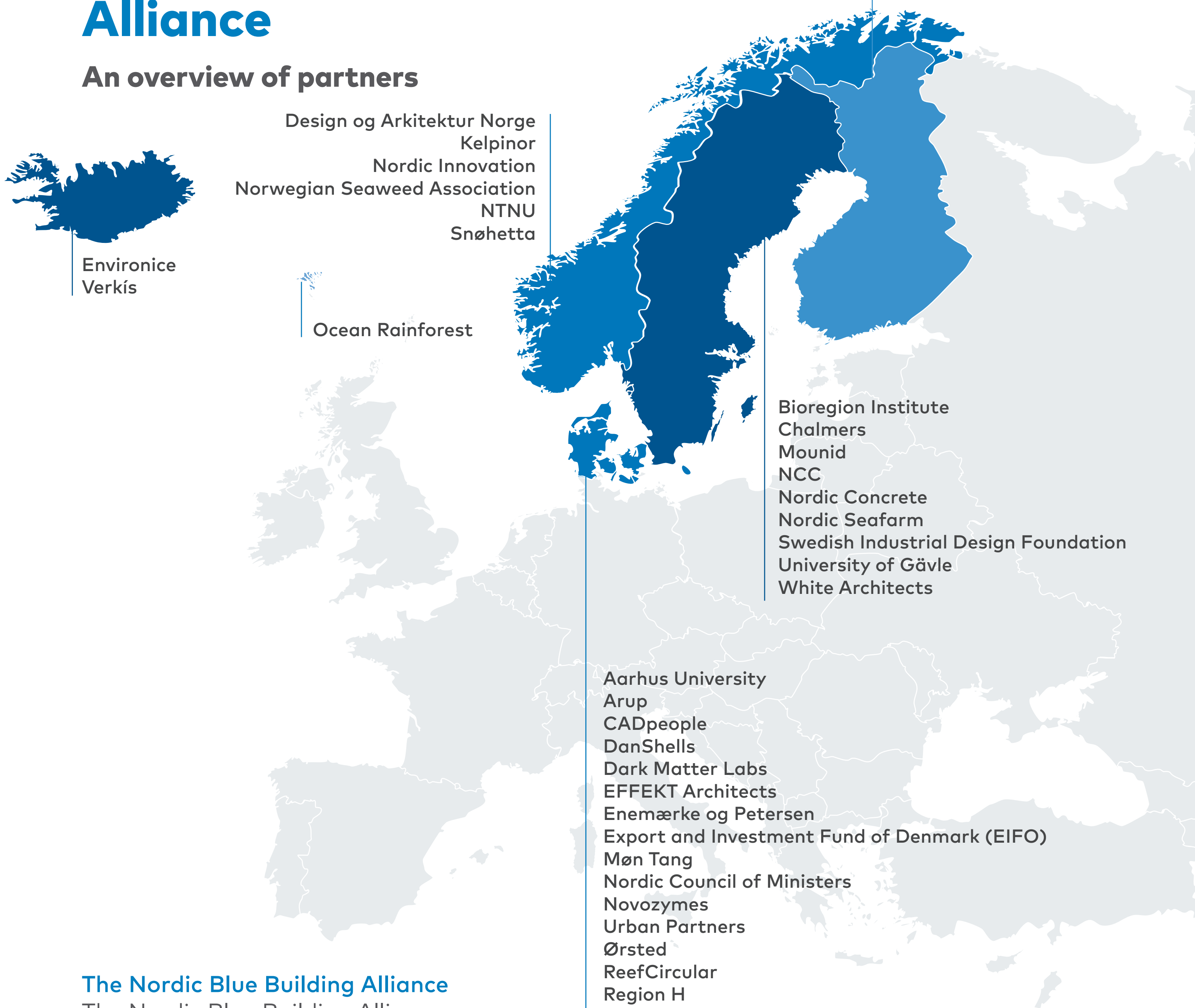
The programme supports the green transition of the Nordic construction sector by creating and sharing new knowledge, initiating debates in the sector, creating networks, workshops and best practice cases, and facilitating Nordic harmonisation of regulation for buildings' climate impact.
Nordic Innovation has partly funded the work leading to this report with the aim of exploring the possibilities for a larger use of marine biobased building materials and hope to inspire the Nordic construction sector to become greener.

Oslo, January 2024

Svein Berg
Managing Director, Nordic Innovation

Nordic Blue Building Alliance

An overview of partners



The Nordic Blue Building Alliance

The Nordic Blue Building Alliance was established as the foundation for this project. The partners in the Alliance are representatives from the full life cycle of marine biobased building materials including stakeholders across the supply chain in the Nordics of the cultivating and harvesting of marine biomass to create products for the built environment.

Table of Contents

Glossary

A1-A3 (LCA) The "product stage" of a component's life cycle. A1 refers to raw material extraction and processing and processing of secondary material input (e.g., recycling processes). A2 refers to transport to the manufacturer. A3 refers to manufacturing.[1]

Aquaculture is the controlled cultivation ("farming") of aquatic organisms. Examples of marine aquaculture production include oysters, clams, mussels, shrimp, fish, and algae.

Binder is a substance that causes two or more other materials to bond together or blend.

Biodegradable means that a material is capable of decomposing depending on the composition and structure of the materials but also on the environment in which it is undergoing biodegradation, including the temperature, pH, ultraviolet radiation, humidity, presence of microorganisms and enzymes, presence of catalysts, and presence or absence of oxygen.[2]

Biomass is derived from organic material such as trees, plants, and agricultural and urban waste.[3]

Biotic Material are materials made from living organisms without further modification.[4]

Bio-based Material are made from substances derived from living organisms. These kinds of materials might go through a process before reaching the product state.[5]

Bio-fabricated Material is any biological product made by micro-organisms such as yeast, mycelium, algae, and bacteria.[6]

Biogenic Carbon is carbon that is sequestered from the atmosphere during growth of biomass and may be released back to the atmosphere later due to combustion of the biomass or decomposition (same as sequestered CO2).[7]

Biomaterials are materials that have non-specific biological association and is all encompassing (includes natural materials e.g., wood through to bio synthetics). All biomaterials are bio-based and are generally used to describe an end-product, a finished material in the built environment.[8]

Biotechnology involves using living organisms, cells, and biological systems to develop products and applications that benefit various industries. It merges biology, chemistry, and technology for purposes like medicine, agriculture, and environmental sustainability, driving advancements in areas like genetic engineering and biofuel production.[9]

Carbon dioxide equivalent (CO2-eq) is a comparable way to measure the emissions from various GHG based on their GWP, by converting amounts of other gases to the equivalent amount of carbon dioxide with the same GWP.[10]

Chitosan is a biopolymer derived from chitin, found in the shells of crustaceans. It's used in various applications like water treatment and wound healing due to its biodegradability and antimicrobial properties.[11]

Eutrophication is when excess nutrients enter water bodies, causing rapid growth of algae and plants. These excessive organisms create algal blooms that deplete oxygen as they decompose. Reduced oxygen levels harm aquatic life and disrupt the ecosystem's balance, stemming from pollution sources like agriculture and sewage. Mitigation involves managing nutrient inputs and restoring affected waters.[12]

Environmental degradation is a process through which the natural environment is compromised in some way, reducing biological diversity and the general health of the environment. This process can be entirely natural in origin, or it can be accelerated or caused by human activities.

Ecosystem comprises the collective of living entities (plants, animals, and organisms) within a specific area, engaging in interactions with one another and with the elements of their inanimate surroundings.[13]

Embodied Carbon is the total GHG emissions associated to the production of a material/product/asset. This includes emissions caused by extraction, manufacture/processing, transportation and assembly of every product and element in a material/product/asset. In some cases, it may also include the maintenance, replacement, deconstruction, disposal and end-of-life aspects of the materials and systems that make up the material/ product/asset.[14]

Environmental Product Declarations (EPD) is a third-party verified, standardised document that provides the environmental impact of a product, based on the data from a Life Cycle Assessment (LCA).[15]

End-of-life refers to the final stages of a products life when it's no longer in the stages of being used.[16]

Greenhouse Gases (GHG) is a common name for the gasses in the atmosphere that trap heat in the atmosphere.[17]

Global Warming Potential (GWP) is a numerical value used to measure the relative contribution of GHGs to global warming. It compares the warming effect of a particular gas to that of CO2 over a specific time, usually 100 years. GWP values help in assessing the overall climate impact of different GHGs.[18]

Life Cycle Assessment (LCA) refers to a method of evaluating the impact that a material, product, or an asset has on the environment during its whole life cycle.

Macro algae and micro algae are multicellular, large-size algae, visible with the naked eye, while microalgae are microscopic single cells.[19]

Oceanic carbon refers to the carbon compounds, primarily in the form of dissolved inorganic carbon (DIC), dissolved organic carbon (DOC), and particulate organic carbon (POC), found in Earth's oceans. It plays a significant role in the global carbon cycle and can influence climate and ocean health.[20]

Ocean economy and blue economy, also known as the blue economy is defined as the sum of the economic activities of ocean-based industries, together with the assets, goods and services provided by marine ecosystems.[21]

Resource stream refers to a continuous flow of materials, energy, or information within a system, process, or ecosystem.

Sequestered carbon dioxide (CO2) is the removal and long-term storage of CO2 that originally comes from the atmosphere (same as biogenic carbon).[22]

Waste stream refers to the continuous flow of discarded materials generated by a particular source or process, such as natural processes, households, industries, or commercial establishments.

Executive Summary

Executive Summary

The marine biobased building materials sector stands at the crossroads of the bioeconomy and the ocean economy, representing a vital and burgeoning field with significant growth potential within low carbon construction. Recognized as a priority area by Nordic Innovations and the Nordic Bioeconomy program, low carbon construction plays a pivotal role in reindustrialization and addressing pressing societal challenges. Marine-based biomaterials offer innovative avenues for resource production and consumption while adhering to planetary boundaries, making them instrumental in advancing the goals of the European Green Deal and the EU's Sustainable Blue Economy strategy.[23]

Oceans, by their very nature, transcend national borders and encompass diverse sectors within aquaculture and fisheries among others. International agreements including EU Water Framework Directive, EU Habitat Directive and EU Common Fisheries Policy has established shared objectives, from economic activities to natural resource use and investments in research and innovation. Collaborative regional efforts such as the Nordic Blue Building Alliance are essential to address common challenges and protect shared resources, driving the growth of a sustainable blue economy.

This Technical Playbook on Marine Biobased Building Materials aims to overcome barriers due to lack of technical understanding amongst policymakers and planners. The playbook is designed as a technical and holistic guidance with the aim to provide practical guidance for policymakers and planners across the Nordic countries.

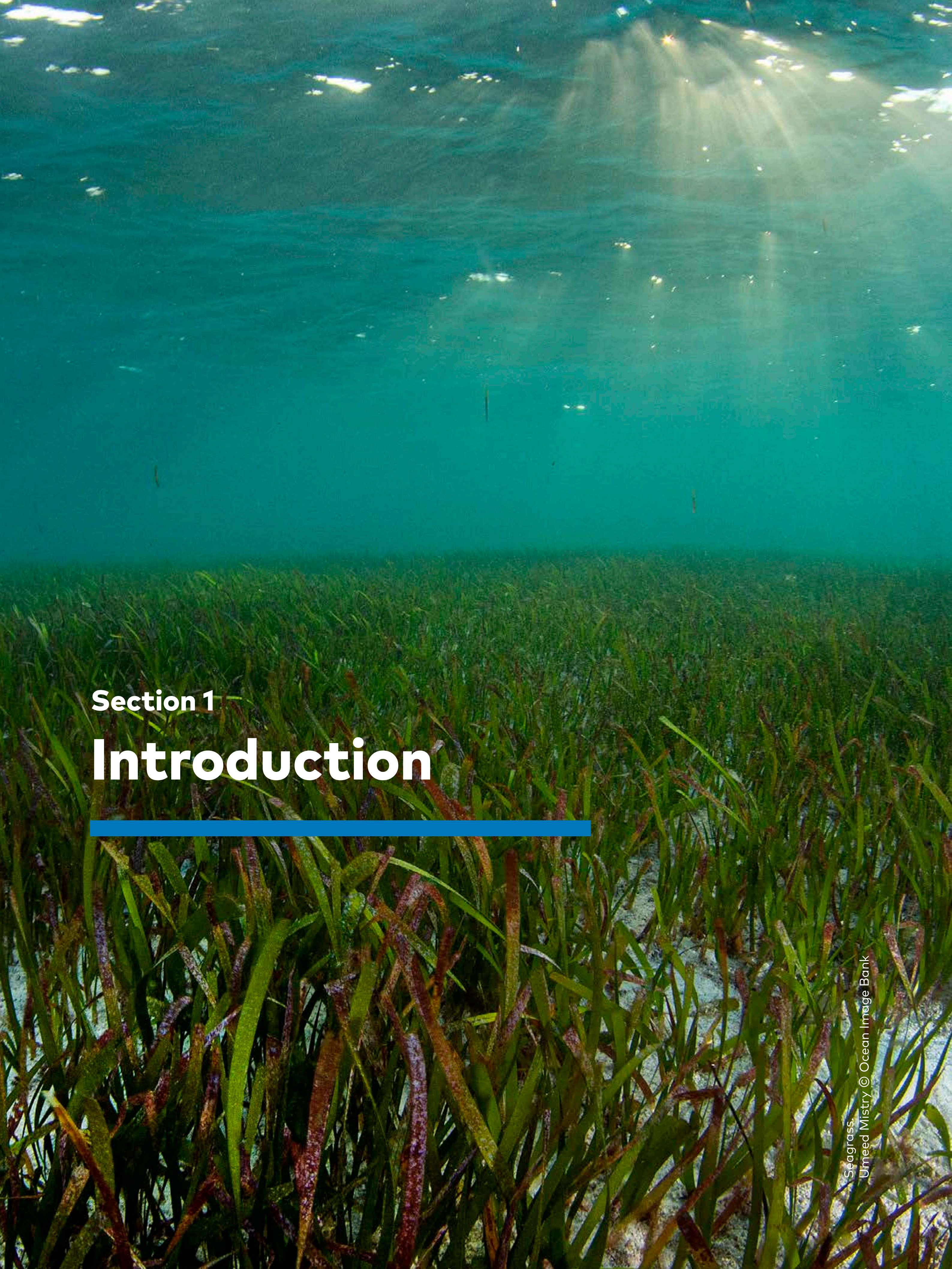
The playbook provides insight into available marine resources streams and marine-based biomaterials in the Nordic market, particularly their potential applications in the built environment. It also underscores key considerations for the large-scale integration of these materials into the construction industry, categorized into two sections.

The playbook is a combination of general and location specific guidance reflecting differences in product and material properties, market needs etc. and will provide a catalogue of practical options to upscale embodied marine based alternatives for conventional building materials. It is furthermore outlined to influence both the public sector through procurement and the private sector through incentives and planning.

In conclusion, the marine biobased materials sector in the Nordics represents a dynamic opportunity to drive rural economic, social, and environmental progress, acting as a bridge between the bioeconomy and the blue economy. It fosters sustainability and innovation in the construction industry, ultimately contributing to the region's and the world's long-term well-being.

Section 1

Introduction



Seagrass.
Umeed Mistry © Ocean Image Bank

1. Introduction

1.1 Background and Aims

The building and construction sector in 2021 accounted for over 34 % of energy demand and around 37% of energy and process-related CO2 according to the 2022 Global Status Report for Buildings and Construction published by the UN Environment Programme.

Out of which materials used in the construction of buildings (i.e., concrete, steel, aluminium, glass, and bricks) are estimated to represent around 9% of overall energy-related CO2 emissions. Furthermore, use of raw material is predicted to double by 2060.

To mitigate this impact, it is crucial to explore innovative and sustainable solutions. One promising way forward involves harnessing marine biobased resources and solutions. By incorporating materials derived from marine sources, such as algae, reed, chitin, seagrasses, into construction processes and project, we can not only reduce the carbon footprint but also capitalize on the regenerative capacity of marine ecosystems and the opportunities they offer if cultivated and harvested in a sustainable matter. This approach aligns with the broader pathway of sustainable construction, offering a tangible and environmentally conscious pathway towards a more resilient and low-carbon built environment.

The Nordic Blue Building Alliance

The Nordic Blue Building Alliance has been established as part of the project. The Alliance represents knowledge partners and stakeholders across the supply chain in the Nordics of the cultivating and harvesting of marine biomass to create products for the built environment.

Nordic Innovation has entered into a partnership with the Nordic Blue Building Alliance, led by Arup. The Alliance consists of various partners, encompassing private companies, universities, knowledge institutions, and city stakeholders - all aligned to transition and to strengthen the Nordics path, collaboration, and innovation on marine biobased building material in the region. Various partners in the Alliance have been engaged throughout the project and whose input has been used as part of developing this Technical Playbook.

A list of stakeholders engaged are presented on the Nordic map at page 3 of this report.

With this Technical Playbook, Arup are together with stakeholders from the Nordic region in the Nordic Blue Building Alliance, exploring:

1. the potential of developing high-value low carbon biomaterials from marine resources and marine waste streams
2. the environmental impacts of extracting these marine resources, and what we can do to preserve and restore our ocean.

This Technical Playbook explores marine waste and resource streams ranging from blue mussel shells and eelgrass to polysaccharide-based biomaterials such as chitin and chitosan which are marine-derived collagens and composites of different organisms of marine origin.

The diversity of marine products, their properties and applications are presented in the publication. Some of the materials and products are readily available and present low carbon alternatives that are biodegradable, moisture resistant, and have fire-resistant characteristics – however while the interest in alternative and low carbon building materials, the global market share is still a defined minority compared to conventional building materials. The Nordic Blue Building Alliance aim therefore, to give inspiration to the Nordic market stakeholders, and include references from around the world on how products and materials are being used for the construction industry.

Furthermore, this playbook aims to highlight that responsible cultivation and harvesting of marine resources is key for this industry to produce sustainable marine biobased materials. Responsible cultivation and harvesting could potentially also lead to improve the marine environment by:

- Create food and shelter for juvenile fish and other marine species.
- Develop local production and provide jobs in rural communities.
- Contribute to carbon uptake and provide oxygen within the marine and coastal ecosystem.

The project has been co-financed under the Nordic Sustainable Construction program which is one of the eight initiatives launched by the five Nordic Ministers of Trade and Industry for the period 2021-2024. The aim of the Sustainable Construction program is to make the Nordics a leading region in sustainable and competitive construction and housing with minimized environmental and climate impact.

1.2 Scope and Limitations

Nordic Innovation has co-financed the work to investigate the potential use of marine based construction materials in the built environment. This Technical Playbook has been developed to support policymakers, industry, and planners in assessing the potential of this and the barriers and opportunities within the marine and construction industry.

The Technical Playbook incorporates the findings from:

- Mapping of the marine building supply chain in the Nordics.
- Interviews and engagement activities carried out with key stakeholders along the supply chain, including UIA World Congress of Architects.
- Review of potential marine resources and commercially viable marine based biomaterials.
- Overview of the regulatory context in the Nordics
- Recommendations and opportunities for incorporating marine based biomaterials within the built environment.

It is important to highlight that:

- This Technical Playbook does not provide an exhaustive list of marine resources, biomaterials, or manufacturers currently available in market.
- Arup has not carried out technical due diligence of the products mentioned in the Technical Playbook.
- There is currently limited data available on the environmental impact of farming and extracting marine resources.
- For detailed procurement guidelines we refer to following EU Green Procurement Guidance. However, since there are limited products available in the market there are also very limited materials with EPDs.

1.3 Methodology

The aim has been to create an alliance that pools existing knowledge, identifies knowledge gaps and barriers, and consolidates the learnings in the form of a Technical Playbook. Furthermore, it has been important to engage stakeholders to both gather existing knowledge, as well as to mobilise the industry, push the sustainable agenda, and create new synergies between the NBBA stakeholders.

Approach

Our approach comprised of two phases:

1. **Inception:** We analysed the supply market for marine-based low carbon materials. Recognizing that stakeholders within the value chain might lack familiarity with viable alternatives or struggle to access information, we aimed to circumvent the status quo. By bridging this information gap, we intend to enable stakeholders to seize opportunities for reducing the impact of climate change and mitigating further impact.
2. **Discovery:** We explored guidelines and design specifications for marine resources and products. Design specifications, though non-binding, guided diverse teams of professionals engaged in building design and construction. By sharing local guidelines, we aimed to foster new markets and business models that favoured marine-based low carbon construction materials.

During the UIA World Congress of Architects 2023 in Copenhagen, two sessions were held to discuss Biobased Low Carbon Construction. The first session debated how upscaling of global marine resources is possible in a sustainable way. The second session included a panel debate and discussed the market barriers of accelerating use of marine bio-based building materials and how low carbon construction needs to invest more in alternative building materials. Various stakeholders in the Alliance and beyond were involved. These sessions delved into the outcomes of the Technical Playbook and explored the evolution of procurement to expedite the broader adoption of bio-based building materials, as well as explored the investment opportunities and challenges. The sessions targeted construction companies, architects, and investors, drawing from distinct user cases originating from various Nordic cities.

Section 2

Marine-based Biomaterials within the Nordic Built Environment

Seaweed and fish
© NN Norden

2. Marine-based Biomaterials within the Nordic Built Environment

The building and construction sector in 2021 accounted for over 34 % of energy demand and around 37% of energy and process-related CO2 according to the 2022 Global Status Report for Buildings and Construction published by the UN Environment Programme[23].

Greenhouse gas emissions from the construction industry arise from energy-intensive processes involved in manufacturing materials like cement and steel, as well as the operation of buildings and infrastructure. The building sector's substantial energy consumption puts pressure on finite resources and contributes to climate change. Moreover, the reliance on non-renewable resources, such as sand and natural stone, leads to resource depletion and habitat destruction. Construction and demolition waste also represent a significant portion of total construction waste generation, posing challenges in terms of proper disposal, recycle, reuse and management.

In response to these challenges, there has been an increasing emphasis on sustainable practices within the construction sector. One of the areas that is gaining significant momentum is the use of marine-based biomaterials. Although there are currently a limited number of commercially viable products in the market both Globally and in the Nordics, researchers and manufacturers are exploring a diverse range of marine-derived materials, including seagrass, seaweed, and waste products from the fishery and aquaculture industries, to develop bio-based construction materials. Innovative applications include using marine biopolymers as binding agents or additives in concrete and using marine fibres as cladding material or insulation. It is important to highlight that the environmental impact of materials and products are not simply defined by the type of material or where it comes from, but how they are used, how long they are used for, and what happens at the end of their useful life, these aspects must be considered when specifying and using any material or product.

The integration of marine biomaterials in construction is one of a range of potential measures of reducing the environmental impact associated with traditional construction materials when used responsibly. The growing interest in marine based biomaterials is in line with the growing ocean economy and the crucial role it plays in global trade, food production, job creation, and economic growth for many coastal and island nations, such as the Nordics. However, there are significant challenges in terms of sustainability and environmental impact, necessitating responsible and well-managed practices to ensure the long-term health and productivity of marine ecosystems.

Currently the Baltic Sea, a part of Kattegat and Danish fjords suffers from eutrophication and an oxygen depleted seabed, while the North-East Atlantic Ocean faces challenges from trawling. Furthermore, these areas are affected by pressure from commercial fishing on seafood stocks, increased litter and plastic pollution, shipping and leisure boating discharges, and ecological changes through climate change[24]. If developed responsibly, the production of marine biomaterials may offer opportunities for coastal protection and restoration projects, supporting sustainable infrastructure development and fostering a more environmentally conscious construction industry.

Seagrass
Umeed Mistry © Ocean Image Bank

Section 3

Regulations

Seagrass
Ben Jones © Ocean Image Bank

3. Regulations

> The biomaterials sector as well as the ocean economy have been identified by the Nordic Bioeconomy programme[25] as a priority area with significant growth potential, essential for reindustrialization and addressing societal challenges.

Marine based biomaterials fall at the interface of these two industries and offers new ways of producing and consuming resources while staying within planetary boundaries, making it a vital contributor to the economic, social, and environmental goals of the European Green Deal[26] and the EU strategy for a Sustainable Blue Economy[27].

Oceans by their very nature are both international and cross-sectoral. International agreements set common goals and objectives. Based on these agreements, laws and regulations are created that guide, for example, the economic activities, the use of natural resources, and investment in research and innovation. Addressing common challenges and protecting common goods through regional cooperation is key to support a sustainable blue economy.

In general, marine regulations can be divided into five categories:

1. Marine environment and marine natural resources (extraction of sand and gravel for the built environment)
2. Environmental load
3. Maritime and marine special planning
4. Marine traffic and civil engineering
5. Cultural heritage (due to marine and coastal protection and change of how the marine environment will or can be used)

This report will focus on the three most relevant to the marine based biomaterials industry.

Maritime and Marine Spatial Planning

The purpose of Maritime and Marine Spatial Planning (MSP) is to promote the sustainable development and growth of the various uses of the sea, such as energy production, maritime transport, fisheries and aquaculture, tourism, recreation, and the environment, as well as nature conservation. The EU Marine Spatial Planning (MSP) Directive[28] provides a framework for the coordinated and sustainable management of human activities in EU marine waters.

It is an essential tool to prevent conflict between policy priorities and to reconcile nature conservation with economic development, other related strategies include:

- EU Strategy for the Baltic Sea Region[29]
- North Sea Region 2030 Strategy[30]
- Environmental Impact Assessment [31]

Marine Environment and Marine Natural Resources

In accordance with the EU strategy for a Sustainable Blue Economy[32], biodiversity conservation and protection marine natural resources are foundational principles for maritime economic activity. Establishing ecological corridors can reverse biodiversity loss, contribute to climate mitigation and resilience and at the same time generate significant financial and social benefits. In line with the above and the EU Biodiversity Strategy for 2030[33], both the North Sea Region 2030 Strategy developed by the North Sea Commission and the EU Strategy for the Baltic Sea Region have made commitments to scale up marine protection and restore degraded ecosystems. Other strategies which build on the above include:

- EU Water Framework Directive[34]
- Environmental Impact Assessment[35]
- EU Habitat Directive[36]
- EU Common Fisheries Policy[37]
- EU Aquaculture Policy[38]
- EU Farm to Fork Strategy[39]
- Convention on the Protection of the Marine Environment of the Baltic Sea area (HELCOM)[40] and HELCOM Baltic Sea action plan[41]

Chitosan
David P. Robinson© Ocean Image Bank

It is essential that the production of marine-based biomaterials aligns with sustainable practices to help reverse the loss of biodiversity, while also contributing to climate mitigation and resilience. By prioritizing sustainability, we can ensure that our actions have a positive impact on the environment, working towards reversing the loss of biodiversity, and the communities that rely on it. Through responsible production methods, we can help to protect marine ecosystems and the species that inhabit them, while also reducing our carbon footprint and promoting long-term resilience in the face of climate change. It is important to recognize the interconnectedness of all living beings and prioritize sustainable practices that benefit both the economy and the environment.

Environmental Load

Seas and oceans are fragile and vulnerable ecosystems. Both the Baltic Sea and the North-East Atlantic Ocean are affected by human activity at sea, on land and along the coast. Pressures range from fisheries, aquaculture, shipping and oil and gas production to runoff of nutrients and other pollutants from onshore industry, agriculture and wastewater treatment, and marine litter. These lead to excessive nutrient loading and the eutrophication resulting from it.

The EU Strategy for the Baltic Sea Region adopted in 2009 include a clean Baltic Sea. The Baltic Sea countries have agreed on targets for reducing nutrient loads within the Framework of the Baltic Marine Environment Protection Commission, also known as the Helsinki Commission (HELCOM). Similarly North Sea Region 2030 Strategy aims to lower emissions and reduced disposal of waste into the North Sea, as well as implement clean marine transport and a sustainable supply-chain in fisheries and aquaculture. Beyond these, in the recent years these several principal policy decisions aimed at reducing human-caused nutrient loading and improving the state of the sea and oceans. These include:

- Zero Pollution Action Plan[42]
- EU Industrial Emission Directive[43] and Ambient Air Quality Directives (AAQD)[44]
- EU Nitrates Directive[45] and EU Sulphur Directive[46]
- EU Chemicals Strategy for Sustainability Towards a Toxic-free Environment[47]
- National Emission Ceilings Directive (NECD)[48]

Regulations at a Product Level

The Blue Economy represents an essential component of the European Green Deal activities in the regions and Member States by safeguarding healthy oceans, seas, and waters. The European Commission has a long-term strategy to support sustainable growth of the marine and maritime sectors applied to harness its untapped potential. Marine based biomaterials lie amongst this untapped potential. If sustainably managed throughout their life cycle, these may be one of the options within the palette of options necessary to support the decarbonization of the construction sector.

There are currently no specific regulations solely dedicated to marine-based biomaterials for construction. However, there are broader regulations and initiatives in place that govern the use of biomaterials and promote sustainable construction practices, these include:

- **European Construction Products Regulation (CPR)** which establishes harmonized rules for the marketing of construction products within the EU. It sets requirements for the performance, safety, and sustainability of construction products. Biomaterials derived from marine sources would need to comply with the relevant standards and testing procedures specified under the CPR.
- **The European Green Deal** which sets out a roadmap to make the EU's economy more sustainable and encourages the use of sustainable materials in construction, which could include marine-based biomaterials if they meet the necessary criteria.
- **Circular Economy Action Plan** sets forth an ambitious agenda for keeping materials and resources in the economy as long as possible and for minimising waste, thus increasing circularity. This plan encourages the use of renewable and bio-based materials in various sectors, including construction. Marine-based biomaterials that comply with circular economy principles may find support and recognition under this initiative.


Vadehavscentret
Dorte Mandrup © Adam Mørk

- **Green Public Procurement (GPP)** is a strategy that encourages public authorities in the EU to factor in environmental and sustainability considerations when acquiring goods and services. This approach has the potential to significantly boost the demand for marine biobased construction materials by incorporating specific requirements or preferences for these materials in public tenders. In a landmark move, the EU Commission ratified a robust provision for GPP in March 2023, underscoring its pivotal role in propelling the development and adoption of low-carbon construction materials. Despite its potential, GPP has been underutilized as a tool to drive low-carbon solutions, highlighting the need for its reinforcement in relevant legislation. Leveraging GPP can serve as a valuable instrument to seamlessly integrate and advance the use of marine biobased, circular, green, and sustainable materials on a regional scale and in significant quantities.

It is important to highlight that marine based biomaterials are at the forefront of innovation therefore public and private funding remain crucial, for less mature technologies and projects that need to bring in investors, bring down costs and uncertainties, and accelerate market entry. Initiatives such as Horizon Europe and the BlueInvest[49] which aims to foster investment, innovation and sustainable growth in the Blue Economy, play an important role in this transition by enabling coastal communities to rebuild or reshape their economies and become local drivers of sustainability.

Other dedicated initiatives such as the European Partnership for a climate neutral, sustainable and productive Blue Economy[50]; the blue bioeconomy and blue biotechnology; and EU Algae Initiative[51] [52] have a similar impact in fostering technological innovation, developing value chains, and building skill ecosystems to support a sustainable blue economy.

Section 4

The Technical Playbook – How to Use it

Green Algae © NN Norden

4. The Technical Playbook - How to use it

The following sections seeks to inform the reader on available marine resources and marine based biomaterials in the Nordic market that have potential applications within the built environment.

Furthermore, it highlights aspects that should be considered for the large-scale implementation of these in the construction industry.

This is divided into two sections:

Marine resources
Structured under the headings of description, potential use & readiness, regulations, and environmental impact.

Marine based biomaterials
Considers products under the following themes, description, technical performance; healthy and safe; responsible sourcing, circularity, and readiness.

The handbook can be used by various stakeholders providing valuable insights into available marine resources and marine-based biomaterials within the Nordic market:

- For procurement specialists, this resource offers a detailed overview of marine resources, including their description, potential use, readiness, regulations, and environmental impact. This information equips procurement specialists with the knowledge necessary to make informed decisions when sourcing materials for construction projects, considering both technical and environmental aspects.
- Contractors can benefit from this publication by gaining insights into the diverse marine-based biomaterials discussed under themes such as description, technical performance, health and safety considerations, responsible sourcing, circularity, and readiness. This knowledge empowers contractors to make sustainable choices in material selection, contributing to environmentally conscious construction practices.
- Planners can utilize the information provided on marine resources and biomaterials to incorporate innovative and sustainable solutions into their designs. Understanding the potential uses, regulatory considerations, and environmental impacts allows planners to align their projects with the principles of responsible and eco-friendly construction.

- Investors can leverage the insights in this publication to assess the viability and sustainability of projects. By considering the information on marine resources and biomaterials, investors can make informed decisions that align with the growing emphasis on environmentally responsible investments in the construction industry.

An overview of what is captured within these sections is described in turn in the following section.

4.1 Marine Resources

4.1.1 Description

The term marine resource is used in the context of this Technical Playbook to refer to biotic components of the marine environment. This includes both primary production of marine resources such as seaweed and the use of waste streams such as the use of mussel shells from the food industry. The source of the material is clearly described for each resource considered as well as the applicable implications this may have on potential products.

4.1.2 Potential Use

A nonexecutive list of the potential use of each marine resources is included in the Technical Playbook together with the relevant organisations exploring this space. It is important to note that this is a fast-changing industry therefore continuous monitoring of both manufacturers/ research institutions and available products is recommended.

Their readiness level of each potential use case is assessed based on the stage of development as described below:

- Research
- Pilot
- Commercially available

4.1.3 Regulations

The Nordic countries have a shared commitment to the sustainable use of marine resources. While each country has its own specific policies, they often align with international agreements and EU regulations. Where applicable, regulations regarding the harvesting, cultivating, or collecting marine resources have been summarised.

4.1.4 Environmental Impact

The sustainability of materials must be considered from a whole life-cycle perspective. Therefore, understanding the biotic origin of these and the environmental impact of growing, harvesting, and extracting these from their natural ecosystem is a key consideration as well as considerations about end-of-life impact e.g., is sequestered carbon released if material biodegrades or is put in landfill.

Beyond the impact of the materials on the planet, consideration must also be made on the impact of the people. Responsible sourcing is 'the management of sustainable development in the provision or procurement of a product'. This involves the incorporation of key ethical, sustainability, and social responsibility/value principles into the sourcing and procurement of materials and labour within the supply chain.

4.2 Marine Based Biomaterials

Marine based biomaterials refer to materials are made from substances derived from marine living organisms; the term is used to describe end products used within the built environment. A selection of Nordic marine based biomaterials is described in the Technical Playbook with their biotic origin and use.

The scale of production of marine based biomaterials in the Nordics is currently limited, in terms of the marine resources available at commercial scale, the local limitations, and the user demand. While there is an increasing interest and demand for alternative construction materials, the overall market share of this is still relatively small compared to conventional construction materials. A high-level overview of the scale of production has been provided for each product in the Nordic context.

While each material will be highlighted, a detailed description may not be available due to their new commercialisation. To ensure that procurement officials and project managers consider marine-based biomaterials, it is recommended to provide comprehensive information about these materials such as through the provision of Environmental Product Declarations (EPDs). For instance, in Denmark, the LCA requirements mandate that all new buildings constructed after 1 January 2023 must include LCA calculations. Additionally, buildings larger than 1000 m^2 are required to meet a threshold of 12 kg CO_2 equivalent per square metre per year. This consideration will be essential. By providing such information, procurement officials and project managers can make informed decisions about the procurement of marine-based biomaterials.

4.2.1 Technical Performance

A summary of the technical performance data for each product is added in products where it is provided.

Continuous monitoring of the development of products is advised due to ongoing fast-paced developments of these types of products.

Emphasizing the organic nature of biobased materials – whether derived from marine sources or others – it's crucial to note their inherent flammability. The regulatory framework surrounding combustible materials plays a pivotal role in shaping the practicality and suitability of utilizing biobased materials in the built environment.

Also, there is a lack of information in durability of the products. The durability of the marine biobased materials compared to conventional materials, must be transparent to ensure that the CO_2 emissions are comparable for the industry to make sustainable choices.

4.2.2 Healthy and Safe

As the built environment industry grows more conscious of its impact, there is an ever-growing scrutiny on the substances used in the supply chain of products and their impact on human health and wellbeing, as well as to environmental systems, from extraction through use and end of life.

In the European Union, legislation, and standards such as REACH, COSHH, ECHA, POPs and local building regulations establish the substances that are restricted in construction products. Compliance with these is highly dependent on the composition of products, where possible (based on data availability) these considerations have been included.

4.2.3 Responsible Sourcing

Beyond the impact of materials on our environmental health and wellbeing consideration must also be made on the impact of the people. Responsible sourcing is 'the management of sustainable development in the provision or procurement of a product'. This involves the incorporation of key ethical, sustainability, and social responsibility/value principles into the sourcing and procurement of materials and labour within the supply chain.

4.2.4 Circularity

The sustainability of materials must be considered from a whole life-cycle perspective. It considers the impact of the existence of the product on both people and the planet from production to its end of life. The 'cradle to gate' emissions consider the impacts associated with the production of a product or material that is ready to ship to the construction site, including raw materials extraction, transport during production, and manufacturing emissions. The transportation of materials to site, construction processes, use and operational carbon are not included.

It is generally accepted that bio-based materials are more sustainable than traditional materials, however the assessment of biogenic benefits is complicated. It must be noted that sequestered carbon needs to be managed at end-of-life. End-of-life options include reuse, recycling, biomass energy extraction through combustion or landfill. In the case of the material is sent to landfill or burned for energy, the sequestered CO_2 will be released and further GHG emissions may occur.

Section 5

Marine Resources

Nature Eelgrass © Søuld

5. Marine Resources

5.1 Seashells

Globally, over 10 million tons of shells are produced each year, of which over 70% are oyster, clam, scallop, and mussel shells.[53] In Denmark alone, towards the year 2050, there is potential to increase the aquaculture production of mussels from 275,000 to 400,000 tons per year, equivalent to 110,000 to 160,000 tons mussel shells per year.[54]

The seashell also has the ability to filter water and trap excess nutrients.[55] Small scale pilots have therefore been made in the Baltic Sea to filter the water due to eutrophication, the enrichment of ecosystem by nutrient, while also farming blue mussels and thereby increasing social value and economies in the region.[55] An aspect influencing its habitat besides eutrophication and its ability to grow its shell is affected by ocean acidification, which is when carbon pollution is absorbed by the ocean and the ocean becomes more acidic.[56]

Seashells produced today are mostly considered waste, however it is a valuable resource due its concentration of calcium carbonate ($CaCO_3$) that is one of the most highly exploited resources globally.[57] This Technical Playbook will take point of view in seashells coming from waste streams as potential materials for construction.

$CaCO_3$, in the form of limestone, is commonly used in the production of building materials, such as concrete, asphalts and mortars but also used as gypsum boards and similar products used in the building and construction sector. By sourcing CaCO3 through seashells, there may be a reduction in mining (and its associated transportation) for limestone.[57]


Mussles © Magda Ehlers

For the Nordics, the following seashells have been found relevant for use in the construction industry:

- **The Blue mussel** (mytilus edulis) also known as the common mussel. The shells make up to 40 % of the mussel weight and have traditionally been seen as waste product, deposited back into the ocean or landfill.
- **The Zebra mussel** (Dreissena polymorpha) is an invasive species in the Baltic Sea in the eastern Gulf of Finland, but also present in other Scandinavian countries.
- **Icelandic scallop** (Chlamys islandica) was fished in the Breiðafjörður bay (mainly) to some extent from 1969 to 2002 when it collapsed due to high scallop mortality, but in recent years infection levels have been low and muscle condition good.
- **Oysters:** Two variations are relevant in the Nordics; the native European oyster and the non-native Pacific oyster, where the faster growing Pacific oyster has established self-sustaining populations. The species is considered alien and invasive and dense populations may cause changes in benthic habitats.

Potential Uses

Current research suggests that the waste streams of seashells, due to its high concentration of calcium carbonate, could be used in the construction industry as or in:

Potential Use	Readiness Level
Thermal insulation (e.g., Ecoshelp[60])	**Pilot**
Road fill and on riding arenas/playgrounds (due to its noise absorbing potential when mixed) (e.g., DanShells[61])	**Commercially available**
Purification media in water traps (research by Aalborg University, Technical University of Denmark, Danish Technological Institute & Orbicon A/S[62])	**Research**
Tiles (e.g., Local Works Studio[63], Bureau de Change architects via method developed by Lulu Harrison (Glass tiles from waste mussel[64]).	**Pilot**
Source of calcium carbonate for cement production (e.g., by Aalborg Portland[65])	**Commercially available**

Regulation

The **Blue mussels** in the Baltic Sea are perceived to be essential, because they are thought to filter the amount of water corresponding to the entire mass of the Baltic Sea every year.[66] Therefore, HELCOM is tracking the blue mussels (as well as other marine species) in the Baltic Sea, because the Baltic Sea is highly threatened by eutrophication.[67]

Both the Pacific oyster and Zebra mussel is considered invasive and alien and are therefore included on the Nordic countries' lists of alien species (EU regulation No. 1143/2014 on prevention and management of introduction and spread of invasive alien species provides a common European framework for the mitigation of alien, invasive species). In Norway, eradication campaigns are used to remove Pacific oysters from public beaches and protected marine areas, and the harvested ones are composted or used as agriculture fertilizer. As such, when not used for food, they must comply with the relevant EU legislation (regulations 1069/2009 and 142/2011).[68]

For the **Icelandic Scallops,** that are mainly present in Iceland, in the Breiðafjörður area (second biggest bay in Iceland), which is a nature reserve, UNESCO World Heritage and therefore protected under the Breiðafjörður Conservation Act no. 54/1995. Since a large part of the harvesting in Iceland takes part within the area, it means that the operators must comply with strict requirements.[69] However, as this Technical Playbook takes point of departure in using the scallops from waste streams after human consumption, we won't list the specific details of such.

Thomas Glass © Bureau de Change Architects

Waste-based tiles made with oyster shells. © Local Works

Environmental Impact

Usage of the seashells is recommended only in the form of waste-product, and as such, transparency in the value chain is crucial, so that the harvested and chosen seashells are from a responsible sourced methods e.g., MSC-certified, however attention must still be paid to the high-impact fishing methods like bottom trawls and dredges that some MSC-certified fisheries still use.[70]

Blue Mussels are traditionally harvested by bottom trawls, fishing liner/net and aquaculture.

- There are several environmental risks (and associated economic/societal risks) associated with the harvesting of blue mussels. One major risk is the potential impact on the environment and other marine organisms as they play a key role in the habitat due its role of filtrating water.
- The Baltic Sea is one of the most polluted waterbodies in the world[71], and efforts have been made with blue mussels to remove nutrients from the sea, because they filter large of amount of water for feeding[72]. A study from the Baltic Sea Centre in 201873 concludes that the potential to use blue mussel farming as a nutrient abatement measure in the Baltic Sea needs to account for the low salinity and for the risk for environmental effects of large-scale farming. Furthermore, it estimates that the efficiency of nitrogen uptake per unit of farming area and time could be 10 times lower in the Baltic Sea compared to blue mussel farms located in regions with greater salinity.
- In Finland, blue mussels can be found mainly in southwestern coastline of Finland, where the water salinity does not fall below the 5 ‰ limit required for mussels to survive. Blue mussels are no longer found in the almost fresh waters of the Bay of Bothnia, and their population has also decreased in the inner reaches of the eastern Gulf of Finland, where the zebra mussel has taken over.[74]

Since the **oysters,** the pacific oyster, are perceived as alien in the Nordics, the environmental impact of harvesting these has not been considered beyond the EU legislation.

For the **Zebra mussel,** since it is an aquatic invasive species, a permit is required for the legal collection, transportation, and the legal holding and experimentation of Zebra Mussel shells. The number of permits and the length of them vary per country. These have not been considered as part of this study.

In terms of circularity, by reusing and recycling seashells instead of disposing them in landfills, we can significantly reduce the number of raw materials needed (substituting other more carbon intensive materials) and thereby lower the associated costs and promoting a more circular economy. The monetary value depends on its application as listed in the potential usage chapter. However, it represents a valid alternative material suitable for building applications. The circularity impact of using it also reduces mining and extractions from the earth, as well as the emissions related to it. The ultimate reusability depends on what the seashells are used to create (e.g., concrete, tiles, insulation), and if it is mixed with other materials as a composite material.

5.2 Algae and Seaweed – Macro and Micro Algae

Description

Macroalgae, (hereafter referred to as seaweed), refers to thousands of species of macroscopic, multicellular, marine algae. Approximately 33 million tons of seaweed is produced globally primarily for food and feed, as well as cosmetics and pharmaceuticals. In the Nordic Atlantic and Baltic region, there is interest in the exploitation of seaweed through harvesting of living biomass and beach cast as well as via seaweed farming, although the poor conditions of the Baltic Sea presented earlier presents suboptimal growth conditions for most species.

According to a 2022 study, the Nordic Blue Carbon Ecosystems have been evaluated in terms of their status and prospects. The study found that Norway has the highest number of seaweed farms, with over 27 in existence, and is expected to have the greatest potential for macroalgal cultivation inshore and offshore. Predictions indicate that Norway's macroalgal cultivation could reach 4 million metric tons annually by 2030 and 20 million metric tons annually by 2050. While Denmark, Faroe Island, Greenland, Iceland, and Sweden have also made efforts towards microalgal cultivation, their focus has been less commercially oriented, resulting in fewer farms - 6 in Denmark, 2 in Faroe Island, and 1 in each of Greenland, Iceland, and Sweden. In Denmark, there is a small production of sugar kelp on lines, while other species, such as bladderwrack, are harvested from the wild[77].

Brown algae © NN - Norden.org

Green algae © Stefan Andrews via Ocean Image

Brown algae © NN - Norden.orgBank

Macroalgae are divided into three main groups:

- **Brown algae,** for example sugar kelp, and bladderwrack
- **Green algae,** there are more than 7000 species of green algae - most are aquatic, but found in a variety of habitats including soils, tree bark, snow, and in symbiotic relationships with a variety of organisms ranging from fungi to animals[78]
- **Red algae** are widely used for agarose a gel widely used in cosmetics and pharmaceuticals as stabilizer. Gelidium and Gracilaria are the dominant industrial seaweeds for cosmetics and pharmaceuticals.[79] **Calcified seaweed** (Lithothamnion) is also a type of red seaweed; it is harvested at one location in the Westfjord area in Iceland and it is mainly used for food and feed.

Microalgae on the other hand are unicellular photosynthetic micro-organisms, living in saline or freshwater environments, converting sunlight, water, and carbon dioxide to biomass.[80]

Potential Uses

As the potential uses and level of readiness for macroalgae and microalgae differ, we will in the following section divide them into two:

Macroalgae

The production of seaweed is expected to grow globally primarily for food and feed consumption, as it is expected to play a crucial role in counteracting the urgent challenges the agricultural sector faces including ensuring global food security and reducing its environmental impact.

A study by Seaweed for Europe[81] shows the economic potential of an expanded seaweed market in Europe could be worth €9 billion in just a decade. The report also finds that the European seaweed industry could create up to 115,000 jobs in Europe by 2030 and deliver significant environmental and health benefits. However, it is important to highlight that seaweed is a high-value product, finding prominent applications in the food and pharmaceutical industries. Consequently, its potential utilization in the construction industry may be constrained, given the industry's historical reliance on low-cost materials. Compounding this challenge is the fact that seaweed comprises approximately 80% water, requiring vast quantities of raw material for the construction of products at a sizable scale.

Beyond the critical role seaweed plays in the production of food and feed, seaweed fibres may also have interesting applications in the construction industry as a composite material or as a binder in cementitious materials. Seaweed is also being tested as a raw material to produce bioplastics and other sustainable packaging[82] alternatives.

Seaweed/algae potential within the construction industry is therefore in:

Potential Use	Readiness Level
Additive in concrete (e.g., "Predicted Response" research project by Royal Danish Academy, CITA, the Department of Chemical Engineering (DTU) and University of Reading (UR) combining additive manufacturing and cellulose-reinforced biopolymers as a building material and Artificial Intelligence (AI) for creating predictive models for unpredictable material practices in architecture[83])	**Research**
Bioplastic (e.g., Interesting Times Gang[84], Notpla[85])	**Commercially available**
Bio textile (e.g., Sea Leather[86])	**Pilot**
Bricks (e.g., SeaBrick[87])	**Pilot**
Dyes (e.g., Living Ink[88])	**Commercially available**

Sea Leather © Gianluca Manago in Collaboration with IKEA Sweden

Sea Leather © Gianluca Manago in Collaboration with IKEA Sweden

Like other plants, seaweed, absorbs CO_2 and nutrients during growth. This sequestered CO_2, also referred to as biogenic carbon, is then trapped in the material when it is harvested, therefore the production of seaweed can be done with a negative carbon and nutrient footprint. Read more about these considerations under the environmental impacts of algae and seaweed.

Seaweed is regarded as a high-value product for both the pharmaceutical and food industry, which can make it expensive to use in other applications such as construction. Additionally, the amount of seaweed needed to make construction products can be quite large, which can result in a significant amount of waste. However, despite these challenges, there are many potential benefits to using seaweed in construction, such as listed above. As research and development in this area continues, it is possible that these challenges can be overcome, and seaweed can become a more widely used and sustainable material in the construction industry.

Microalgae

Microalgae again is primarily used for food and feed consumption and cosmetics, and the use of microalgae in the built environment is still very niche. In the Nordics and globally, Nordic Microalgae[90], a network by the Swedish Meteorological and Hydrological Institute (SMHI), a service part of the Swedish Biodiversity Data Infrastructure (SBDI), currently counts for 4486 species.

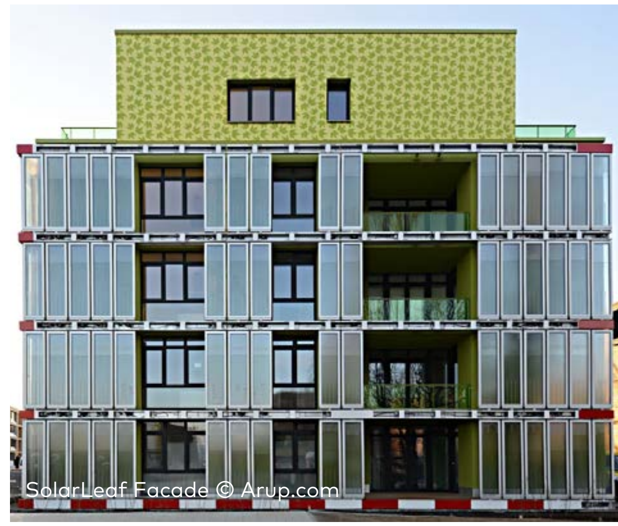
Microalgae are very robust and stress tolerant as it grown all year round, in all temperatures, grows well also in brackish water, and it has a high growth rate. As such, it gives the potential production of it a high productivity rate, which ensures quick generation of desired products and more importantly cause higher capacity and rate of CO_2 fixation.[91]

Microalgae has in particular raised interest of researchers and biotechnological industries due to its ability to function in bioenergy with carbon capture and storage (BECCS) processes, and their ability to produce different high-value compounds.[92] A study from 2023[93] showed that certain microalgae in the Nordics has a high stress tolerance despite the change in daylight and water temperatures – especially the species Chlorococcum sp. (MC1) and Scenedesmus sp. (B2–2) - they produced the most biomass and bioactive compounds and can potentially be cultivated in large-scale processes in a Nordic environment.[93]

In Iceland, microalgae production has grown considerably in the past ten years, with plans to scale in the near term, with estimated growth from 0.1kT output in 2021 towards 0.5-6kT in 2032 due to its growing advantages and existing infrastructure. However, taking point of departure in it still primarily being produced as feed, food, pharmaceuticals, and cosmetics. Despite this, Iceland sees great potential in it bringing both additional capital and job creation to the country.[94]

For the construction industry, two innovative ways of utilizing its characteristics as described above is to use it as:

Potential Use	Readiness Level
Algae based cement E.g., Prometheus Materials[95], a company based in the US, have a bio-cement by combining microalgae with water, exposing it to sunlight, and CO_2. The process is like how corals build reefs and oysters.[96]	**Pilot**
Bio reactive façade system E.g., SolarLeaf is the world's first bio-reactive façade developed through a collaborative effort by Strategic Science Consult of Germany (SSC), Colt International, and Arup. The façade generates renewable energy from algal biomass and solar thermal heat and can be implemented in both new and existing buildings. The energy produced by the façade, including the biomass and heat, is transferred through a closed loop system to the building's energy management center. The biomass is harvested through floatation and the heat is obtained via a heat exchanger. Because the system is fully integrated with the building services, excess heat from the PBRs can be utilized to provide hot water or heat to the building or can be stored for future use.[97]	**Pilot**


SolarLeaf Facade © Arup.com


Segmented Wall Unit Solution © Prometheus Materials

Regulations

In general, our interviews and surveys indicate that there is a current regulatory gap for algae aquaculture. As it has primarily been used for food, feed, pharmaceuticals it is regulated as such. Therefore, references in the interviews are made towards general harvesting, licensing of areas to grow and harvest and of restoring and regenerating those areas to decrease its potential negative environmental impact on biodiversity. Furthermore, a study made on algae production in Northern Europe (2022)[98] also shows that micro- and macroalgae biomass production is generally regulated by environmental and/or water laws, lacking a specific regulatory framework and considered, in most cases, as water operation.[98] Table below shows the various macroalgae-related activities, permits, laws, and authorities involved in the licensing process in chosen Nordic countries: Finland, Sweden, Iceland, Norway (adopted by[98]). The same study also shows that companies demand a specific macroalgae regulatory framework.

Country	Cultivation or Harvesting	Activity	Permits	Regulation	Authorities
Finland	Cultivation	Water resource management issue	Water and environmental permit	Water Act Environmental Act	Centre for Economic, Development, Transport, and Environment (ELY) Regional State Administrative Agency (AVI)
Sweden	Cultivation	Water operation	Water permit (>0.3ha)	Environmental Code Act 1998/812	Land and Environmental Court County Administrative Board
Iceland	Harvesting	Acquisition of seaweed for commercial purposes	Contract from landowner	Regulation no 90/2018	Directorate of Fisheries
Norway	Harvesting	Management of wild living marine resources Harvesting of seaweed and sea tangle	Harvesting permit	Marine Resources Act FOR-2004-11-26-1526 FOR-2018-09-10-1310 FOR-2019-09-26-1274	Directorate of Fisheries
Norway	Cultivation	Production of aquatic organisms	Fishing, water, discharge, and seaweed permits Environmental assessment for >10hr	Aquaculture Act FOR-2004-12-22-1799 Pollution Control Act	State Administrator Directorate of Fisheries Coastal Administration

Table Macroalgae-related activities, permits, laws, and authorities involved in the licensing process in chosen Nordic countries: Finland, Sweden, Iceland, Norway (adopted by Camenera-Goméz (2022)[98]). (Marine license includes project description, mitigation plan and application fee. Aquaculture lease includes business plan, marine license, and the project description).

Together with the lack of legislation follows a lack of investment. A survey conducted in the Nordic and Baltic regions by the "The State and Future of Aquaculture in Iceland" found that applications for a seaweed cultivation license took anywhere from 9 months to 5 years due to a lack of clarity on seaweed specific legislation. Consequently, this might be slowing investment and development of the sector. Iceland currently does not regulate commercial macroalgae cultivation specifically, but recently, Norway, Faroe Islands, and Denmark, have adopted seaweed specific licensing frameworks to increase clarity and speed up processes for approvals.[99]

For microalgae, that are primarily used in the food sector, no specific regulatory framework in the EU nor the Nordics apply. Operators are subject to general food operations regulations including land permit, regular health and safety checks and contracts with municipal utility provider for water/energy. For Iceland specifically, a clear framework for tracking output volumes is suggested to better understand the market and how the government can better support.[100]

However, various national and European vision and strategy documents, as highlighted in the chapter on "Regulations", indicates that countries are starting to consider how we should regulate the marine space due to high interest in bioeconomy. Regarding micro- and macroalgae which is the most mature market of the marine resources mentioned in this Technical Playbook (not necessarily in the construction industry), table below (adapted by Camenera-Goméz (2022)[98]) shows how the marine resources are considered in the various countries' visions and strategies. In these, its potential applications beyond food, feed, fertilizer etc., is shown in it being mentioned as potential in blue biotechnology, energy production, raw materials, or aquaculture.

Country	Marine Management plans	Marine strategies	Microalgae included
Finland	*Maritime Spatial Plan 2030	National Aquaculture Strategy 2022 *Finish Bioeconomy Strategy	*Potential in blue biotechnology (Vision 2030) *Potential in energy production
Sweden	*Marine Spatial Plans for Gulf of Bothnia, Baltic Sea, and North Sea	*Maritime Strategy National Food Strategy	*Macro- and microalgae, potential in food production and fertilizer. Potential as eutrophication remediation *Macro- and microalgae, potential in aquaculture activity
Iceland	In process: Marine spatial		Not included
Norway	Integrated Marine Management Plans for Barents Sea, Norwegian Sea, and North Sea and Skagerrak	Strategy for an Environmentally Sustainable Norwegian Aquaculture Industry 2009	Not included

Table: Marine management plans and marine strategies across examples of Nordic countries (Finland, Sweden, Iceland, Norway). Third column shows whether macroalgae is mentioned in either/both (adapted by Camenera-Goméz (2022)[98])

Environmental Impact

Overall, the environmental impact of growing and harvesting algae has shown via our research and interviews to be a less explored space. The sector is therefore limited by the collection of reliable and accessible data on different algal strains, processing methods, and their potential. As such, the environmental impact in the following chapter is therefore scattered in terms of giving concluding recommendations.

Our research and interviews suggest that the environmental impact depends on the phase of the cultivation and processing and/or in which environments it is, as well as the potential multipurpose of the application – e.g., carbon capture, cleaning of oceans in the Baltic Sea, restoring ecosystems beyond cultivation and harvesting purposes. As well as for all resources, the environmental impact of materials made from algae also depends on the further pre-processing and production. When evaluating the environmental impact of seaweed products, it is crucial to consider the methods employed in their production and harvesting, as these factors significantly contribute to the overall carbon footprint. Additionally, the processing of seaweed materials plays a pivotal role in determining their environmental sustainability. It's important to recognize that carbon dioxide (CO_2) sequestered within seaweed may potentially be released at the end of the product's life, contingent upon the disposal methods used.[101]

Overall, the study from 2022 in the status and outlook for the Nordic concludes that macroalgal farming and cultivation could potentially benefit wild macroalgal forests by leading to reduced harvest of

Oysters
© ONN Norden

wild macroalgae. Also, the farming may have associated ecosystem benefits including uptake of excess nutrients and supporting carbon sequestration and reduced emissions - this is if farming follows sustainability standards for both the methodology of cultivating - avoiding negative effects on the habitat, and standards and practices connected to carbon accounting and offsetting. However, this is lacking at the moment, and it requires careful documentation.[102]

The cultivation and processing can roughly by divided into the following:

1. Apply for license to cultivate.
2. Planting and cultivating
3. Harvesting
4. Restoring and regenerating those areas to decrease its potential negative environmental impact on biodiversity.
5. Processing into material

Seaweed can be obtained through either farming or wild harvesting, with farming increasingly becoming the preferred method in Europe. Despite the need for additional infrastructure, seaweed farming has great potential to be scaled sustainably. The study carried out in 2022[102] on Nordic Blue Carbon Ecosystems, highlights that if commercial demand increases in the future, and more efficient harvesting equipment is developed, marine habitats and ecosystems may be severely impacted without further legislation.

Norway is the biggest macroalgae cultivator in the Nordics, while it is sought to harvest sustainably, some companies trawl the seabed. This negatively impacts the environment and makes it hard to restore and regenerate the original ecosystem. The Norwegian coast is divided into harvesting zones by latitude minutes (1 nautical mile), and each zone is open for harvest every 5-6 years to allow for regrowth, however with no regulatory upper limit on biomass harvest, each zone can theoretically be depleted every 5 years.[102]

On the contrary, in Iceland, the harvest of macroalgae is mainly confined to Breiðafjörður, where The Marine & Freshwater Research Institute has advised that the annual harvest 2018-2022 of A. nodosum in Breiðafjörður should not exceed 40,000 metric tons, or around 3% annually of estimated rockweed biomass in the area.[102] This is of course also linked to the fact that the Breiðafjörður fjord is an UNESCO heritage area, and conservation of the area is prioritized.

In terms of circularity, two main challenges are regarding composites and the recyclability, and the other being biodegradability of bioplastics being a wide spectrum. The choice of biopolymer blend including any fillers and additives is key to ensuring that products manufactured achieve the intended low impact outcome. As well as influencing the environmental profile of a product, the selection of feedstock will also influence the processing procedures required and the resultant technical properties of the product.

Threats to macroalgae is mainly removal of anchoring stones, aggressive fishery practices, and destructive grazing by sea urchins, which often requires establishment of new reefs. Various successful examples of restoration of macroalgae across the world are:

- The Blue Reef project[103] in the Kattegat resulted in a manual on best practices and has inspired additional projects in Danish coastal waters (e.g., in Als Fjord and Limfjorden, and planned projects).
- Restoration of macroalgae along the Norwegian coast due to lost sea urchins has led to a strategy on how to recover kelp ecosystems from urchin barrens, where "Green gravel" (i.e., small rocks seeded with kelp) has recently been applied to restore sugar kelp.
- In Iceland, calcified seaweed harvesting is only harvested when dead, however the renewal time is long (most likely a few centuries). But because the species can only grow at appropriate depths which is influenced by the level of sunlight reaching them, harvesting from dead top layers, may create favourable conditions again. However, due to the long renewal time, harvesting sustainably may be a critical issue.[104]

For inspiration, projects to restore and preserve ocean habitats and macroalgae have been made internationally which may inspire the Nordic countries to take similar action. These examples include:

- Across Europe, the MERCES project has restored macroalgal habitats due to a holistic approach to the overall habitat – and not only treating the symptoms but the root causes of the habitat degradation. This included for example active intervention in sea urchin removal for the fish populations to continue the controlling the sea urchin populations.[105]
- Internationally, Japan has the longest experience on macroalgal restoration where they have been successful in including fishermen in the process. Actions include for example removal of sea urchins and transplantation of kelp.[106]
- Regarding the political landscape, the European Commission took a significant step in 2022 by introducing a communication on a policy framework for biobased, biodegradable, and compostable plastics. This framework holds relevance for products derived from algae-based bioplastics.
The Commission emphasizes the importance of considering the entire life cycle of biobased plastics, aiming for environmental benefits that go beyond reducing fossil resource consumption. This resonates with the approach taken in the algae industry, which entails assessing the complete lifecycle of algae production to ensure minimal environmental impact during harvest and encourages the application of regenerative measures at harvesting locations.[107]

5.3 Chitosan and Chitin

Description

Chitosan and its parent compound chitin are commercially available products (chitosan and chitin are therefore both referred to in this Playbook as potential usage for the built environment). Currently, sources of chitosan used for industrial application is mainly from crustaceans (especially crab, prawns and shrimp shells and snails), whose exoskeletons are available as waste from the food processing industry. Sources of chitin, the parent compound of chitosan is present in many more organisms such as[108]:

- Exoskeletons of the crustaceans (e.g., lobster, shrimps, krill, barnacles, crayfish etc.)
- Molluscs (e.g., octopus, cuttlefish, clams, oysters, squids, snails), algae (for example, diatoms, brown algae, green algae)
- Insects (e.g.,housefly, silkworms, ants, cockroaches, spiders, beetles, brachiopods, scorpions)
- Cell wall of fungi (e.g., Ascomycetes, Basidiomycetes, and Phycomycetes for example, Aspergillus niger, Mucor rouxii, Penicillium notatum, Trichoderma reesi cell walls)

Chitosan is therefore the second most abundant chemical compound after cellulose, and widely used in areas such as agriculture, water treatment, food preservation, packaging, and cosmetics. In construction, it has received attention as a functional non-toxic, antimicrobial, biocompatible and biodegradable biopolymer useable in biomaterials.[110]

Chitosan
David P Robinson © Ocean Image

Chitosan
Michiel Va © Ocean Image Bank

In the Nordics, there are two main producers of chitosan and chitin products, mainly for medicine, being NovaMatrix (Norway), and Primex (Icelandic). Across Europe, Germany has two producers (Heppe and Heppe Medical Chitosan GmbH), and from France there is France Chitin.[111]

Potential Uses

Chitosan is considered a rich resource expected to replace other traditional materials due to its versatility, abundance, and interesting properties of being a biopolymer. Chitosan has numerous valuable applications in various fields, particularly in wastewater treatment, where it is used for absorbing pollutants. Additionally, it can be utilized as a chelation agent, an antiviral agent, or a substitute material in the paper industry.[112]

The source of chitosan has been found for the relevance of the built environment as:

Potential Use	Readiness Level
Binder in bio-based insulation material (e.g., French National Research Agency)[113]	**Research**
Biopolymer-cement composites (e.g., Department of Chemistry and Soil Science, University of Navarra, Spain[114])	**Research**
Bioplastic components (e.g., McGill University Montreal[116])	**Research**
Fire retardant (e.g., Tidal Vision[116])	**Commercialy Available**
Chitosan-based membranes for water treatment in production of materials (made of biogenic materials or other materials[117])	**Pilot**

Regulations

To ensure responsible sourcing and harvesting of chitosan, it is important to follow fishing regulations and management practices that are in place for fishing crustaceans such as shrimps. These regulations can help protect crustaceans and ensure that they are farmed and fished in a sustainable manner. By adhering to these laws and standards, we can help safeguard the future of our oceans and the creatures that inhabit them. These regulations are highly variable between countries.

- In Sweden, through the Ordinance on Fishing, Aquaculture and Fishing Industry (SFS 1994:1716) it is prohibited to fish thick-shelled freshwater mussels and ramshorn snails, as they are protected throughout the country in accordance with the species protection ordinance.[118]
- In Iceland, for Primex the fishing of shrimps is regulated by Statement on Responsible Fisheries in Iceland (from 2007) with newly released standard 'Responsible Fisheries Management Standard' – a tool for voluntary use in markets for products of marine capture fisheries which can be accredited with the certification.[119] Furthermore, Primex states to work according to Hazards Analysis Critical Control Point Program (HACCP) to assure product safety and quality in the production of chitosan powder and chitosan derivatives. Again, this is in relation to the fishing of shrimps.
- In Norway, Articsource1 sources shrimps from Northeast Atlantic Ocean and produces chitosan powder for cosmetics in Norway – and are certified by the Marine Stewardship Council (MSC) and regulated by the Norwegian authorities. Again, due to consumption and application of these, the production and cleanliness of chitosan needs to follow strict regulation.

See more about these fishing regulations in chapter 3.

Various bodies also support responsible sourcing of chitosan e.g. The European Chitin Society (EUCHIS) which is a non-profit organisation which objectives are to encourage basic and applied scientific studies of all aspects of chitosan, including chitosan and derivatives of chitin, and related enzymes.[120] Due to the fishing heritage of Iceland, they will host The 14th International Conference of the European Chitin Society (EUCHIS 2023) and the 15th International Conference on Chitin and Chitosan (15th ICCC) will be held in Iceland.[120]

Environmental Impact

From being the second abundant biopolymer in nature, chitosan has the potential for being a future sustainable construction material.[121] However, chitosan production has a notable negative environmental impact, particularly related to water consumption and emissions. To address this, a focus on developing fractionation methods is crucial, aimed at separating chitin and other valuable compounds with reduced reliance on corrosive or hazardous substances. Establishing a scalable processing line for fisheries waste akin to wood biomass processing is essential.[122]

While striving for zero-waste processes is an ideal goal, it's important to recognize that all production has some environmental impact due to raw materials, energy usage, and emissions. Hence, a "closed loop" approach to chitosan production is to be preferred, as this approach enhances process quality, facilitates recycling, and resource recovery. Transforming former waste (fishing industry residues) into valuable chitosan resources and water treatment technology is a sustainable path worth pursuing in the fishing industry.[122]

Beyond the environmental impact of the processes and application of chitosan, what also needs to be considered is the raw material sourcing. Utilizing waste streams rather than harvesting crustaceans exclusively for chitosan production is a more sustainable approach. Nevertheless, there is a need to establish regulations concerning waste streams to ensure adherence to sustainable fishing practices.[122]

5.4 Seagrass and Eelgrass

Description

Seagrasses are marine flowering plants that can form underwater meadows. Seagrass species come in different shapes and sizes. The largest number of seagrasses are found in northern Europe as well as on the coasts of the Americas, Australia, and the Mediterranean Sea.

There are 72 species of seagrasses that are commonly divided into four main groups:

- Zosteraceae (e.g., eelgrass), the most predominant species in the Nordics
- Hydrocharitaceae
- Posidoniaceae
- Cymodoceaceae

Seagrass
by Dimitris Poursanidis © Ocean Image Bank

Seagrass © Ben Jones, Ocean Image Bank

Seagrass
by Ben Jones © Ocean Image Bank

Seagrass
by Michiel Vos © Ocean Image Bank

Seagrass
by Ben Jones © Ocean Image Bank

Eelgrass grows in the sea at depths down to 5-10 m, and the long leaves of eelgrass are washed up on land, continuously shed, wash ashore, and accumulate on beaches around the coasts especially in Denmark and especially on Bogø, Tærø and Møn. The washed-up material on those islands is relatively clean and easier to use in materials compared to the usual mix of sand and seaweed found in normal washed-up material. Seagrass is harvested directly from the beach and laid out to dry. When the water content of the material is below 15-20%, the eelgrass is pressed into round bales that are stored under a roof until further processing.[123]

In the Nordics, as reported by a study by Boström et al. in 2014, eelgrass meadows have been declining. The study states that to define the eelgrass habitat and protect it, it fundamental to develop complete and high-quality eelgrass distribution maps. Today this is still lacking, and the level of completeness is variable across most regions of the Nordics.[124]

Potential Uses

For many years, eelgrass has been used in vernacular architecture, for example as cladding as seen in the island of Læsø in Denmark[1]. In the Nordics, eelgrass is usually harvested using natural harvesting methods. It is collected on the beach, dried on the meadows, and transported short distances to the factory. Eelgrass is usually used for:

Potential Use	Readiness Level
Acoustic insulation (e.g., Søuld[125])	**Commercially Available**
Thatched roofs (e.g., Møn Tang[126])	**Commercially Available**
Filler materials for mattresses (e.g., Møn Tang[126])	**Commercially Available**
Cladding (e.g., Møn Tang[126])	**Commercially Available**
Thermal insulation (e.g., Møn Tang provides various insulation products[126])	**Commercially Available**
Walls (e.g., Søuld) and ceilings (e.g., Søuld[128])	**Commercially Available**

Regulations

In a study conducted by Norderhaug et al. in 2021, the status and outlook for Nordic Blue Carbon Ecosystems were examined. This research comes in response to the recent decline of eelgrass meadows. Subsequently, several policy initiatives and regulations have been established to safeguard and rejuvenate seagrass habitats, which are detailed below. [129]

- HELCOM highlights the need for protecting eelgrass habitats (and several macroalgal habitats) in the Baltic Sea due to eutrophication and anchoring.[130] The Baltic Sea Action Plan (2021) by the Helsinki Commission (HELCOM) monitors the Baltic Sea, but with no legal implications.[129]

- Eelgrass beds is on the OSPAR's (Convention for the Protection of the Marine Environment of the North-East Atlantic) list of threatened species and is also on OSPAR Recommendation 2012/4 to further protect and conserve eelgrass beds (OSPAR 12/22/1, Annex 13). This is relevant for North-East Atlantic and Greenland, who is also part of the OSPAR.[129]
- Multiple working groups within the Arctic Council collaborate on marine activities focused on safeguarding eelgrass and, to some extent, addressing Nordic habitats. These working groups consist of participants from various regions, including Denmark, Greenland, Faroe Islands, Iceland, Norway, Sweden, and Finland. Examples of groups involved are the "Arctic Monitoring and Assessment Program", "Protection of the Arctic Marine Environment", and the "Biodiversity Working Group of the Arctic Council", which includes the Conservation of Arctic Flora and Fauna (CAFF) and their Circumpolar Biodiversity Monitoring Programs (CMBP) dedicated to coastal and marine ecosystems.[129]
- EU member states report on marine habitat types as part of the EU Habitats Directive, but these habitat types are defined based on geomorphology rather than targeting specific vegetated habitats like eelgrass. As a result, there is no specific monitoring requirement for eelgrass under the EU Habitats Directive.[129]

Acoustic mats
by Søuld © Søuld

Isolation
by Møn Tang © Møn Tang

Environmental Impact

Seagrass has a great value to the marine environment and local communities. Seagrass meadows produce oxygen, absorb carbon dioxide, provide sustenance and shelter for various marine organisms, and significantly contribute to the global marine food chain. Seagrass meadows play an important role in protecting our coastal areas from erosion, storms and floods as they absorb the impact of waves.

However, seagrasses are declining due to threats with agricultural and industrial run-off, coastal development, and climate change as well as unregulated fishing activities, anchoring, tramping, and dredging. Conservation efforts are therefore made by the United Nations Environment Program, The World Seagrass Association and more.[131]

Monitoring and mapping seagrass and eelgrass is being done across the world by various networks such as Seagrass Watch, Global Seagrass Monitoring Network (SeagrassNet), Global Ocean Observing System (GOOS) and Marine Biodiversity Observation Network (MBON).[132]

For eelgrass, in countries surrounded by the Baltic Sea, eelgrass production is in decline threatened by eutrophication, rising temperatures and disturbances on the seabed. In Denmark, large-scale losses have been recorded since the 1900s, and in west Sweden since the mid-1980s. This decline makes the eelgrass meadows among one of the most threatened marine ecosystems on the planet.[133]

Restoration efforts have been made across the Nordic region with learnings from international experience. The most successful one involves eelgrass transplants rather than seeds.[134]

An example of a successful restoration is by the University of Southern Denmark, the Department of Biology, in Denmark, where the researchers transplanted 14,400 small new eelgrass shoots into Horsens Fjord, and after two years, the plant density grew to 70 times higher and the fields with transplants have extended by approx. 30 percent.[135] The general learnings across these projects are[136]:

1. Careful site selection so that restoration takes place where eelgrass used to grow and where habitat requirements are presently fulfilled.
2. Sufficient spatial scale of the restoration to increase the chance of building resilience in the new patches.
3. Sufficient time perspective for monitoring the effects of the restoration across years.

It is important to highlight that, once the seagrass plants have been damaged for example by raw material extraction, anchors, or nets, it can take many years for the seagrass beds to recover – and in some cases destroy the habitat due to lack of oxygen.[137] Some seagrass beds are now protected, and some countries have regulations on the harvesting of seagrass.

In terms of circularity, seagrass and eelgrass can be shredded or blended at its end of life for use in different products, and secondary applications of these grasses should be sought to prevent release of biogenic carbon for example avoid burning as it will release the biogenic carbon.

5.5 Reed

Description

Reed is a common name for several tall, grass-like plants that grown in salt marshes, around lakes, swamps, and other water canals. Salt marshes are common habitats, which are located along sheltered soft bottom shores and contain a diversity of habitats from full marine tidal areas dominated by typical tidal marsh to brackish microtidal regions. The salt marshes function as a sponge for sediments from the land and agriculture, making it an essential habitat especially after the increase of eutrophication in the oceans caused by agricultural practices.

Historical European building traditions involve reed. Reed has been widely used in vernacular building traditions worldwide for centuries. However, like several other historical building traditions, the use of reed in construction is disappearing in many parts of the world, also due to lack of monitoring and preservation of it (see more in chapter around environmental and regulation).[139]

Potential Uses

An interest in reed is being revitalised with modern construction techniques.

Potential Use	Readiness Level
Historically, reed has been used for thatching roofs.	**Commercially Available**
Cladding and insulation (e.g., mycelium composite biobased insulation[140], Sundby School by Henning Larsen with a thatched facade made entirely of reeds, learnings by Henning Larsen on working with reed , and Vadehavscenteret by Dorte Mandrup[143]).	**Pilot**
Substrate for mycelium to grow in, creating e.g., acoustic panels. Though mycelium is the main material, the substrate is essential to the growth of the mycelium (e.g., The Growing Pavilion[114]).	**Pilot**


Reed
© Oleksandr P

Reed can be, if used and managed correctly, considered to be a carbon-neutral and a carbon dioxide sink material, if managed appropriately at its end-of-life. For reed to have no environmental impact in the use for the construction industry, it needs to be dismantled and reused after construction. Consequently, if we burn it, we release the biogenic carbon, and thereby it loses its carbon-neutral stamp of approval.

It is a non-toxic material, easy to handle making it a flexible material easily used in construction. The high content of lignin and cellulose, as well as the salt and mineral content present in reed make it a durable material. Furthermore, as it contains high carbon/nitrogen ratio and silica content microorganisms break down reed at a slower rate.

Some reed varieties can reach an average height of 2,5 meters, it has a low water absorption and dries out quickly after rainfall (though reed from fresh water sources tend to be more durable and water resistant), hence reed has been used widely for thatched roofs.

As an example, in Denmark, there's 11 reed harvesting companies, harvesting approximately 100,000 bundles of reed each year, ending in 350.000 m2 of roof thatched each year in Denmark, with an average use of 8 bundles per m^2. This gives an annual spending of 2,8 million bundles (in reed and straw). However, only 15% of the reed used for thatching in Denmark is sourced locally. Around half of the reed is imported from China.


Vadehavscenteret
by Dorthe Mandrup © Adam Mørk


Vadehavscenteret
by Dorthe Mandrup © Adam Mørk


House under the reed
© torange.biz

Regulations

To elaborate on the regulations of reed, we need to broaden the scope and context reed is in, namely salt marshes. Due to various names for salt marshes and their heterogenous species and habitats make it challenging to get an overview across the Nordic countries, and even more complicated because of the various national and international classification systems such as:

- the European Nature Information System (EUNIS) in the EU
- the Nature in Norway (NiN) system in Norway
- HELCOM for the Baltic Sea.

Various regulation and programs are requiring mapping salt marshes and hence, reed:

- For the NATURE 2000 network in the EU, the Nordic EU member states are required to map salt marshes.
- Across Europe, the Atlantic coastal meadows are categorized as vulnerable in the European Red List of Habitats.
- The EU project "NordSalt"[145]((2021-2024) will explore information on salt marshes in the Nordic region.

Mapping as part of national programs across the Nordic countries is also taking place, however, this is not systematic and not following the same classification and methodology. As such, mapping salt marshes and reed is not extensive enough. For example, in Greenland, Faroe Islands, and Iceland, there is very little to no monitoring, overview of area distribution or changes in distribution of salt marshes. In Norway, some mapping efforts have been completed (in connection to mapping RAMSAR areas), but there is no systematic mapping program. Denmark, Finland, and Sweden are the countries with the most mapping and systematic mapping due to EU habitat representations, so in Denmark and Sweden, it is systematically being synthesized and published every six years – in Sweden by the Swedish Species Information Centre, Art Databanken, and in Denmark through the NOVANA program.[129]

Environmental Impact

Harvesting of reeds in wetland areas can have various environmental impacts on oceans and coastal ecosystems:[146,147,148]

1. **Invertebrate Communities:** Reed harvesting can significantly affect invertebrate communities in reed bed habitats. The study found that the biomass and diversity of ground-dwelling and aerial invertebrates varied across reed bed ages. Young reed beds supported higher invertebrate biomass, while older reed beds had greater biodiversity.
2. **Biodiversity:** Reed management practices, including harvesting, burning, mowing, and grazing, were found to modify the structure of re-growing reed stands. Short-term harvesting had no significant impact on invertebrates, while long-term management reduced invertebrate abundance. Reed harvesting and burning were associated with reduced numbers of butterflies, beetles, and spiders. This can affect the overall biodiversity of reed bed ecosystems.

3. **Greenhouse Gas Emissions:** Reed harvesting influenced soil characteristics and greenhouse gas emissions. It led to a decrease in soil organic carbon and total nitrogen. The emissions of nitrous oxide (N2O) and methane (CH4) decreased after reed harvesting, while carbon dioxide (CO2) emissions were less affected. Temperature was a significant factor influencing CO2 and N2O emissions.

4. **Microbial Response:** Metagenomic analysis indicated changes in the abundance of functional genes related to greenhouse gas sources and sinks after reed harvesting. This suggests alterations in microbial communities that can impact the wetland ecosystem.

These findings emphasize that reed harvesting can have complex and varied environmental consequences, affecting invertebrate communities, biodiversity, and greenhouse gas emissions in wetland areas. Careful management and understanding of the impacts are essential when considering reed harvesting practices in coastal regions.

The EU Habitat Directive grants salt marshes a higher level of protection compared to broader habitat categories, such as eelgrass meadows and kelp forests.[149] Similarly, the Finnish Nature Conservation Act safeguards coastal meadows, while Icelandic laws extend protection to mudflats, eelgrass, and salt marshes.[150]

To preserve salt marshes, various strategies are employed, including controlled grazing and hay harvesting to prevent overgrowth and shading by tall vegetation like reeds. In Denmark, approximately two-thirds of mapped salt marshes are managed using these methods. In Finland, the abandonment of traditional agriculture has posed a threat to boreal coastal meadows, but recent management efforts have successfully increased the salt marsh area. This progress is supported by initiatives like the LIFE CoastNet project.[151]

Restoring former salt marshes often involves removing structures like dikes to restore natural hydrology, a practice known as "managed coastal realignment". Examples of successful implementation can be found in the Baltic Sea region and Denmark. It is crucial to address public perceptions and engage in effective communication since salt marshes may have mixed public reception, and there is a prevalent reliance on engineering solutions. Denmark's plans include the conversion of lowlands into wet marshlands to mitigate CO2 emissions from agriculture, with a focus on fostering reed growth through periodic flooding.[152]

Section 6

Marine biomaterial products

Nature Eelgrass © Søuld

6. Marine biomaterial products

This section will offer the reader an overview of marine bio-based products available for construction in the Nordics. Given the novelty of this field, there are few products readily available for sale in the market. Consequently, this overview will encompass both ongoing innovations and products currently under development. This approach aims to shed light on the range of offerings the marine bio-based materials industry will potentially provide in the future. It's important to acknowledge that the extent of information may vary based on the available data for products still in the developmental phase.

6.1 Søuld: Acoustic Mats and Boards Made from Eelgrass

Søuld ("Seawool"), is a Danish manufacture of acoustic mats and boards made from eelgrass. Eelgrass reproduces itself annually in the sea, washes ashore without any human intervention. Søuld in collaboration with Danish farmers collects the eelgrass which washes ashore, and this forms the base of its product. The dried and shredded eelgrass fibers are the impregnated with a natural, non-toxic flame retardant and mixed with a binder specially designed for cellulose fibers and recyclability. The blended fibers are then formed into eelgrass batts and then compressed into matts.

Acoustic mats © Søuld

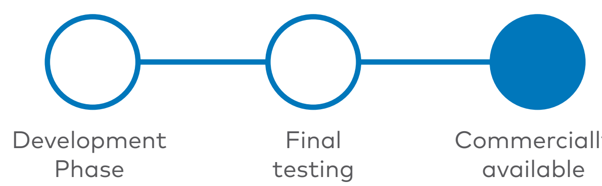
Acoustic mats © Søuld

Søuld's products are manufactured without noxious chemicals and do not release harmful substances into the indoor environment. Furthermore, the products are designed for circularity. When they reach their end-of-life, they can be returned to the factory, re-shredded and either blended into standard products or used to create a base for second-generation Søuld materials.

Products are CE marked in accordance with EAD 040005-00-1201 for factory-made thermal and/or acoustic insulation products made of vegetable or animal fibers. Søuld has obtained Gold Certified & Material Health Platinum Cradle to Cradle Certification and comply with the Danish Indoor Climate Label requirements.[153]

Acoustic mats © Søuld

Thickness	Boards:18mm, Mats: 35mm
Bulk Density	Boards:260 kg/m3, Mats: 1318 mm - Boards:18mm, Mats: 35mm3 kg/m^3
Reaction To Fire	Boards: D-s1,d2, Mats: C-s1,d1
Sound Absorption Coefficient α:	Boards: Class C, Mats: Class B (MH)
GWP (kg-CO2-eq/m^2): BIOGENIC CARBON:	-1,8 kg CO2-eq/m2. (A1-A3)



6.2 Møn Tang: Insulation and roofing material from eelgrass

Møn Tang, a distinguished Danish company, has positioned itself as a pioneer in the realm of eelgrass utilization, showcasing a specialization in this natural resource. Their product range includes insulation and roofing materials, each derived from the eelgrass.

At the core of Møn Tang's operations lies a commitment to sustainability and environmental responsibility. Eelgrass, harvested from various beaches across Denmark, becomes the focal point of their innovative processes. The harvested eelgrass is carefully laid out, allowing rain to rinse and cleanse the material, while wind and sunlight collaborate to dry and prepare it for its multitude of applications, particularly in the construction industry.[153]

Bulk Density	55-60 kg/m^3
Reaction To Fire	B2
Thermal Conductivity: W/Mk Thermal Resistance Rd: M²K/W	0.4 W/m2 K at 13cm thick-ness 0.0463 W/(m*K) at 40kg/m^3

Development Phase — Final testing — Commercially available (current stage: Commercially available)

The Modern Seaweed House by Vandkunsten @ Helene Høyer Mikkelsen

Insulation from Møn Tang © Møn Tang

6.3 Thatched Roofs from Reed

Many Nordic enterprises are specialized in the realm of thatching, with a keen focus on utilizing reed as a primary material. Their product line features roofing solutions crafted from this natural resource.

The harvested reed undergoes treatment, where it is properly dried and prepared to bring out its inherent durability and strength. These reed-based roofing materials embodies balance between traditional handcrafting and contemporary sustainability.

Due to the products fire hazard, it is beneficial to treat the reeds with a fireproofing coating. When treating reef with coatings it should be taken into consideration how it affects the end-of-life and thereby the overall impact of the product. If thatched roofs from reed are maintained well, it will have a technical lifetime of 50 years.[154]

Technical information is provided from EDP made for Thomas Guld Aps.[155]

Vadehavscentret, Dorte Mandrup
© Adam Mørk

Vadehavscentret, Dorte Mandrup
© Adam Mørk

Thickness	1 m^3
Bulk Density	93,7 kg/m^3
GWP (kg-CO_2-eq/m²): BIOGENIC CARBON:	-1,8 kg CO2-eq/m2. (A1-A3) -1,82E+02 kg CO2-eq/m2. (A1-A3) 8,67E-01 kg CO2-eq/m2. (C2) 8,64E+01 kg CO2-eq/m2. (C3) 46,9 Kg C /m^3

6.4 Interesting Times Gang: Bioplastic from Sugar Kelp and Oyster Shells

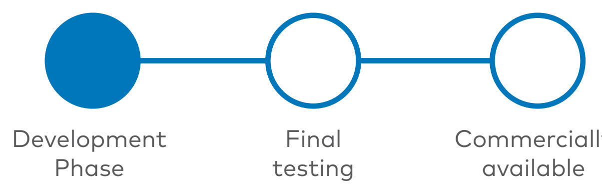
Interesting Times Gang, a Swedish design firm based in Stockholm creates biophilic concepts, products, and experiences, made from recycled sources and renewable biomaterials. They are the lead partner of the bioplastic project funded by Nordic Innovation. Together with a comprehensive consortium across the Nordics, including OBOS, Nordic SeaFarm, MS Donna, Ocean Forest / Lerøy Seafood Group, Material Factor, Bioextrax and Studio Kathryn Larsen, Interesting Times Gang is creating a biomaterial from Nordic Sugar Kelp and Pacific Oyster Shells.[156]

The project uses sugar kelp fibres and crushed pacific oyster shells as fillers and additives to polyhydroxyalkanoates (PHA). PHA is a biodegradable and compostable polyester produced naturally by microorganisms, such as bacteria, in response to nutrient imbalances.

The biopolymer blend produced is a versatile polymer that can be customized to exhibit various physical and chemical attributes, adaptable to specific applications. It can be transformed into diverse forms including films, fibres, filaments, and injection-moulded products. The project explores if this may be a viable alternative to traditional petroleum-based plastics across a broad spectrum of industries.

As the product is currently under development, no technical data is currently available.

Prototype of bioplastic developed by Interesting Times Gang in corporation with OBOS, Nordic SeaFarm, MS Donna, Ocean Forest, Material Factor, Bioextrax, Studio Kathryn Larsen



6.5 ReefCircular: Bioconcrete Made from Waste Oyster Shells

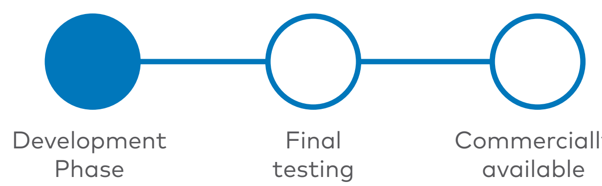
ReefCircular, a Danish start-up based in Copenhagen, has developed a no-heat bioconcrete exclusively derived of marine biomass which the company aims to use to 3D print bespoke artificial reefs to restore ecosystems previously damaged due to human activity.

Bioconcrete, a construction material under development, is crafted entirely from marine biomass, prominently featuring oyster shells and a binder derived from marine sources. Shells are currently sourced from local restaurants and fisheries, and integrated into the production of the bioconcrete, a high value material, aligning with the principles of circular economy.

Bioconcrete developed by ReefCircular, unlike traditional concrete, does not require high temperatures for cement production. This leads to a reduction of CO_2 in the production phase distinguishing it from conventional concrete alternatives and avoid CO_2 process emissions from the calcination process.

ReefCircular are still in the development phase of bioconcrete, however, they aim to begin testing the technical performance of the product in late 2023. The product developed has the potential to ensure the safety of its application in the marine environments (as it is exclusive derived of marine biomass) but also underscores its minimal impact on ecosystems beyond the ocean.[157]

Bio concrete
by ReefCircular @ ReefCircular



6.6 Mounid: Microalgae-Based Ink for Textile Dyeing

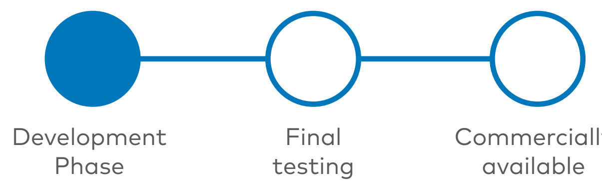
The startup company Mounid develops algae ink as a sustainable alternative to conventional dye for the textile industry, which is relevant for especially interior fit-out for the built environment and especially for the retail industry. Using algae ink contributes to phasing out the environmentally and health-damaging pigments and microplastic particles that are currently used in the industry. The algae ink is non-toxic, however health risks associated with the use of this products has not currently been assessed in accordance with REACH, SVHCs, PoPs and ODPs.

The ink is made of color pigments that are extracted and processed from microalgae. Generally, algae are better than land-based plant colors at generating biomass and storing carbon dioxide.

The project's model means that water and energy consumption can be reduced by up to 90 percent and carbon dioxide emissions in the same order of magnitude compared to conventional dyeing.

The use of algae in textile dyeing enables the creation of non-toxic designs from the outset and promotes the production of circular end-products. Mounid is collaborating with textile companies to develop algae ink for textiles, driving the transition towards a more sustainable and circular textile industry while reducing its climate impact.[158]

Algae ink
by Mounid @ Mounid



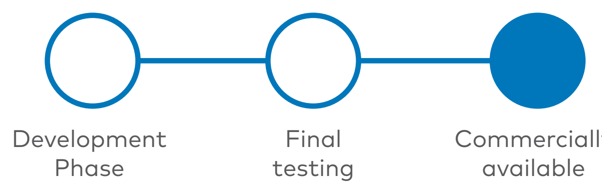
6.7 DanShells: Mussel Shells

DanShells, is a Danish company, which supplies whole and crushed mussel shells. Mussel shells are used as an enriching additive for poultry feed due to their high calcium concentration, as a biological filter to remove unpleasant odours from run-off water from farms or for landscaping in parks and gardens as an alternative for gravel.

DanShells offers a slab sand with ultra-fine particles, measuring less than 1 mm, and a beautiful grayish-white hue. This sand is a by-product, free from additives. It serves as a choice for filling gaps between slabs, effectively preventing weed and algae growth. DanShells' slab sand is also suitable for slab installation and paving renovation projects. In summary, it's fine and clean, making it a practical option for various landscaping needs.[159]

The shells are collected on the west coast of Norway in the North Sea and around the Faroe Islands in the North Atlantic. They also buy empty shells from Danish mussel farms. The shells are driven on a conveyor belt into a drum oven, which has an entrance temperature of between 450 and 800 degrees, for drying. Discussion are ongoing how to use renewable energy during the drying process. Outside again, the 60-degree hot shells are crushed, sorted, and stored.[160]

Shell supplier DanShells
@ Danshells



Section 7

Recommendations and Opportunities

Seagrass
Michiel Vos © Ocean Image Bank

7. Recommendations and Opportunities

In culmination of our research, including a series of engaging interviews, workshops, and debates with stakeholders across the Nordics, this Technical Playbook offers a thorough examination of the domain of marine biobased materials. Our primary objective was to reveal the opportunities and challenges that define this landscape while developing a deep appreciation for the complexities involved in harvesting, cultivating, and crafting these materials and products.

Through this exploration, it is evident that biobased materials hold a central position in advancing sustainability, particularly within the construction industry. In a time where sustainable practices are vital for reducing the carbon footprint and work within planetary boundaries, these materials emerge as a powerful solution to meet the growing demand for environmentally responsible construction and solutions to reduce to embodied carbon of the construction industry.

In line with the Nordic countries commitment to environmental protection, the publication presents a series of recommendations that provide pathways for enhancing the adoption of marine biobased materials within the construction sector. These recommendations have been made to ensure minimal harm to the environment while maximizing the positive impacts of these materials. They embody the principles of the circular economy, embracing a holistic view of sustainability and aligning with our collective responsibility for a regenerative future.

These recommendations, collectively, offer a comprehensive framework for navigating the integration of marine biobased materials into the construction industry while safeguarding our natural environment. In adhering to these principles, we can pave the way for a more sustainable and resilient future in construction practices.

Monitoring, Preservation, and Utilization of Marine Resources

What has been highlighted throughout this Technical Playbook as well as by our Nordic stakeholders is the need to map and monitor the resources and the health of the marine ecosystem and its impact on various habitats. Across the different marine resources described, there is an overall decline due to global warming, eutrophication, fishing activities and human interaction. There is to some extent an overall focus on restoring and preserving the marine and the various species, however due to a lack of impactful regulation, the monitoring and preservation activities are moving slowly compared to the high and accelerating focus on the Blue Economy.

Preserving and restoring coastal vegetation systems (e.g., tidal marshes, mangroves, seagrasses), oceans (e.g., seabed, water quality, anchoring stones) as well as the agricultural restoration can contribute considerably to the European Green Deal's decarbonisation and biodiversity targets. Restoring oceans requires a holistic approach and include both attention to oceans as well as land/coastal areas. This includes restoring important sea-bed habitats (coral reefs, macro-algal forests, and others), designing artificial reefs, and developing solutions to depollute areas or fight eutrophication, key to rebuilding biodiversity and thus the resilience of coastal and marine ecosystems.[161] Blue biotechnologies offer solutions to solving some of these restoring activities such as ReefCircular (see chapter 6.5).

Another aspect of monitoring the resources is to understand the availability of raw materials and thereby finding out what the investment potential should be to transform the resources into construction materials.

To minimize environmental impact, it is recommended to use waste streams that are not currently being used instead of virgin resources. However, if using virgin resources has an overall positive impact on the environment and marine life, it can be considered as a lower carbon option. It's important to ensure that the waste streams used are from sustainable practices to address the root cause of the problem. This approach is highlighted throughout the Technical Playbook.

Collaboration to Support a Sustainable Acceleration of Marine Biobased Materials

After conducting thorough research and interviews, it is highly recommended to establish collaborative partnerships like the Nordic Blue Building Alliance with industry and other stakeholders to develop clear frameworks and work to create physical pilots in the build environment that address the environmental impacts of marine biobased materials and minimizes negative effects on the environment.[162] By doing so, we create an environment that not only enables capacity expansion but also supports the coexistence of various activities within the ocean ecosystem, while simultaneously facilitating seamless integration with other ocean uses.

Investing in robust knowledge and data for large-scale marine biobased product production is crucial for transformative shifts in the Nordics. This initiative can unlock insights, driving innovation and effectiveness throughout our system, influencing both immediate and long-term financial landscapes.

Multiple stakeholders in the Nordic Blue Building Alliance have expressed interested to actively test some of the product identified in this catalog in specific pilots or demonstrations projects and jointly develop a step-by-step guide or roadmap for implementation of marine biobased building materials in the Nordic.

Economic Growth Decoupled from Resource Use

The marine habitat poses a unique challenge when it comes to assigning a specific monetary value to it. Among the most risked ecosystems are our oceans. In the future, ownership of materials is likely to shift towards a collective model rather than an individual one.

As highlighted by the panel debates during the UIA World Congress of Architects 2023, a novel economic paradigm is imperative, one that takes point of departure in material depletion – a concern that the pathways outlined in this Technical Playbook could unconsciously lead to. To avert this, it becomes paramount to steer the focus towards environmental restoration and not only mitigation. These measures are fundamental to safeguarding our marine resources from depletion.

The experts on the panel recommended a change in perspective: evaluating worth based on more than just financial gain. Therefore, our strategy for rejuvenating the oceans by using marine biobased materials requires us to move away from the traditional import/export system. We need to move beyond the limited view of materials and resources as either one or the other. Instead, we must begin our journey within a system and economy that values the sharing and exchange of information and knowledge – a structure that is fundamentally different from profit-driven models.

In this context, the true essence of value resides not within the raw materials themselves, but within the wealth of information and knowledge they encapsulate, and how this will entail enabling coastal communities to rebuild or reshape their economic sustainability drivers creating local jobs and creating healthier living marine environments. It is through this approach that we can unlock the full potential of these marine resources and ensure a brighter future for all.

It is also emphasized the importance of having an ecosystem-based approach, underscoring the interconnectedness of the ocean with various facets of our environment. This perspective implies that we cannot view the ocean in isolation; rather, we must approach it holistically within our planetary system. Therefore, when engaging in the harvesting and utilization of marine biobased materials, it becomes imperative to concurrently address and contemplate agricultural issues. By integrating these concerns, we can ensure a more comprehensive and sustainable strategy.

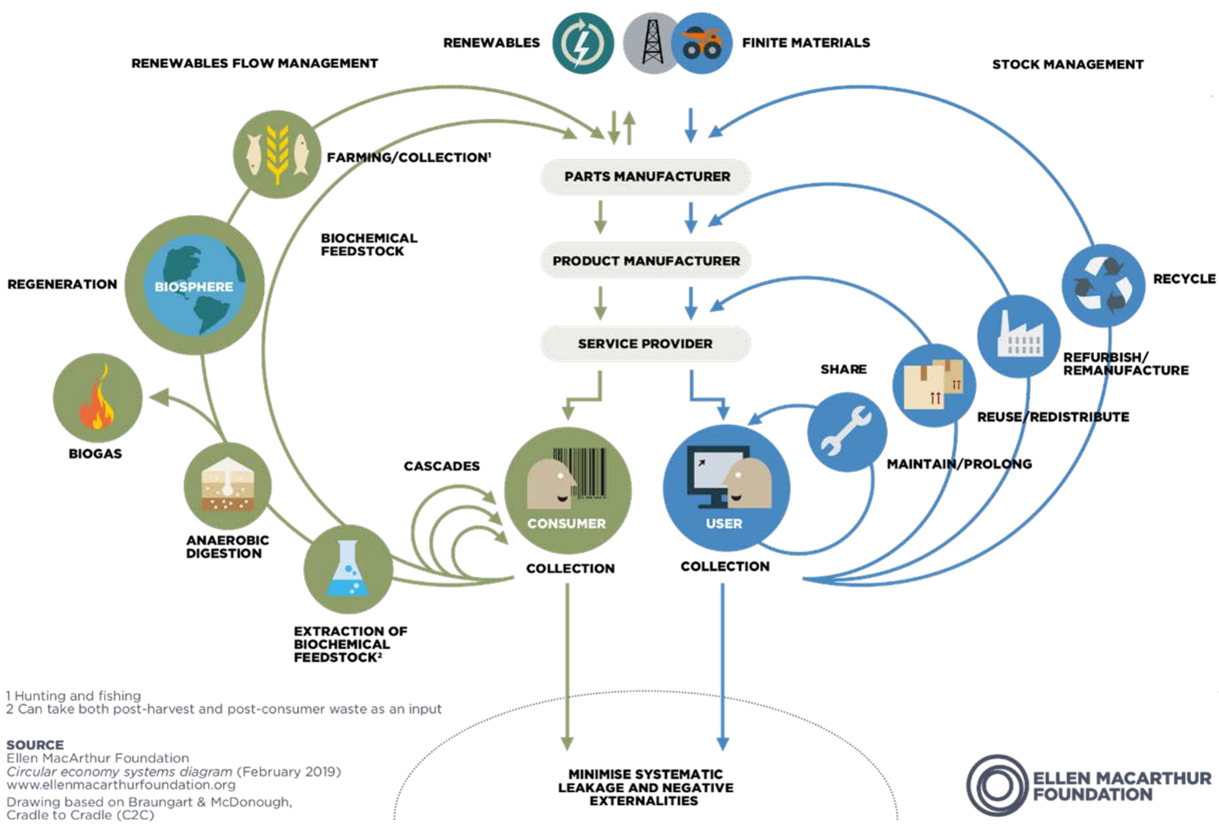
Towards a Circular Design approach and Fostering a Culture of Material Consciousness

It is important to highlight the fundamental design principles that underpin the Circular Economy: To eliminate waste and pollution, to circulate products and materials (at their highest value), and to regenerate nature. These principles remain vital in our pursuit of minimizing embedded carbon. To mitigate the depletion of our planet's resources, we must embrace a transformation by trusting emerging materials and reshaping our current design norms. It is crucial that we recognize the accelerating impact that our current materials have on our planet and take proactive steps towards a sustainable future.

Many biobased materials are composites (non-biobased binder and biobased material) which makes it difficult to separate and recycle. Biogenic material can therefore lose its economic, circular value if it is not treated and considered in the 'technical cycle loops' such as extending life, reusing, and recycling. Therefore, it is critical for extending the materials life, that it can be disassembled with ease or is made as a mono-material. In that case, biogenic materials present a unique opportunity by offering dual advantages, potentially reducing their embodied carbon footprint.

To ensure sustainable utilization, the notion of transparency and open-source knowledge has been proposed. This approach not only empowers the responsible use of these materials but also serves as a conduit for self-education and knowledge enrichment. Ultimately, this empowerment will extend beyond the Nordics, fostering a global impact.

It is important to note that there is no one solution to saving our planet. Instead, a variety of different approaches is necessary. Our goal is to embrace diversity and foster a relentless desire to explore innovative methods.



The butterfly diagram by the Ellen MacArthur Foundation
@ The Ellen MacArthur Foundation[163]

Enabling Coastal Communities to Rebuild or Reshape their Economies and Become Local Drivers of Sustainability

By promoting and cultivating the market for marine biobased materials, we can provide a significant boost to local coastal communities, helping to revitalize and reshape their economies. This will undoubtedly generate new sources of income for communities that have experienced economic decline in recent years, allowing them to thrive once again. As a result, these communities can become important drivers of sustainability.

On the other hand, supply chains utilizing marine biobased materials have a global reach, extending beyond just the Nordic region. It is crucial to adopt an inclusive perspective that considers not only regional concerns but also global implications. In this regard, there has been a concerted effort to recognize the significant role of third-world countries in these dynamics. It is imperative to prioritize human capital development in these developing nations.

To promote the use of low-carbon materials worldwide, a comprehensive strategy is required. This involves not only implementing innovative production methods, but also considering the developmental goals of different countries when making investment decisions regarding new materials. By aligning these goals, we can ensure that everyone has access to the benefits of low-carbon materials and contribute to reducing carbon footprints globally.

To thrive in the new economic paradigm, it is crucial to have an all-encompassing ecosystem that includes research, academia, and developing nations. This ecosystem should prioritize knowledge and value, with profit embedded within. By fostering this ethos, an inclusive framework emerges that benefit developing countries. Ultimately, the global impact of these efforts not only pioneers a sustainable and equitable approach but also fosters a sense of shared responsibility that resonates across diverse economies and regions.

Building Codes, Regulation, Procurement for/of Marine Biobased Materials

The current building codes and regulations do not consider the distinctiveness of (marine) biobased materials, which presents challenges to the producers of such due to their lack of consistency being a living organism. This is not entirely distinct to marine biobased materials, as other "natural materials" like stone show natural variability. Testing can therefore be a barrier, as it is necessary to demonstrate compliance with building codes, which can be difficult for a startup developing these new niche products, and the high cost of testing to ensure compliance with building regulations makes it hard to get new products to market.

However, it is important to acknowledge that (marine) biobased products exhibit impressive performance and safety features. Furthermore, biomaterials often offer other benefits to the built environment that are not considered in the current market like CO2 sequestration and creating healthy and safe environments. Incentives and externalities to account for these benefits could therefore be considered on a regulatory level.[164]

Hence, there's a pressing need to redefine the boundaries of performance criteria, all while upholding essential considerations such as fire and health & safety. Striking a balance is paramount, as over-engineering has been identified as a concern that hampers the reduction of the embodied carbon footprint within our built environment.

This calls for sustainable procurement practices and underscores the importance of establishing a shared taxonomy and regulatory frameworks. These mechanisms are pivotal in ushering in a transformation in how procurement is approached, both within the public and private sectors. The impact of this shift will reverberate through due diligence processes, risk assessments, and even aspects pertaining to insurance.

In sum, harmonizing building codes, fostering sustainable procurement, and instating robust regulatory frameworks are interconnected strategies that collectively steer us toward a future marked by resource-efficient construction practices and environmentally conscious development.

Promoting and Investing in the Market for Marine Biobased Materials

An important factor to consider when evaluating investment opportunities is the degree to which they align with carbon reduction and circular practices. Ensuring continuity over time will also be crucial for achieving long-term success.

As we compare export and import theories, it becomes evident that traditional methods of transporting goods may soon become obsolete. The emphasis will shift towards managing information and tracking the origin of products. By managing assets in this way, we have the potential to bolster local economies. It is crucial to reassess the dynamics of profitability, particularly when it comes to questioning the current paradigms of the extraction economy.

While funding programmes in the Nordics such as the Nordic Environment Finance Corporation (NEFCO) and The Export and Investment Fund of Denmark (EIKO) have impactful investment programs, it is important to consider the potential for further collaboration and coordination among these funding programs, governmental initiatives and strategies and the private sector to maximize their impact. By working together, we ensure that investment for protection and restoration of ocean habitats and creating low embedded carbon products are prioritized because of the potential to deliver climate change mitigation and co-benefits. Pooling their resources and expertise will support a wider range of sustainable projects and initiatives across the region. Additionally, expanding the reach of these programs can also create new opportunities for international collaboration and knowledge sharing, which can lead to innovative solutions and improved outcomes. Furthermore, it is crucial to ensure that these programs are accessible and inclusive, so that a diverse range of stakeholders can benefit from their investments. This can be achieved through transparent and equitable application processes, as well as by engaging with local communities and stakeholders to understand their needs and priorities. Ultimately, by prioritizing collaboration, coordination, and inclusivity, funding programs in the Nordics can play a key role in driving sustainable development and creating a more resilient and equitable future for all.

Foster Innovative Procurement Strategies

Advocate for the adoption of innovative procurement measures tailored to marine biobased materials, such as open innovation calls and targeted solicitations designed for small and medium-sized enterprises (SMEs). These initiatives aim to encourage collaboration and drive the development and supply of marine biobased materials, thereby contributing to the growth of the marine biobased industry. By diversifying the market and promoting healthy competition, these measures ensure a vibrant and sustainable marketplace for marine biobased materials. An exemplary case is the Baltic Sea Action Plan Fund, which enhances the implementation of the Baltic Sea Action Plan as adopted by the HELCOM countries. This fund serves as a model for leveraging innovative procurement strategies to address environmental challenges and promote sustainable practices within the marine ecosystem. Similarly, adopting such approaches can catalyse advancements in the use of marine biobased materials for construction projects, aligning with broader environmental conservation goals.

References

The Modern Seaweed House
by Vandkunsten @Helene Høyer Mikkelsen

References

[1]EPD Danmark. LCA. https://www.epddanmark.dk/at-lave-epd-er/kort-om-lca/

[2]European Environment Agency. Biodegradable. https://www.eea.europa.eu/help/glossary/eea-glossary/biodegradable

[3]Energy. Biomass. European Commission. https://energy.ec.europa.eu/topics/renewable-energy/bioenergy/biomass_en

[4]Science Direct, Biotic Material. https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/biotic-material

[5]Science Direct, Bio Based Materials. https://www.sciencedirect.com/topics/engineering/bio-based-material

[6]Materials Collections, Bio Materials. Healthy Materials Lab. https://healthymaterialslab.org/material-collections/bio-materials

[7]Life Cycle Initiative. Biogenic Carbon. https://www.lifecycleinitiative.org/activities/life-cycle-assessment-data-and-methods/biogenic-carbon/

[8]Nature. Biomaterials. https://www.nature.com/subjects/biomaterials

[9]Biotechnology Innovation Organization. What is biotechnology? https://www.bio.org/what-biotechnology

[10]My Climate. CO2 Equivalent. https://www.myclimate.org/en/information/faq/faq-detail/what-are-co2-equivalents/

[11]Roy. S. (2022). Chitosan in biomedical Applications. Science Direct. https://www.sciencedirect.com/topics/materials-science/chitosan

[12]Smith. V.H. (2009). Encyclopdia on Inland Waters. Science Direct. https://www.sciencedirect.com/topics/earth-and-planetary-sciences/eutrophication

[13]National Geographic. Ecosystem. https://education.nationalgeographic.org/resource/ecosystem/

[14]Carbon Cure. Embodied Carbon. https://www.carboncure.com/concrete-corner/what-is-embodied-carbon/

[15]EPD Danmark. EPD. https://www.epddanmark.dk/om-epd-er/hvad-er-en-epd/

[16]Ecochain. End of Life. https://ecochain.com/blog/end-of-life-eol-in-lca/

[17]EPA. Greenhouse Gasses. https://www.epa.gov/ghgemissions/overview-greenhouse-gases

[18]EPA. Global Warming Potentials. https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

[19]Mran Khan, M., Hyuk Shin. J., Deog Kim. J. (2018). The promising future of microalgae: Current status, challenges, and optimization of a sustainable and renewable industry for biofuels, feed and other products. Microbial Cell Factories. https://microbialcellfactories.biomedcentral.com/articles/10.1186/s12934-018-0879-x

[20]Oceanic Carbon. ScienceDirect, Elsevier. https://www.sciencedirect.com/topics/earth-and-planetary-sciences/oceanic-carbon

[21]The Ocean. Ocean Economy and Innovation. OECD. https://www.oecd.org/ocean/topics/ocean-economy/

[22]USGS. Carbon Sequestration. https://www.usgs.gov/faqs/what-carbon-sequestration

[23]UN environment Programme. (2022, November 09). 2022 Global Status Report for Buildings and Construction. https://www.unep.org/resources/publication/2022-global-status-report-buildings-and-construction

[24]Sepponen. S., Hjelt. M., Kuusela-Opas. E., Pakkala. A., Suominen. F., Värre. U. (2021) Sustainable Ocean Economy. Mapping of Nordic Strongholds. Nordic Innovation. https://norden.diva-portal.org/smash/get/diva2:1611425/FULLTEXT01

[25]Nordic Bioeconomy Programme. 15 Action Points for Sustainable Change. (2018). Nordic Council of Ministers. http://norden.diva-portal.org/smash/get/diva2:1222743/FULLTEXT01.pdf

[26]A European Green Deal. Striving to be the first climate-neutral continent. European Commission. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

[27]COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS. (2021, May 17). on a new approach for a sustainable blue economy in the EU Transforming the EU's Blue Economy for a Sustainable Future. European Commission. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021DC0240&qid=1624869846426&from=EN

[28]EU Marine Strategy Framework Directive. What it is, why it's needed, research contribution to achieving goals. European Commission. https://research-and-innovation.ec.europa.eu/research-area/environment/oceans-and-seas/eu-marine-strategy-framework-directive_en

[29]European Commission. EU Strategy for the Baltic Sea Region. https://ec.europa.eu/regional_policy/policy/cooperation/macro-regional-strategies/baltic-sea_en

[30]North Sea Region 2030 Strategy. North Sea Region 2030 Strategy. North Sea Commission. https://cpmr-northsea.org/policy-work/north-sea-region-2030-strategy/

[31]Environment. Environmental Impact Assessment. European Commission. https://environment.ec.europa.eu/law-and-governance/environmental-assessments/environmental-impact-assessment_en

[32]COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS. (2021, May 17). on a new approach for a sustainable blue economy in the EU Transforming the EU's Blue Economy for a Sustainable Future. European Commission. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021DC0240&qid=1624869846426&from=EN

[33]Environment. Biodiversity Strategy for 2030. European Commission. https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en

[34]Environment. Water Framework Directive. European Commission. https://environment.ec.europa.eu/topics/water/water-framework-directive_en

[35]Environment. Environmental Impact Assessment. European Commission. https://environment.ec.europa.eu/law-and-governance/environmental-assessments/environmental-impact-assessment_en

[36]European Commission. The Habitats Directive. https://environment.ec.europa.eu/topics/nature-and-biodiversity/habitats-directive_en

[37]Oceans and fisheries. Common Fisheries Policy (CFP). European Commission. https://oceans-and-fisheries.ec.europa.eu/policy/common-fisheries-policy-cfp_en

[38]Oceans and fisheries. Aquaculture policy. European commission. https://oceans-and-fisheries.ec.europa.eu/policy/aquaculture-policy_en

[39]European Commission. Farm to Fork strategy. https://food.ec.europa.eu/horizontal-topics/farm-fork-strategy_en

[40]HELCOM. The Helsinki Convention – HELCOM. https://helcom.fi/about-us/convention/

[41]HELCOM. Baltic Sea Action Plan – HELCOM. https://helcom.fi/baltic-sea-action-plan/

[42]European Commission. Zero pollution action plan. (2023, October 13). Environment. https://environment.ec.europa.eu/strategy/zero-pollution-action-plan_en

[43]Laws and agreements: Nutrient loading. Laws, agreements, and programmes related to nutrient loading. Marine Finland. https://www.marinefinland.fi/en-US/Humans_and_the_Baltic_Sea/Legislation_conventions_and_programmes/Environmental_load

[44]European Commission. Air. (2023, August 10). Environment. https://environment.ec.europa.eu/topics/air_en

[45]Environment. Nitrates, protecting waters against pollution caused by nitrates from agricultural sources. European Commission. https://www.marinefinland.fi/en-US/Humans_and_the_Baltic_Sea/Legislation_conventions_and_programmes/Environmental_load

[46]DIRECTIVE (EU) 2016/802 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL. (2016, May 11). Relating to a reduction in the sulphur content of certain liquid fuels. EUR-Lex. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32016L0802

[47]European Commission. Chemicals strategy. Environment. https://environment.ec.europa.eu/strategy/chemicals-strategy_en

[48]European Environment Agency. NEC Directive reporting status 2019 — European Environment Agency. https://www.eea.europa.eu/publications/nec-directive-reporting-status-2019 [Accessed 8 Nov. 2023].

[49]European Commission. Maritime Forum. BlueInvest. European Commission. https://maritime-forum.ec.europa.eu/en/frontpage/1451

[50]European MSP Platform. European Partnership for a climate neutral, sustainable, and productive Blue Economy. European Commission. https://maritime-spatial-planning.ec.europa.eu/fundings/european-partnership-climate-neutral-sustainable-and-productive-blue-economy

[51]Oceans and fisheries. Blue Bioeconomy and blue technology. European Commission. https://oceans-and-fisheries.ec.europa.eu/ocean/blue-economy/blue-bioeconomy-and-blue-biotechnology_en

[52]Oceans and fisheries. Communication from the Commission: Towards a strong and sustainable EU algae sector. European Commission. https://oceans-and-fisheries.ec.europa.eu/publications/communication-commission-towards-strong-and-sustainable-eu-algae-sector_en

[53]Summa, D.; Lanzoni, M.; Castaldelli, G.; Fano, E.A.; Tamburini, E. Trends and Opportunities of Bivalve Shells' Waste Valorization in a Prospect of Circular Blue Bioeconomy. Resources 2022, 11, 48. https://doi.org/10.3390/resources11050048

[54]Rasmussen, T. V. et al. (2022). Biogene materialers anvendelse i byggeriet. Institut for Byggeri, By og Miljø (BUILD), Aalborg Universitet. BUILD Rapport Bind 1 Nr. 2022:09

[55]Interreg Baltic Sea Region. Baltic Blue Growth. https://interreg-baltic.eu/project/baltic-blue-growth/

[56]Jet Propulsion Laboratory California Institute of Technology. JPL Earth Science. How is Climate change impacting shellfish in the ocean. https://earth.jpl.nasa.gov/news/28/how-is-climate-change-impacting-shellfish-in-the-ocean/

[57]Popović, N.T. et al. (2023) 'Shell Waste Management and Utilization: Mitigating organic pollution and enhancing sustainability,' Applied Sciences, 13(1), p. 623. https://doi.org/10.3390/app13010623

[58]Marine and Freshwater Research Institute. 2022. MFRI Assessment Reports 2022: Iceland Scallop Chlamys Islandica. , (https://www.hafogvatn.is/static/extras/images/25-horpudiskur_tr1326059.pdf).

[59]Mortensen. S., Dolmer. P., Strand. Å., Naustvoll. L. 2019 Policy Brief: The Pacific Oyster - new Nordic food resource and basis for tourism, Nordic Council of Ministers. http://norden.diva-portal.org/smash/get/diva2:1297472/FULLTEXT01.pdf

[60]ProCirc, Interreg VB North Sea Region Programme. Shells serve as floor insulation within pilot case 't Centrum (Westerlo, Belgium), Interreg VB North Sea Region Programme. https://northsearegion.eu/procirc/news/shells-serve-as-floor-insulation-within-pilot-case-t-centrum-westerlo-belgium/

[61]DanShells. Haveanlæg. https://danshells.dk/produkter/haveanlaeg/

[62]Gabriel, S., Larsen, T. and Vollertsen, J. (2012). Baggrundsrapport BAT -Lokale nedsivnings- og renseløsninger. https://separatvand.dk/download/BAT_BAGGRUNDSRAPPORT.pdf

[63]Local Works Studio. Building Materials from shells. https://localworksstudio.com/projects/shellcrete-transforming-sea-shells-into-low-carbon-materials/

[64]Dezeen. Bureau de Change created architectural tiles using glass made from mussels. https://www.dezeen.com/2022/05/19/thames-glass-tiles-mussels-bureau-de-change-lulu-harrison/

[65]Aalborg Portland. Miljøredegørelse 2019. Grønt Regnskab og arbejdsmiljø. https://www.aalborgportland.is/wp-content/uploads/2020/10/Aalborg_Portland_Miljoredegorelse_2019_web.pdf

[66]Marine Finland. Blue mussels are one of the most important and common benthic animals in the Baltic Sea. https://marinefinland.fi/en-US/Nature_and_how_it_changes/Habitats/Hard_seafloors/Blue_mussel_communities

[67]HELCOM Map and data service. https://maps.helcom.fi/website/mapservice/index.html

[68]Mortensen. S., Dolmer. P., Strand. Å., Naustvoll. L. (2019) Policy Brief: The Pacific Oyster - new Nordic food resource and basis for tourism, Nordic Council of Ministers. http://norden.diva-portal.org/smash/get/diva2:1297472/FULLTEXT01.pdf

[69]Council of Europe. Convention on the conservation of European wildlife a natural habitat. Possible negative impact on Breiðafjörður Nature Reserve and its surroundings from new road infrastructure (Iceland). https://rm.coe.int/-2021-files02rev-2021-tor-iceland-breidafjordurnr-final/1680a5ed93

[70]Rattle J. (2020) Blue Marine Foundation. MSC Labelled a “sham” in new report. https://www.bluemarinefoundation.com/2020/05/07/msc-labelled-a-sham-in-new-report/

[71]Baltic Sea. (2023). Oceans and Fisheries. https://oceans-and-fisheries.ec.europa.eu/ocean/sea-basins/baltic-sea_en

[72]Baltic Blue Growth - Initiation of full scale mussel farming in the Baltic sea - Interreg Baltic Sea Region. (2022, May 16). Interreg Baltic Sea Region. https://interreg-baltic.eu/project/baltic-blue-growth/

[73]Baltic Sea Centre, Stockholm University. (2018). Limitations of using blue mussel farms as a nutrient reduction measure in the Baltic Sea. https://www.su.se/polopoly_fs/1.622578.1660911344!/menu/standard/file/BSC_Mussels_report_2_2018_lowresNEW.pdf

[74]Marine Finland. Blue mussels are one of the most important and common benthic animals in the Baltic Sea. https://marinefinland.fi/en-US/Nature_and_how_it_changes/Habitats/Hard_seafloors/Blue_mussel_communities

[75]Chopin T. and Tacon A.G.J., (2020) via Frontiers. (2022) Nordic Blue Carbon Ecosystems: Status and Outlook. https://www.frontiersin.org/articles/10.3389/fmars.2022.847544/full

[76]Weinberger et al., (2020); Araújo et al., (2021) via Frontiers. (2022) Nordic Blue Carbon Ecosystems: Status and Outlook. https://www.frontiersin.org/articles/10.3389/fmars.2022.847544/full

[77]Araújo et al., (2021) via Frontiers. (2022) Nordic Blue Carbon Ecosystems: Status and Outlook. https://www.frontiersin.org/articles/10.3389/fmars.2022.847544/full

[78]Garcia-Pichel F., Belnap J. (2021). Principles and Applications of Soil Microbiology (Third Edition). https://www.sciencedirect.com/topics/earth-and-planetary-sciences/green-alga

[79]Beaumont et al. (2021) via Deng L., Guo W. (2022) Biomass, Biofuels, and Biochemicals.

[80]Science Direct. Microalgae. https://www.sciencedirect.com/topics/earth-and-planetary-sciences/microalgae

[81]Seaweed for Europe. A coalition to advance and scale a sustainable and innovative seaweed industry in Europe. Seaweed for Europe | Advancing the European seaweed industry (seaweedeurope.com)

[82]Rasmussen, T. V. et al. (2022). Biogene materialers anvendelse i byggeriet. Institut for Byggeri, By og Miljø (BUILD), Aalborg Universitet. BUILD Rapport Bind 1 Nr. 2022:09

[83]Royal Danish Academy. Predicting Response. https://royaldanishacademy.com/case/predicting-response

[84]Nordic Innovation. Bioplastic from Nordic Kelp. https://www.nordicinnovation.org/programs/bioplastic-nordic-kelp

[85]Notpla (2019). We make packaging disappear - Notpla. https://www.notpla.com/

[86]Lund University, School of Industrial Design. Sea Leather, Carbon Negative textiles issued from marine materials. https://lusid.se/project/sea-leather/

[87]Fiorenza, M. (2023, February 15). SeaBrick, Better and Less Expensive than Concrete, It's Eco Restorative and Sequesters CO2. The Seasteading Institute. https://www.seasteading.org/seabrick/

[88]Living Ink Technologies. LivingInkTech. https://livingink.co/

[89]Rasmussen, T. V. et al. (2022). Biogene materialers anvendelse i byggeriet. Institut for Byggeri, By og Miljø (BUILD), Aalborg Universitet. BUILD Rapport Bind 1 Nr. 2022:09

[90]Nordic Microalgae and aquatic protozoa. Introduction. http://nordicmicroalgae.org/

[91]Hadipoor. M., Keivanimehr. F., Baghban. A., Ganjali. M.R., Habibzadeh. S. (2021) Sorbents Materials for Controlling Environmental Pollution. Chapter 24 – Carbon Dioxide as a main source of air pollution: Prospective and current trends to control. Pp. 623-688. Via Science Direct. https://www.sciencedirect.com/science/article/abs/pii/B9780128200421000043

[92]M. Sørensen, J. Andersen-Ranberg, B. Hankamer, B.L. Møller, Circular biomanufacturing through harvesting solar energy and CO2, Trends Plant Sci, 27 (2022), Pp. 655-673, 10.1016/j.tplants.2022.03.001

[93]León-Vaz. A., León. R., Vigara. J., Funk. C. (2023) New Biotechnology. Exploring Nordic microalgae as a potential novel source of antioxidant and bioactive compounds. Pp. 1-8. via Science Direct. https://www.sciencedirect.com/science/article/pii/S1871678422000656#bib1

[94]Government of Iceland. Ministry of Food, Agriculture and Fisheries. (2023). The State and Future of Aquaculture in Iceland. https://www.stjornarradid.is/library/01--Frettatengt---myndir-og-skrar/MAR/Fylgiskjol/The%20State%20and%20Future%20of%20Aquaculture%20in%20Iceland%20(1).pdf

[95]Promethueus Materials. Home. https://prometheusmaterials.com/

[96]Prodyogi. Algae-Based Cement – Zero-Carbon Building Material. https://www.prodyogi.com/2022/06/algae-based-cement-zero-carbon-building.html

[97]Circalgae. Project Plans. CIRCALGAE EU Project | Project Plans

[98]Camarena-Goméz. M. T., Lähteenmäki-Uutela. A., Spilling. K. (2022). Aquaculture. Macroalgae production in Northern Europe: Business and government perspectives on how to regulate a novel blue bioeconomy. Via Science Direct. https://www.sciencedirect.com/science/article/pii/S0044848622005506#ab0010

[99]Government of Iceland. Ministry of Food, Agriculture and Fisheries. (2023). The State and Future of Aquaculture in Iceland. https://www.stjornarradid.is/library/01- -Frettatengt---myndir-og-skrar/MAR/ Fylgiskjol/The%20State%20and%20Future%20of%20Aquaculture%20in%20Iceland%20(1).pdf

[100]Government of Iceland. Ministry of Food, Agriculture and Fisheries. (2023). The State and Future of Aquaculture in Iceland. https://www.stjornarradid.is/library/01--Frettatengt---myndir-og-skrar/MAR/Fylgiskjol/The%20State%20and%20Future%20of%20Aquaculture%20in%20Iceland%20(1).pdf

[101]Zhang, X., & Thomsen, M. (2021). Techno-economic and environmental assessment of novel biorefinery designs for sequential extraction of high-value biomolecules from brown macroalgae Laminaria digitata, Fucus vesiculosus, and Saccharina latissima. Algal Research, 60, 102499. https://doi.org/10.1016/j.algal.2021.102499

[102]Frontiers. (2022) Nordic Blue Carbon Ecosystems: Status and Outlook. https://www.frontiersin.org/articles/10.3389/fmars.2022.847544

[103]Naturstyrelsen: Blue Reef. https://naturstyrelsen.dk/naturbeskyttelse/naturprojekter/blue-reef/

[104]Íslenska. Í sátt við umhverfið. http://iskalk.is/

[105]Norderhaug et al., (2021), Bekkby et al., (2020) via Frontiers. (2022) Nordic Blue Carbon Ecosystems: Status and Outlook. https://www.frontiersin.org/articles/10.3389/fmars.2022.847544

[106]Watanuki et al., (2010) via Frontiers. (2022) Nordic Blue Carbon Ecosystems: Status and Outlook. https://www.frontiersin.org/articles/10.3389/fmars.2022.847544

[107]European Commission. Biobased, biodegradable, and compostable plastics. https://environment.ec.europa.eu/topics/plastics/biobased-biodegradable-and-compostable-plastics_en

[108]Pellis A, Guebitz GM, Nyanhongo GS. Chitosan: Sources, Processing and Modification Techniques. Gels. 2022 Jun 21;8(7):393. doi: 10.3390/gels8070393. PMID: 35877478; PMCID: PMC9322947. Via PubMed Central: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9322947/

[109]Piekarska. K., Sikora. M., Owczarek. M., Józwik-Pruska. J., Wisniewska-Wrona. M. (2023) Chitin and Chitosan as Polymers of the Future – Obtaining, Modification, Life Cycle Assessment and Main Directions of Application. Via MDPI. https://www.mdpi.com/2073-4360/15/4/793

[110] Ashori et al., (2013), Dash et al., (2011), Kumar, (2000), Muzzarelli et al., (2012), Nair and Laurencin, (2007), No et al., (2007), Patel et al., (2013), Shalaby et al., (2004), Umemura et al., (2010). via Mati-Baouche. N., Baynast. H.D., Lebert. A., Sun. S., Lopez-Mingo. C.J.S., Leclaire. P., Michaud. P. (2014) Industrial Crops and Products. Mechanical, thermal, and acoustical characterizations of an insulating bio-based composite made from sunflower stalks particles and chitosan. Pp 244-250. Via Science Direct. https://www.sciencedirect.com/science/article/abs/pii/S0926669014002258?via%3Dihub

[111] European Chitin Society. What is chitin? https://euchis.org/

[112] Maliki. S., Sharma. G., Kumar. A., Moral-Zamorano. M., Moradi. O., Baselga. J., Stadler. F.J., García-Penas. A. (2022) Chitosan as a Tool for Sustainable Development: A mini review. Via National Library of Medicin. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9003291/

[113] Mati-Baouche, N. et al. (2014) Mechanical, thermal and acoustical characterizations of an insulating bio-based composite made from sunflower stalks particles and chitosan. Industrial Crops and Products, 58:244-250. Via Science Direct. https://www.sciencedirect.com/science/article/abs/pii/S0926669014002258?via%3Dihub

[114] Lasheras-Zubiate. M., Navrro-Blasco. Í., Álvares. J.I., Fernandez. J.M. (2010). Biopolymer-cement composites for building purposes. performance of chitosan and some of its derivatives as cement admixtures. Nevarra, Spain. https://dadun.unav.edu/bitstream/10171/27711/3/2010-09-ICNP_1.pdf

[115] McHill University Newsroom. (2020). A new solution to plastic pollution. https://www.mcgill.ca/newsroom/article/new-solution-plastic-pollution

[116] Malucelli, G. (2020). Flame-Retardant systems based on Chitosan and its derivatives: state of the art and perspectives. Molecules, 25(18), p. 4046. https://doi.org/10.3390/molecules25184046

[117] Junceda-Mena, I., García-Junceda, E., & Revuelta, J. (2023, June 1). From the problem to the solution: Chitosan valorization cycle. Carbohydrate Polymers; Elsevier BV. https://doi.org/10.1016/j.carbpol.2023.120674

[118] Natur Vårds Verket. Protected Species. https://www.naturvardsverket.se/en/topics/species-protection/protected-species/

[119] Iceland Responsible Fisheries Foundation. (2023). Responsible Fisheries Management Standard. A Tool for voluntary Use in Market for Products of Marine Capture Fisheries. https://www.responsiblefisheries.is/media/1/irfmstandard-ver-2.1-april2023--approved-version.pdf

[120] European Chitin Society. What is chitin? https://euchis.org/

[121] Maliki. S., Sharma. G., Kumar. A., Moral-Zamorano. M., Moradi. O., Baselga. J., Stadler. F.J., García-Penas. A. (2022) Chitosan as a Tool for Sustainable Development: A mini-Review. Via National Library of Medicin. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9003291/

[122] Junceda-Mena, I., García-Junceda, E. and Revuelta, J. (2023) 'From the problem to the solution: Chitosan valorization cycle,' Carbohydrate Polymers, 309, p. 120674. https://doi.org/10.1016/j.carbpol.2023.120674

[123]Rasmussen, T. V. et al. (2022). Biogene materialers anvendelse i byggeriet. Institut for Byggeri, By og Miljø (BUILD), Aalborg Universitet. BUILD Rapport Bind 1 Nr. 2022:09

[124]Boström. C. et al. (2014). Distribution, structure, and function of Nordic eelgrass (Zostera marina) ecosystems: implications for coastal management and conservation. Via Wiley Online Library. https://onlinelibrary.wiley.com/doi/10.1002/aqc.2424

[125]Søuld (2022). Søuld. https://www.sould.dk/

[126]Møn Tang. https://www.moentang.dk/

[127]Søuld (2023). Products - Acoustic walls. https://www.sould.dk/acoustic-walls

[128]Søuld (2023). Products - Acoustic ceilings. https://www.sould.dk/acoustic-ceilings.

[129]Norderhaug et al., (2021) in Bekkby et al. (2020) via Frontiers. (2022) Nordic Blue Carbon Ecosystems: Status and Outlook. https://www.frontiersin.org/articles/10.3389/fmars.2022.847544/full

[130]HELCOM. Biotope Information Sheets – HELCOM. https://helcom.fi/baltic-sea-trends/biodiversity/red-list-of-biotopes-habitats-and-biotope-complexes/biotope-information-sheets/

[131]United Nations Environment Programme (2020). Out of the Blue. The Value of Seagrasses to Environment and to People. UNEP, Nairobi. https://grid.cld.bz/Out-of-the-blue-The-value-of-seagrasses-to-the-environment-and-to-people

[132]Ocean Best Practices. Our Vision. https://www.oceanbestpractices.org/

[133]Boström. C. et al. (2014). Distribution, structure, and function of Nordic eelgrass (Zostera marina) ecosystems: implications for coastal management and conservation. Via Wiley Online Library. https://onlinelibrary.wiley.com/doi/10.1002/aqc.2424

[134]Moksnes et al., (2016) via Frontiers. (2022) Nordic Blue Carbon Ecosystems: Status and Outlook. https://www.frontiersin.org/articles/10.3389/fmars.2022.847544/full#h15

[135]Svennevig. B. (2022). Finally, the eelgrass is coming back. Via SDU. https://www.sdu.dk/en/nyheder/endelig-breder-aalegraesset-sig and https://www.int-res.com/abstracts/meps/v685/p97-109/ Via SDU. https://www.sdu.dk/en/nyheder/endelig-breder-aalegraesset-sig and Lange. T. et al. (2022). Large-scale eelgrass transplantation: a measure for carbon and nutrient sequestration in estuaries. Via Inter-Research Science Publisher. https://www.int-res.com/abstracts/meps/v685/p97-109/

[136]Bayraktarov et al., (2016); van Katwijk et al., (2016); Orth et al., (2020) via Norderhaug et al., (2021), Bekkby et al., (2020) via Frontiers. (2022) Nordic Blue Carbon Ecosystems: Status and Outlook. https://www.frontiersin.org/articles/10.3389/fmars.2022.847544/full

[137]Authors interview with Ocean Thinktank 13.06.23.

[138]Norderhaug et al., (2021), Bekkby et al., (2020) via Frontiers. (2022) Nordic Blue Carbon Ecosystems: Status and Outlook. https://www.frontiersin.org/articles/10.3389/fmars.2022.847544/full#h15

[139]Dabaieh. M., Sakr. M. (2015). Building with reeds: revitalizing a building tradition for low carbon building practice. Via ResearchGate. https://www.researchgate.net/publication/286458843_BUILDING_WITH_REEDS_Revitalizing_a_building_tradition_for_low_carbon_building_practice

[140]Vette. J.F., Bötger. W.O.J. (2019). Properties of mycelium-composite biobased insulation materials with local organic waste streams as substrate and after use for mushroom cultivation. The Netherlands. https://www.mnext.nl/app/uploads/2020/02/ProductieMycelium.pdf

[141]Henning Larsen. Sundby School. https://henninglarsen.com/en/projects/featured/1976-sundby-school

[142]Henning Larsen. Harvesting ancient wisdom: a guide to designing with straw. https://henninglarsen.com/en/news/archive/2023/06/an-architect-s-guide-to-designing-with-straw

[143]Dorte Mandrup. The Wadden Sea Centre, Denmark | Dorte Mandrup. https://dortemandrup.dk/work/wadden-sea-centre-denmark

[144]Pownall. A. (2019). Pavillion grown from mycelium acts as pop-up performance space at Dutch Design Week. Dezeen. https://www.dezeen.com/2019/10/29/growing-pavilion-mycelium-dutch-design-week/

[145]SDU. Nordsalt. www.sdu.dk/en/forskning/nordsalt

[146]Liu, F. et al. (2019) 'Long-term harvesting of reeds affects greenhouse gas emissions and microbial functional genes in alkaline wetlands,' Water Research, 164, p. 114936. https://doi.org/10.1016/j.watres.2019.114936.

[147]Bajikama et al. (2008) 'The impact of reed management on wildlife: A meta-analytical review of European studies,' Biological Conservation, 141(2), pp. 364–374. https://doi.org/10.1016/j.biocon.2007.11.006.

[148]Andersen, L.B. et al. (2021) 'Can reed harvest be used as a management strategy for improving invertebrate biomass and diversity?,' Journal of Environmental Management, 300, p. 113637. https://doi.org/10.1016/j.jenvman.2021.113637.

[149]European Commission (2023). The Habitats Directive. https://environment.ec.europa.eu/topics/nature-and-biodiversity/habitats-directive_en.

[150]Finnish Ministry of the Environment. Nature Conservation Legislation - Ministry of the Environment (no date). https://ym.fi/en/nature-conservation-legislation

[151]CoastNet LIFE | Metsähallitus (2023). https://www.metsa.fi/en/project/coastnet-life/.

[152]Ministry of Environment of Denmark. Wetlands. https://eng.mst.dk/water/aquatic-environment/wetlands.

[153]Møn Tang. Om Møn Tang. https://www.moentang.dk/om-mon-tang

[154]Sepatec, EPD. https://sepatec.dk/wp-content/uploads/2019/02/md-17001-en.pdf

[155]EPD Danmark. Thomas Guls ApS. https://www.epddanmark.dk/media/z1tlqwya/md-22113-da.pdf

[156]Nordic Innovation. (2023, June 05). Swedish design firm to be mail partner in Kelpwood & Bioplastic project. https://www.nordicinnovation.org/news/swedish-design-firm-be-main-partner-kelpwood-bioplastic-project

[157]ReefCircular. ReefCircular. https://www.reefcircular.com/

[158]Mounid. Mounid. https://www.mounid.se/mounid

[159]DanShells. Parks and gardens. https://danshells.dk/en/products/parks-and-gardens/

[160]DanShells. Om produktionen. https://danshells.dk/produktion/

[161]European Commission (2021) Communication from the commission to the European parliament, the council, the European economic and social committee, and the committee of the regions. On a new approach for a sustainable blue economy in the EU Transforming the EU's Blue Economy for a Sustainable Future. Brussels. eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021DC0240&qid=1624869846426&from=EN

[162]Sepponen. S., Hjelt. M., Kuusela-Opas. E., Pakkala. A., Suominen. F., Värre. U. (2021) Sustainable Ocean Economy. Mapping of Nordic Strongholds. Gaia Consulting Ltd., Nordic Innovation. *FULLTEXT01 (diva-portal.org)

[163]The Ellen MacArhtur Foundation. The butterfly diagram: visualising the circular economy. https://www.ellenmacarthur-foundation.org/circular-economy-diagram

[164]Built by Nature. Discussing Timber Myths: a dialogue between our ambitions and the facts. https://www.ams-institute.org/documents/100/230607_Timber_Myth_booklet_-_PRINT.pdf

Eelgrass by @ Søuld