Cluster **O**n **A**naerobic digestion, environmental **S**ervices and nu**T**rients remov**AL**

A report on best practice and lessons learned

September, 2021

Deliverable 3.1

Preface

The project receives funding by the Interreg South Baltic Programme 2014-2020 under the project “Cluster On Anaerobic digestion, environmental Services and nuTrients removAL (COASTAL Biogas)“, STHB.02.02.00-DE-0129/17.

Authors

Airingas Šuopys, Lithuanian Energy Institute, Lithuania
Dovilė Gimžauskaitė, Lithuanian Energy Institute, Lithuania
Liutauras Marcinauskas, Lithuanian Energy Institute, Lithuania
Andrius Tamošiūnas, Lithuanian Energy Institute, Lithuania

Project partners:

1. Agency for Renewable Resources (FNR), Germany – project coordinator
2. Gdansk University of Technology (GUT), Poland – project partner
3. Baltic Energy Innovation Centre (BEIC), Sweden – project partner
4. Roskilde University (RUC), Denmark – project partner
5. University of Rostock (UROS), Germany – project partner
6. Lithuanian Energy Institute (LEI), Lithuania – project partner

Table of Contents

Figures

Summary

The purpose of this report is to summarize experiences, 'Good Practice' examples and technology advances of ongoing and recently or some decade ago finished projects, supplemented by information from the COASTAL Biogas network of biogas experts. This review contributes to COASTAL Biogas' aim of finding strategies to mitigate negative eutrophication consequences around the Baltic Sea and other regions (e.g. the Curonian Lagoon, the Wadden Sea, the Caspian Sea, the Black Sea, the Ythan estuary, Scotland, etc.) with similar eutrophication problems. Therefore, the project concentrates on handling aquatic biomass (algae, seaweeds) washed onshore, and which has bound nutrients (mainly N, P) mainly originating from human-induced activities, such as agriculture, shipping, aquaculture, domestic and industrial sewage and waste water, etc. As an outcome, cultures and species, such as mussels, algae, or floating wetlands could be specifically cultivated and used to increase the rate of absorption and thus removing excessive nutrients and enhancing local water quality for habitats and humans.

Introduction

The Baltic Sea area suffers from severe eutrophication due to past and present excessive discharges of nutrients (mostly nitrogen and phosphorus) to the marine environment. The prevailing nitrogen load mainly comes from agricultural areas. Other sources of nitrogen include nitrogen gases (e.g. ammonium from manuring, NOx from ships transferred via the atmosphere to water body), aquaculture, wastewater treatment plants and industrial water discharge. Whereas, the main contribution of human-induced phosphorous load comes from domestic and industrial sewage and waste water. As a result, eutrophication causes a threat to the biodiversity of the Baltic Sea due to elevated levels of algal and plant growth, increased turbidity, oxygen depletion, changes in species composition and nuisance blooms of algae. Therefore, there is a need to concentrate the efforts of all stakeholders, including from politics, science, communities, business, industry, NGOs, etc., in order to find sustainable solutions towards a circular economy as well as climate change mitigation. Such efforts of stakeholders, especially municipalities, academia, industry (biogas plant operators), utility companies, etc. are usually united by implementing some key projects dedicated to solving specific issues, i.e. eutrophication, habitat or species protection and restoration, etc. The goal of this report is to review best practice, technology advances and lessons learned during implementation of projects or established networks intending to mitigate negative eutrophication consequences around the Baltic Sea and other regions or catchment areas. As a result, 19 projects were identified and reviewed. The results and findings of these projects are summarized in this report.

Regarding the perspectives of the COASTAL Biogas project it was also important to position it among other relevant identified projects and take over the experience, especially collecting cast seaweed from beaches (the WAB project, the AlgaeService for Life project, etc.), sand removal (the Solrød project), nutrients recovery (the SeaRefinery project, the MAB4 project, etc.) and biogas production (the BioMara project, the Bucefalos project, the Solrød project, etc.). The COASTAL Biogas also demonstrates a new approach how the collected seaweed could be treated via thermochemical pathway for energy recovery in case it is not suitable for direct biogas production due to the threshold limit of heavy metals content.

1. ALGAE Service for Life – Economy based ecological service of aquatic ecosystems

LIFE17 ENV/LT/000407

Project summary

The research and innovation action (RIA) project will demonstrate the efficiency of constructed prototypes in harvesting of cyanobacteria scums and macroalgae mats, as the source of phosphorus, nitrogen and hazardous cyanotoxins, in various types of water bodies. Also, this project focuses on developing technologies to provide a reliable, cost-effective and sustainable supply of algal biomass as a feedstock source[1].

Project website: https://algaeservice.gamtostyrimai.lt/lt/

Coordinating beneficiary:

Nature Research Centre, Lithuania

Partners:

Adam Mickiewicz University in Poznan, Poland
JSC Baltic Environment, Lithuania
Institute of Nature Conservation, Polish Academy of Sciences (INC), Poland
Nature Heritage Fund (NHF), Lithuania
JSC Spila, Lithuania

Project start – 2018-08
Project end – 2023-07

Project type – Research and innovation action (RIA)

Aim of the project:

The project AlgaeService for LIFE seeks to promote best practices in ecological service and the circular economics approach by implementing innovative complex system which has both demonstration and innovation character [1].

Objectives:

- To demonstrate integrated efficient management of nutrients and algal nuisance blooms at the catchment scale by harvesting of cyanobacteria scums and macroalgae mats in various types of water bodies (rivers, lakes, the Curonian Lagoon).

- To test and demonstrate the redesigning of waste biomass of cyanobacteria and macroalgae into potential valuable products for sustainable management and recycling of environmental resources.
- To raise awareness on environmental, water quality and health hazard issues among the national governments, local authorities, the business community and society for the continuation and transfer of proposed measures application on a broader scale after the end of the Life project.

Results:
The results of the project will demonstrate the efficiency of the prototype-harvesters for mitigation of excess algal biomass, as the source of phosphorus, nitrogen and hazardous cyanotoxins, in the ecosystems to ensure their applicability and transferability to a high variety of EU aquatic ecosystems (Fig. 1). Also, this project focuses on developing technologies to provide a reliable, affordable, and sustainable supply of algal biomass as a feedstock source.

The project addresses the integrated management of nutrients and organic pollution from agricultural origin and suggests measures needed in river basins or catchment areas to achieve the requirements of the Water Framework Directive, Marine Strategy Framework Directive, Bathing Waters Directive, Nitrates Directive. Removal of nutrients using "natural-like" processes contributes to the EU Strategy for the Baltic Sea Region and provides an integrated framework for improving the environmental condition of the Baltic Sea. The project promotes the ecosystem-based approaches controlling harmful blooms in inland waters and diminishing nutrient loads to the Baltic Sea from the catchments. It is intended to develop the technologies for the provision of water service and gently mitigate eutrophication.

Figure 1: Prototype AS-S in operation designed in the AlgaeService for LIFE project (photo by Andrius Tamošiūnas)

Project-related publications:

Koreivienė, J.; Karosienė, J.; Kasperovičienė, J.; Paškauskas, R.; Messyasz, B.; Łęska, B.; Pankiewicz, R.; Gulbinas, Z.; Valskys, V.; Walusiak, E.; Krzton, W.; Kustosz, D.; Wilk-Woźniak, E.
EU project of LIFE programme “Algae Service for LIFE” creates tools for ecological service aiming to mitigate cyanobacteria and macroalgae blooms in freshwater ecosystems. Botanica, 2019, 25(1): 65–73. DOI: 10.2478/botlit-2019-0007

Koreivienė, J.; Karosienė, J.; Kasperovičienė, J.; Paškauskas, R.; Łęska, B.; Pankiewicz, R.; Juškaitė, L.; Zagorskis, A.; Wilk-Woźniak, E.; Valskys, V.; Gulbinas, Z.; Walusiak, E.; Krzton, W.; Morudov, D.; Radzevičius, K.; Treska, E.; Tabisz, Ł.; Papsdorf, M.; Piotrowicz, Z.; Messyasz, B. EU project of LIFE programme ‘Algae Service for LIFE’ develops ecologically sustainable bioproducts from freshwater cyanobacteria and macroalgae biomass. Botanica, 2019, 25(2): 176–185. DOI: 10.2478/botlit-2019-0019

Korzeniowska, K.; Łęska, B.; Wieczorek, P.P. Isolation and determination of phenolic compounds from freshwater Cladophora glomerata. Algal Research, 2020, 48:101912, DOI: 10.1016/j.algal.2020.101912

2. Baltic Blue Growth – Initiation of full-scale mussel farming in the Baltic sea

Project website: https://www.submariner-network.eu/balticbluegrowth

Coordinating beneficiary:
Region Östergötland, Sweden

Partners:
The County Administrative Board of Kalmar, Sweden
The East Regional Aquaculture Centre, Sweden
Kalmar municipality, Sweden
Kurzeme Planning Region, Latvia
The Latvian Institute of Aquatic Ecology, Latvia
The Maritime Institute in Gdańsk, Poland
The Ministry for Energy Transition, Germany
Agriculture, Environment, Nature and Digitalization (MELUND)
Borgholm municipality, Sweden
The Swedish University of Agricultural Sciences (SLU), Sweden
The County Administrative Board of Östergötland, Sweden
The University of Tartu, Estonia
Coastal Research & Management (CRM), Germany
Musholm, Denmark
Orbicon, Denmark
The Coastal Union Germany (EUCC-D), Germany
The Swedish Institute of Agricultural and Environmental Engineering (JTI), Sweden

Project start – 2016-05
Project end – 2019-04

Project type – RIA

Aim of the project:
To advance mussel farming in the Baltic Sea from experimental to full scale. The objective of the project was to remove nutrients from the Baltic Sea Region by farming and harvesting blue mussels [2].

Objectives:

- The recognition of blue mussels as an efficient way of counteracting eutrophication, complementing legally required source-related measures.
- Acceptance of a compensation scheme for the ecosystem service provided by the mussels.
- The establishment of mussel farming as an attractive market for entrepreneurs.
- The production of mussel meal as an ingredient in animal feed.

Results:

The project partners established five mussel farms: in St Anna and Kalmar (Sweden), Musholm Bay (Denmark), Kiel Bay (Germany) and Kurzeme coast (Latvia). Cooperation with two other farms in Sweden and one in Estonia was initiated as well. These farms act as trial sites to demonstrate efficient methods of growing and harvesting mussels under different conditions in the eastern and western Baltic Sea. On all sites, the environmental data was compiled and all costs and man hours spent on the farms were recorded. Production costs per harvested amount in different places in the Baltic Sea and using various mussel farming techniques were calculated. It was determined that the total cost of mussel farming in the Baltic Sea varied from 0.5 to 5.5 EUR/kg. The collected data were used to create business plans and manuals to support further investments [3].

It was demonstrated that mussel farming can remove significant amounts of nitrogen and phosphorus. The obtained data indicated that nutrient uptake of nitrogen is possible in the range of 17–65 t/year from the Baltic Sea. In parallel, a demonstration scale production chain for animal feed from the Baltic Sea mussels was initiated. An innovative solution, proposed by the project partners, was tested: using insect larvae composting for separation of the meat and shell fractions. The project created a feed task force to facilitate mussel farmers' access to feed-related industry knowledge and contacts [2].

Based on data and experiences collected at the fully operational trial sites, the project's main outputs included:

- Models and functional decision support tools on suitable farming sites and their production potential
- Business plans and farming manuals for large scale mussel farms
- A demonstration line for processing mussels into fish and poultry feed
- A guide on licensing processes for mussel farming in the Baltic Sea Region
- Recommendations on harmonized maritime spatial planning and ecosystem service compensation measures.

Project-related publications:

Ewald, N.; Vidakovic, A.; Langeland, M.; Kiessling, A.; Sampels, S.; Lalander, C. Fatty acid composition of black soldier fly larvae (Hermetia illucens) – Possibilities and limitations for modification through diet. Waste Management, 2020, 102:40-47. https://doi.org/10.1016/j.wasman.2019.10.014

Ozoliņa, Z. Mussel Farming and Its Potential in the Baltic Sea. Economics and Business. 2017, 30(1): 40-50. DOI:10.1515/eb-2017-0004.

Petersen, J. K.; Hasler, B.; Timmermann, K.; Nielsen, P.; Tørring, D.B.; Larsen, M.M.; Holmer, M. Mussels as a tool for mitigation of nutrients in the marine environment. Marine Pollution Bulletin. 2014, 1-2: 137-143. https://doi.org/10.1016/j.marpolbul.2014.03.006

3. BioMara – Sustainable Fuels from Marine Biomass

Project website: http://www.biomara.org/index.html

Funding source: 2007 - 2013 Northern Ireland - Border Region of Ireland - Western Scotland (IE-UK), co-financed by the European Regional Development Fund

Coordinating beneficiary:
The Scottish Association for Marine Science (SAMS), Scotland

Partners:
The Centre for Renewable Energy at Dundalk Institute of Technology (CREDIT), Ireland
Fraser of Allander Institute, University of Strathclyde, Scotland
Centre for Sustainable Technologies, University of Ulster, Northern Ireland
Institute of Technology, Sligo, Ireland
The Questor Centre, The Queen's University Belfast, Northern Ireland [4]

Project start – 2009-01
Project end – 2012-12

Project type – Coordination and support action (CSA)

Aim of the project:
The project aims to investigate the feasibility and viability of producing third-generation biofuels from marine biomass: macroalgal (seaweeds) and microalgal (single-celled plants) as an alternative to agro-fuels production from terrestrial land plants [5], [6].

Objectives:
- Identify the most appropriate seaweeds for biofuel generation
- Identify high oil-producing microalgae
- Evaluate the environmental impacts of algal cultivation and extraction
- Examine the technological and socio-economic practicalities of producing competitive and sustainable biofuels from marine biomass

Results:
The potential of brown seaweed (or kelp) biomass conversion into biogas via anaerobic digestion or bioethanol through fermentation process was investigated during BioMara project [5]. The researchers identified that due to the highest sugar content in the seaweed, hence the highest biofuel production potential, autumn is the most appropriate season to harvest the seaweeds. Also, they suggested that

the production of multi-species seaweed would prolong the harvest season because different seaweed species reach their peak sugar content at different times in the autumn. Moreover, BioMara has identified a range of marine bacteria capable of seaweed saccharification (process needed before fermentation), since commercially-available enzymes are not sufficient enough.

Furthermore, it was determined that maximum biogas yields are produced when the seaweed is digested with sheep gut rumen and/or feces from seaweed-eating sheep. Additionally, biogas yields are increased when seaweed is harvested from July to October and is freshly minced as well as air-dried or freeze-dried before it is fed into an anaerobic digester. The researchers determined that two-stage digestion results in higher yields from the same amount of seaweed if the hydrolytic and acidogenic phases of anaerobic digestion are separated [7].

BioMara has investigated the basic biology of oil generation from microalgae concerning their potential use as a source of oils for biodiesel. BioMara scientists examined 200 marine algal strains and identified that the marine eustigmatophyte and Nannochloropsis alga has the highest oil content. Four strains as suitable for biodiesel production were suggested: Chlorella ovalis, Dunaliella primolecta, Nannochloropsis oculata and Tetraselmis sp. [7].

BioMara evaluated the environmental impact of harvesting storm-cast seaweed for biofuel production. Applied models predicted a direct and rapid decline of invertebrates and bird populations if 50% of beach cast seaweed is removed over a decade. Researchers noted that nearshore floating kelp (seaweed) is a source of food and habitat for marine animals. Also, beach-cast kelp (seaweed) is colonised by flies and beetles, which are high-energy food for migrating birds. BioMara scientists remarked that invertebrates would recover rapidly, but bird populations would take up to 30 years to recover to their original numbers. Moreover, it was determined that harvesting of wild seaweed for biofuels would cause a long-lasting effect on beach productivity as well as on broader coastal ecosystems [7].

BioMara evaluated the techno-economic and socio-economic impact of the development of algal biomass as sources of biofuels. Obtained results revealed that estimations of production cost and energy yields differ and demonstration projects could verify economic feasibility. Also, it was noted that seaweed cultivation would increase employment. Thus, high employment would disperse economic impact through the community. Furthermore, it was proposed that heat and electricity generation from seaweed biogas could be a useful option in places where infrastructure and capacity exist.

BioMara identified that energy production from seaweed is expensive. For example, their evaluation concluded that 14,400 m of seeded collector string could yield up to 100 t. At a price of 50 EUR/t of seaweed, electricity from an anaerobic digestion plant using this resource would currently cost around 120 EUR/MWh. However, researchers suggested that combined heat and power plants could reduce operating costs [7].

The project promoters also stated that harvesting of the algal biomass and extraction of the oil from biomass are two main concerns in regard to their cost intensity in the biodiesel production process. The algal separation from the liquid in which they are cultivated is an energy-consuming process. Furthermore, present separation methods are not precisely adapted for the microalgae. However, according to the BioMara promoters, novel methods that combine technologies for extraction and conversion into biofuel are hopeful for future development and improved economic viability [7].

Project-related publications:

Callaway, R.; Shinn, A.P.; Grenfell, SE.; Bron, J.E.; Burnell, G.; Cook, E.J.; Crumlish, M.; Culloty, S.; Davidson, K.; Ellis, R.P.; Flynn, K.J.; Fox, C.; Green, D.M.; Hays, C.; Hughes, A.D.; Erin Johnston, E.; Lowe, C.D.; Lupatsch, I.; Malham, S.; Mendzil, A.F.; Nickell, T.; Pickerell, T.; Rowley, A.F.; Stanley, M.S.; Tocher, D.R.; Turnbull, J.F.; Webb, G.; Wootton, E.; Shields, R.J. Review of climate change impacts on marine aquaculture in the UK and Ireland. Aquatic Conservation: marine and Freshwater Ecosystems, 2012, 22(3): 389-421, DOI: 10.1002/aqc.2247

Dave, A.; Huang, Y.; Rezvani, S.; McIllveen-Wright, D.; Novaes, M.; Hewitt, N. Techno-economic assessment of biofuel development by anaerobic digestion of European marine cold-water seaweeds. Bioresource Technology, 2013, 135: 120-127 DOI: 10.1016/j.biortech.2013.01.005

Day, J.G.; Slocombe, S.P.; Stanley, M.S. Overcoming biological constraints to enable the exploitation of microalgae for biofuels. Bioresource Technology, 2012, 109:245-251, DOI: 10.1016/j.biortech.2011.05.033

Hughes, A.D.; Kelly, M.S.; Black, K.D.; Stanley, M.S. Biogas from Macroalgae: is it time to revisit the idea? Biotechnol Biofuels, 2012, 27(1): 86 DOI: 10.1186/1754-6834-5-86

Roleda, M.Y.; Slocombe, S.P.; Leakey, R.J.G.; Day, J.G.; Bell, E.M.; Stanley, M.S. Effects of temperature and nutrient regimes on biomass and lipid production by six oleaginous microalgae in batch culture employing a two-phase cultivation strategy. Bioresource Technology, 2013, 129:439-449 DOI: 10.1016/j.biortech.2012.11.043

Slocombe, S.P.; Ross, M.; Thomas, N.; McNeill, S.; Stanley, M.S. A rapid and general method for measurement of protein in micro-algal biomass. Bioresource Technology, 2013, 129:51-57 DOI: 10.1016/j.biortech.2012.10.163

Slocombe, S.P.; Zhang, Q.Y.; Black, K.D.; Day, J.G.; Stanley, M.S. Comparison of screening methods for high-throughput determination of oil yields in micro-algal biofuel strains. Journal of Applied Phycology, 2013, 25: 961-972 DOI: 10.1007/s10811-012-9947-5

Vanegas, C.H.; Bartlett J. Anaerobic Digestion of Laminaria digitata*:* The Effect of Temperature on Biogas Production and Composition. Waste and Biomass Valorization, 2013, 4:509-515, DOI: 10.1007/s12649-012-9181-z

Vanegas, C.H.; Bartlett, J. Green energy from marine algae: biogas production and composition from the anaerobic digestion of Irish seaweed species. Environmental Technology, 2013, 34(15): 2277-2283 DOI: 10.1080/09593330.2013.765922

4. Bucefalos – BlUe ConcEpt For A Low nutrient/carbOn System – regional aqua resource management

Project website:
https://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=4182

Funding source: LIFE programme

Coordinating beneficiary:
City of Malmö, Sweden

Partners:
Skåne Regional Council, Sweden
Municipality of Trelleborg, Sweden

Project start – 2012-09
Project end – 2015-08

Project type – RIA

Aim of the project:
The project aims to demonstrate a holistic approach for the regional coordination of sustainable resource management of aquatic biomass. The project aimed to do this via the implementation of innovative methodologies and technological applications for cultivating and harvesting mussels on a full-scale demonstration site using vertical harvesting in the Baltic Sea. The project also aimed to restore wetlands and establish algae cultivation sites to clean freshwater and provide efficient yields of biomass for biogas production. Additionally, aquatic biomass was used as a feedstock in the biogas plant instead of the conventional utilization as waste [8].

Objectives:

- Demonstrate methodologies, tools and stakeholder communication for the regional coordination of sustainable resource management of aquatic biomass;
- Demonstrate methods and techniques on a concrete business/action level that both contribute to the cleaning of water and air and also make profitable and sustainable use of aquatic biomass;

- Establish and demonstrate a full-scale mussel cultivation site in the Baltic Sea;
- Demonstrate vertical harvesting of mussels on submerged artificial constructions;
- Establish and demonstrate a number of wetlands and algae cultivation sites with the dual purpose of cleaning water and producing biomass for biogas;
- Establish and demonstrate a full-scale biogas plant for biogas production from aquatic biomass;
- Assess and test a number of usage areas and applications for aquatic biomass, including the rest products [8].

Results:
A demonstration biogas plant producing renewable biogas from beach cast algae was constructed in Smygehuk, Sweden. The two-step reactor design was chosen due to the high amount of sand in cast algae and rough texture of algae. The residue from the biogas process was used as biofertilizer in the agriculture sector. A full production cycle involving the collection of the algae (Fig. 2), transportation (Fig. 3), analysis of the feedstock, biogas process, analysis of the residue (biofertilizer) was developed and demonstrated during the implementation of the project [9]. The biogas plant produced 85 l CH_4/kg volatile solids within the project by using beach algae.

Figure 2: a) algae collected in Smyge marina, b) algae collected at Dalabadet (photo by City of Malmö)

Figure 3: Transportation of algae in containers to biogas plant (photo by City of Malmö)

Two different types of production wetlands (Tullstorp and Albäcken) were created in Trelleborg for demonstration purposes (Fig. 4, 5). An innovative method – two-stage ditch design was used for the construction of one wetland. The Bucefalos project demonstrated that biomass harvested from the wetlands could be used as a raw material for biogas production.

Figure 4: Reed planting in production wetland, Tullstorp (photo by City of Malmö)

Figure 5: Production wetland, Albäcken (photo by City of Malmö)

The experimental microalgae cultivation facility was built in conjunction with a wastewater treatment plant right next to the biogas plant in Smygehamn. The combination of these facilities created a synergetic effect. The sewage water contained high amounts of nutrients, which could be used by the microalgae. Wastewater was used for the cultivation of microalgae in photobioreactors. Different photobioreactor designs with and without artificial light were tested and evaluated during the Bucefalos project (Fig. 6). The artificial algae growing site led to a phosphorus removal of over 90% and the removal of about 60% of inorganic nitrogen from effluents.

Figure 6: Photobioreactors a) – the glass column, b) – the raceway (photo by City of Malmö)

Implementers of the project prepared the technical report on microalgae cultivation for cleaning effluents and producing algal biomass. This approach is being further developed in a national research and investment project.

Three ways of cultivating blue mussels off the coast of Malmö were demonstrated during the Bucefalos project. Blue mussels can absorb the nutrients from the water and accumulate it in their biomass. Consequently, the removal of mussels from the water can remove the surplus of nutrients from the water. The results obtained during the project showed that it is feasible to cultivate blue mussels for nutrient reduction and biomass production in the Öresund strait. The mussel cultivation site resulted in average biomass of 23.5 kg/m^2 on the most efficient small mesh nets. This equals to a total reduction of 176 kg of nitrogen and 17.6 kg of phosphorus.

The methods demonstrated during the Bucefalos project can easily be transferred from the region of Skåne to other regions with similar conditions. The implementation of the project caused direct environmental effects [9]:

- the biogas plant in Smygehuk has produced renewable biogas from beach cast algae, previously considered as useless;
- the production wetlands in Trelleborg have reduced the outflow of nutrients to the Baltic Sea;
- the mussel cultivation site in Malmö and the harvest of these mussels have reduced the nutrient levels in the Baltic Sea.

5. CONTRA – Conversion of a Nuisance To a Resource and Asset

Project website: https://www.beachwrack-contra.eu/

Coordinating beneficiary:

University of Rostock, Germany

Partners:

Institute of Oceanology of the Polish Academy of Sciences, Poland
Coastal Union Germany – EUCC, Germany
KS-VTCtech GmbH, Germany
Association of Polish Communes Euroregion Baltic, Poland
Linnaeus University, Sweden
Estonian Ministry of Environment, Estonia
University of Tartu, Estonia
Atlantic Branch of Shirshov Institute of Oceanology, Russia
University of Southern Denmark, Denmark
Krinova AB, Sweden
Municipality of Koge, Denmark
Gdansk University of Technology, Poland
Hanseatic Environment CAM GmbH, Germany

Project start – 2019-01
Project end – 2021-06

Project type – CSA

Aim of the project:
The project aims to change how coastal municipalities perceive and deal with beach wrack land to help to develop the knowledge required for its sustainable treatment as part of coastal water management [10].

Objectives:

- Test and propose utilization/recycling options that are sustainable & economically viable;
- Investigate and define value chains, market opportunities & legal frameworks for wrack-based products;
- Analyse recycling potential for pollution & nutrient remediation;

- Improve knowledge about the role & importance of beach wrack;
- Raise awareness about the impact of beach cleaning operations;
- Reduce the costs of problematic beach wrack for local authorities.

Results:

The project compiled a tool-kit of options for removing and using beach-wrack in a useful manner. The tool-kit was meant to help municipalities along the Baltic Sea coast to balance tourist demands for clean beaches with environmental protection. The project established an international network for knowledge exchange, capacity building, awareness raising and promotion of low-treatment or no-treatment options for beach wrack. Regarding the expertise of the consortium, it covered the whole range of the concerned areas including marine systems, coastal tourism, sustainable development as well as administrative structures of the Baltic Sea region [10]. This allowed for a comprehensive investigation of the topic, including different perspectives of the concerned stakeholders. Seven case studies in five different participating countries were basis for data collection, the development of strategies for handling the beach wrack and justification of these measures.

In summary, the project's outputs include:

- A 'Toolkit' of innovative & sustainable recycling options for problematic beach wrack
- Guidance on resource management and value chains
- Guidance to help municipalities put into daily practice the processes that will bring the most benefits, both environmental & economic
- Information on tourism trends & socio-economic responses to beach wrack and its management.
- Transnational & cross-discipline stakeholder support network

Project-related publications:

Sterr, H.; Ahrendt, K.; Enderwitz, S. Seegras und Treibsel - Altbekannte Strandressource neu entdeckt (in German), 2019, CR26_cover_0124.cdr (eucc-d.de)

6. EUAlgae – European Network for Algal-Bioproducts

Network website: https://www.energy.imdea.org/research/projects/eualgae

Action coordination:
IMDEA Energy

The EUALGAE COST Action "European network for algal-bioproducts", financed by the European Cooperation in Science and Technology (COST) and supported by the EU Framework Programme Horizon 2020, is coordinated by IMDEA Energy and counts with more than 190 researchers from 27 COST countries and 4 COST International Partner Countries.

Action start – 2015-03
Action end – 2019-03

Project type – CSA

Aim of the project:
To develop an economically-feasible model of the commercialization of algae-based bioproducts, as well as stimulate not only interaction among research groups across Europe, but also to foster cooperation between academia and industry. A further aim is to generate a synergistic approach for utilization of microalgae biomass for sustainable fuels and fine chemical products [11].

Objectives:
The general objective is to create an EU cluster for a successful development of algae-based bioproducts. The goal will be addressing optimum overall energy and mass balances, to improve the reliability and robustness of the relevant bioproducts, lowering capital and operational costs. Even though participants focus on individual stages of the overall process, their collaboration will ensure that aspects are still considered together as a whole. With this action, participants will be given the opportunity to network, collaborate and exchange information which otherwise will be limited. This action attempts to gather European top scientists in the field and thus become an important pillar of its further development worldwide.

Results:

This project benefited the research and development in the field of algae-based biofuel and biomaterials production by bringing together a diverse group of researchers. Various benefits achieved during the project timeline [11]:

- Environmental - entail carbon dioxide abatement by CO_2 uptake for microalgae growth and wastewater bioremediation by nutrients recycling or removal. Additionally, the substitution of existing products by alternative ones that are safer may reduce negative environmental impact:
- Economic - minimizing land use for microalgae culture production and energy requirements since microalgae are sun-powered microorganisms
- Societal - mitigation of negative impacts of current fuels
- The development of algae bioproducts would raise the need to safeguard natural resources by elaborating public policies

Additional benefits of the project:

- Coordination of research efforts, transfer of knowledge and critical analysis of data
- Improvements in the knowledge of microalgae biomass utilization for biochemical and biofuel productions
- Increase of European economy competitiveness by implementing new technologies and alternative bioproducts generation in small and medium enterprises

7. GRASS – Growing Algae Sustainably in the Baltic Sea

Project website: https://www.submariner-network.eu/grass

Coordinating beneficiary:
KTH, Royal Institute of Technology, Sweden

Partners:
University of Tartu, Estonia
Finnish Environment Institute, Finland
National Marine Fishers Research Institute, Poland
University of Turku, Finland
Latvian Institute of Aquatic Ecology (LIAE), Latvia
SUBMARINER Network for Blue Growth EEIG, Germany
Republic of Estonia Ministry of Environment, Estonia
Kurzeme Planning Region, Latvia
Uppsala University, Sweden

Project start – 2019-01
Project end – 2021-06

Project type – CSA

Aim of the project:
The project aims to raise awareness and to develop capacity building in macroalgae cultivation, harvesting and use among public authorities (PAs) and other relevant stakeholders across the Baltic Sea Region (BSA). PAs, ministries, planning regions and countries play crucial role in promoting macroalgae as they are the main legislative bodies that also control much of the national and regional funding. GRASS aims to close the legislative gap for macroalgae cultivation in order to facilitate its introduction to the market as food, energy and consumables, such as plastics. The project maps possible sites for macroalgae cultivation and harvesting, which include implications for spatial planning [12].

Objectives:
The project aims to assess the potential and effects of macroalgae cultivation and harvesting in the BSR by collecting and analysing environmental data, identifying suitable sites and efficient production methods, looking at current gaps in legislation and regulation to unlock the potential of sustainable

production and use of macroalgae (e.g. food), through knowledge transfer activities and guiding materials for PAs
Highlighting the socio-economic benefits and opportunities of macroalgae cultivation, harvesting and use in different regions in the BSR, and developing a decision support tool for macroalgae production.
The activities will be supported by:

- Extensive stakeholder involvement through regional dialogue meetings;
- Three transnational Working Groups operating across the WPs to analyse complex transnational issues;
- A transnational conference to bring together and transfer knowledge among relevant stakeholders in the Baltic Sea regions

Results:

1. A knowledge pack for public authorities will include all necessary information, collected from the project work on the topics of:
    a) Cultivation and harvesting of macroalgae in the Baltic Sea
    b) Macroalgae applications and markets
    c) Regulation
2. A synthesis report of benefits, risks and opportunities of macroalgae cultivation, harvesting, and use with bundling of environmental, regulatory and socio-economic aspects.
3. Maps illustrating the suitable sites for cultivation, as well as special planning synergies and conflicts [13].

8. Greater BIO – Optimize the use of biomass

Project website: http://www.gate21.dk/greater-bio/

Coordinating beneficiary:

Gate21, Denmark

Partners:

2050 Consulting, Sweden
Roskilde University, Denmark
Sustainable Business Hub, Sweden
Odsherred Municipality, Denmark
Energy Consulting Network A/S, Denmark
Lejre Municipality, Denmark
Lund University, Sweden
Business Lolland-Falster, Denmark
Biotrans, Denmark
BOFA, Denmark
Bornholm's Waste Treatment, Denmark
NSR AB, Sweden

Project start – 2020-01
Project end – 2022-12

Project type – CSA

Aim of the project:

To optimize the circular utilization of the biomass, from raw biomass to the production of bio-based materials and energy - and finally as nutrients that are returned to nature and thus contribute to the formation of new biomass by:

- Sharing knowledge between municipalities that actively work with the bioeconomy and based on this develop tools or guidelines, which should make it easier for a municipality to prioritize the use of local biomass and support relevant actors who can implement this.
- Increase collection and use of biomass where, based on the prior assessment, it is sustainably and economically feasible, in terms of energy and biodiversity.

- Increase the production of biogas from new biomass, which is not yet considered or not efficiently utilized. This could be residual biomass from other uses, where the by-products or waste products could be used in biogas plants. Furthermore, the use of biogas plant residues as organic fertilisers should be improved, in order to achieve a higher value and thereby improve the overall profitability of biogas production.
- Investigate the usefulness of biochar and assess when biomass should be converted to biochar and energy rather than biogas.
- Promote biodiversity by collecting biomass in cases, which make is more favourable for the local species. For example, by removing grass and thus nutrients from areas that need to be nutrient-poor in order to regain the original habitat type and the high species diversity [14].

The project is based on seven different cases: One case is supposed to represent as a model case, on which basis an assessment tool will be developed that could help municipalities prioritize the use of their biomass, in order to use it most optimally. The other seven cases have their own focus in regard to the uses of the available biomasses [14]:

1. **Municipal prioritization and management of biomass**

The purpose of the case is to develop an assessment basis for the municipalities' prioritization of local biomass, so that it becomes easier to assess the application possibilities of the biomass.

2. **Seaweed as an energy source**

The purpose of the case is to identify and optimize the methods for collecting seaweed based on the rules in Sweden and Denmark by performing environmental and economic analysis on the efficiency of different areas of use of seaweed. Also, to develop a concept for how the municipalities can make it attractive for companies to receive and use the seaweed for energy production.

3. **Smaller grass, greater biodiversity**

The purpose of the case is to, among other things, find profitable collection methods for grass on municipal land, by investigating how new machinery or new collection and application methods can provide an opportunity to collect the biomass without additional costs for the municipality.

4. **Biochar as a new raw material**

The case is divided into three areas: 1) Knowledge collection and market analysis 2) development and testing of biochar with different properties and development of product prototypes, 3) dissemination of knowledge. Central to the case is the work of developing production and creating a market for the sale of biochar.

5. **Collection of organic waste**

The case is an interdisciplinary collaboration between Gate 21's partners as well as hotels and restaurants on Bornholm.

6. **Biogas**

The purpose is to support the (possibly) upcoming gas pipeline to Lolland, so that it becomes green (biogas). Including a support for the establishment of two biogas plants.

7. **Bio-based materials**

In this case, work is being done to utilize unused quantities of biomass by investigating whether the residual biomass can be used for bio-based building materials in the construction industry in Sweden and Denmark.

9. LiveLagoons – The use of active barriers for the nutrient removal and local water quality improvement in Baltic lagoons

Project website: http://www.balticlagoons.net/livelagoons/

Coordinating beneficiary:

Klaipėda University, Lithuania

Partners:

EUCC – The Coastal Union Germany E.V., Germany
IBW PAN – Institute of Hydro-Engineering of the Polish Academy of Sciences, Poland
Curonian Spit National Park, Lithuania
Seaside Resort Ueckermuende, Germany
LUNG – State Authority for Environment, Nature Protection and Geology Mecklenburg-Vorpommern, Germany
Wolinski National Park, Poland
Tolkmicko Town and Commune, Poland
Federal State Institute of Agriculture and Fishery, Germany

Project start – 2017-08
Project end – 2020-07

Project type – RIA

Aim of the project:
To improve water quality and create bathing conditions inside the South Baltic lagoons, where under normal conditions algal blooms and sediment resuspension prevent recreational bathing [15].

Objectives:

- Stocktaking of the best available green technologies for trapping and removing nutrients from the shallow lagoon waters adjacent to the beaches that can be suitable for bathing
- Building a network of communities and stakeholders interested to test the green technologies of nutrient trapping and removal in practice
- Implementation of the living barriers at selected pilot sites

- Transfer of acquired knowledge and dissemination of good practices to other South Baltic lagoon communities and beyond.

Results:
Floating wetlands were found to be a promising solution to tackle the eutrophication issue. Floating structures are planned with native emergent macrophytes. The plant roots adsorb phosphorus and nitrogen directly from the water, enhance particle settling due to the reduction of flow velocity and offer diverse habitats for fish, birds and insects. Concluding recommendations were given that should anticipate the installation of floating wetlands:

- Talk to stakeholders and make a list of possible installation sites
- Gather information regarding environmental conditions and location factors
- Water depth, water level fluctuations, waves and currents influence anchoring
- Consider regional fisheries, tourism, maritime traffic and nature protection areas in order to prevent spatial conflicts of use
- Get informed about regional laws and regulation.

First floating island were installed in the Curonian lagoon, Darss-Zingst and Szczecin lagoon in 2018 and 2019 (Fig. 7).

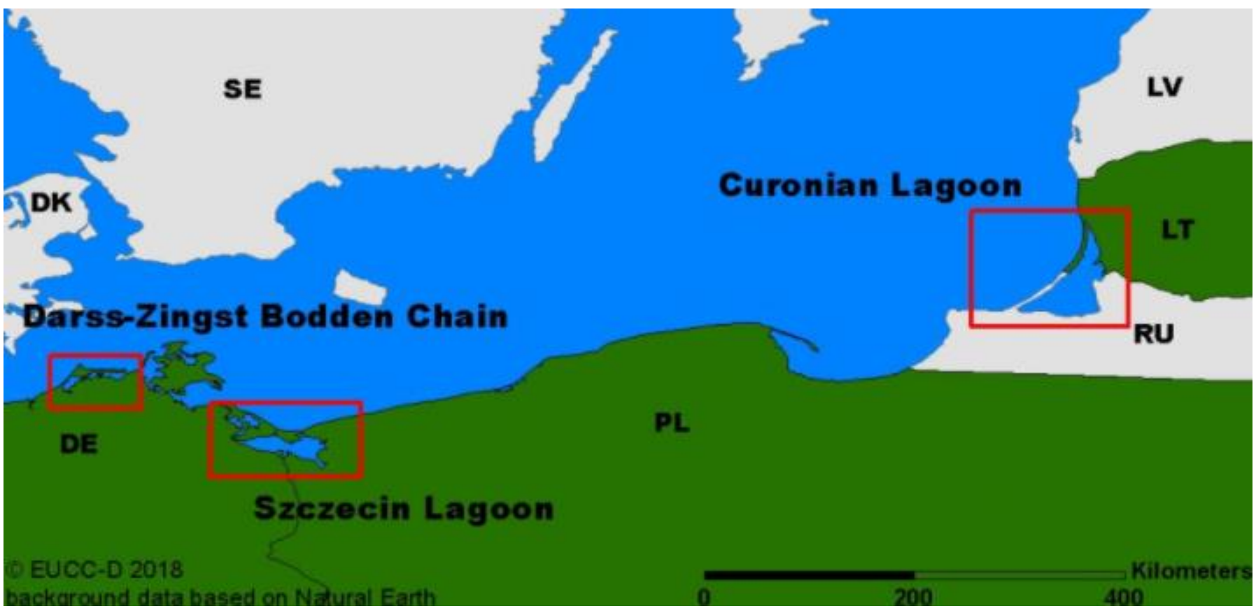

Figure 7: Map of pilot sites of floating wetlands installed within the LiveLagoons project along the South Coast (figure by EUCC-D, More information on https://www.balticlagoons.net/livelagoons/)

The first two small floating islands were installed in the aquaculture research station in Born at the Darss-Zingst Bodden Chain in 2018. The water quality as well as nutrient removal in the plant biomass was monitored [16].

Curonian spit national park installed the first active barrier in the Curonian lagoon in 2018 (Fig. 8). Local plants were chosen because they might have a highest chance to adapt to the particular environmental conditions of the Curonian lagoon. The growth as well as nutrient accumulation were monitored by students and researchers from Klaipėda University [16].

Figure 8: Net in Nida (photo by Žilvinas Grigaitis)

In 2019 in the Curonian lagoon two islands each of approximately 32 m² were installed close to Juodkrante (Fig. 9). Macrophytes like Common rush, Narrowleaf cattail, Flowering rush or Great manna grass were planted individually between extra hollow pipe spaces.

Figure 9: Floating island installed in Juodkrantė (photo by Małgorzata Bielecka)

The floating island in Poland was located in a marina on Wicko Lake, in Wolin National Park in the Szczecin lagoon. Emergent macrophytes like Lakeshore bulrush, Carex riparia, Broadleaf cattail and Iris pseudacorus were planted in the determined hollow spaces [16]. Several videos and media articles were produced, which can be found on the project website [17].

Project-related publications:

Karstens, S.; Nazzari, C.; Bâlon, C.; Bielecka, M.; Grigaitis, Z.; Schumacher, J.; Stybel, N.; Razinkovas-Baziukas, A. Floating wetlands for nutrient removal in eutrophicated coastal lagoons: Decision support for site selection and permit process. Marine Policy, 2018, 97: 51-60
DOI: 10.1016/j.marpol.2018.08.030

10. MAB4 – Macroalgae biorefinery for high value products

Project website: https://www.dti.dk/projects/project-8211-macroalgae-biorefinery-for-high-value-products-mab4/37420

Funding source: Innovation Fund Denmark

Coordinating beneficiary:
Danish Technological Institute, Denmark

Partners:
Aarhus University Department of Bioscience, Denmark
Aarhus University Department of Environmental Science, Denmark
University of Copenhagen Department of Veterinary and Clinical Animal Sciences, Denmark
DTU Department of Chemical Engineering, Denmark
DTU National Food Institute, Denmark
Ocean Rainforest, Denmark
FermentationExperts, Denmark
AT-SEA Technologies, Belgium
Kattegatcentret, Denmark
Hoejmark Group – BHJ A/S, Denmark
Mellisa Naturkosmetik ApS, Denmark
Nordisk Tang by Endelave Seaweed, Denmark
Hortimare BV, Denmark

Project start – 2016-05
Project end – 2020-10

Project type – RIA

Aim of the project:
To establish seaweed cultivation as a Danish discipline for providing seaweed biomass for the business sectors of food and feed ingredients, and cosmetics [18].

Objectives:

Breed and mature sea-farmed crops of seaweed by improved and new cultivation methods in Danish and Faroese waters, with particular attention to seasonal development of algae bioactive substances and their conservation during harvesting and storage.

- Develop sustainable enzymatic and Green Solvent extraction methods for development of new algae products i.e., antioxidants, fucoidan, laminarin, alginate, proteins, and minerals. The products will be tested as food and feed ingredients as well as in skincare products.
- Techno-economic feasibility and LCA will assess for the whole value chain from cultivation to final marketed seaweed products.
- Industrial cultivation of 1-2 macroalgae in Denmark (4 hectares);
- Process for extracting food and feed ingredients from algae e.g., laminarin, alginate and fucoidan;
- Establishment of method for extracting antioxidants with selected qualities which can be implemented in skin care products;
- Bio refinery as a pilot facility will be established;
- Identification of barriers in algae cultivation and industry;
- Establishment of platform for stakeholders.

Results:

MAB4 bridged the gap between research, innovation and market within the macroalgae (seaweed) sector. The results provided guidelines for stakeholders from industry and for future seaweed cultivation. Professor Marianne Thomsen led and primarily worked with feasibility and identification of barriers in algae industry, and support the techno-economic and sustainability assessment of the supply chain of macroalgae resources and products, including socioeconomic measures. The results from MAB4 provided guidelines for stakeholders from industry and for future seaweed cultivation [18].

11. MACRO CASCADE – Cascading Marine Macroalgal Biorefinery

Project website: https://www.macrocascade.eu/

Funding source: Europe Union, Horizon 2020 programme

Coordinating beneficiary:

Danish Technological Institute, Denmark

Partners:

Ocean Rainforest company, Faroe Islands
Food and Biobased research, Netherlands
Wageningen University & Research, Netherlands
Matis, Iceland
Fermentationexperts, Denmark
The Energy Research Centre of the Netherlands (ECN), Netherlands
eCOAST Marine Research, Belgium
Novozymes, Denmark
Lund University, Sweden
Technical University of Denmark, Denmark
Hortimare, Netherlands
Region Midtjylland, Denmark
Cargill R&D Centre Europe, Belgium

Project start – 2016-10
Project end – 2021-03

Project type – RIA

Aim of the project:

To prove the concept of the cascading marine macroalgal biorefinery. Exploring and developing new technologies for breeding and cultivating *S. latissima* and *P. palmata* with the aim to create the production platform that covers the whole technological chain for processing sustainable cultivated macroalgae biomass – also known as seaweed – to highly processed value-added products [19].

Objectives:

The project has nine specific objectives:

- Obtain optimized strains of seaweeds to increase levels of target components in S. latissimi (sugerkelp, kombu) and Palmaria palmata (red seaweed, dulse);
- Improve scalable cultivation of seaweeds using 1D and 2D cultivation substrates, develop mechanical harvesting, increase biomass yield by a factor of 5, and reduce overall cultivation cost 50–75%;
- Improve methods for seaweed biomass preparation and storage stability;
- Develop patentable feed and food products with health promoting functions through innovative microbial refining methods of macroalgae in combination with rape seed;
- Develop scalable and sustainable extraction/separation methods for the production of multiple products from brown and red seaweeds or seaweeds residues by enzyme aided physicochemical methods. Targeted intermediate products are alginate, fucoidan, mannitol and protein;
- Develop a variety of efficient and robust carbohydrate active enzymes, with a range of specificities of relevance for processing macroalgal polysaccharides. Target high value products for feed, food, pharmaceuticals, cosmetics and chemicals are enzymatic derivatives of alginate, laminarin and fucoidans;
- Study the economic viability of the macroalgae cascading valorization schemes;
- Quantitatively assess the sustainability of the seaweed-based value chains, via a multi-criteria evaluation of the technological, environmental, economic, and social aspects;
- Develop sustainable business cases for a "blueprint" of the cascading marine macroalgal biorefinery.

Results:

Selective breeding of Saccharina latissima to obtain high biomass yield and increased levels of target components was performed. The better understanding of the biochemical composition of cultivated macroalgae (Saccharina latissima, A. esculenta and Laminaria digitata) was performed. It was demonstrated that the most important variables affecting biochemical content are macroalgal species and seasonal variation. Screw pressing of brown algae in laboratory (for Saccharina latissima, Alaria esculenta, and green seaweed Ulva lactuca) and pilot scale (for Saccharina latissima) on the Faroe Islands were realized. It was demonstrated that the use of flash dryers or multipass conveyor dryers is the most cost-efficient technology for removing moisture from algae biomass for industrial use. The application of biological and chemical ensiling additives for storage of algae biomass was performed. The degree of biomass grinding, temperature, type of used biological and chemical additives, concentration of used additives is important and affects to the final products.

Biorefinery schemes were developed for fresh, air dried and ensiled seaweed samples based on the chemical composition and properties of the various target compounds.
Various reports and protocols were delivered [20]:

- Based on the selective breeding of the selected species identification of the best combination of growth characteristics and content of value-added compounds;
- Report on seasonal variation of value-added components in different types of macroalgae
- Report of optimized conditioning process for seaweed;
- Report on drying and semi drying algae biomass for storage of algae biomass for valorization high-value-added products;
- Report on biological and chemical ensiling techniques for storage of algae biomass for valorization medium with value-added products;
- Report detailing the results of long-term storage;
- Report evaluating the feasibility of collecting the algae-juice during conditioning and pre-treatment;
- Process of conversion of algae into nutritious feed additives with increased (25%) digestibility;
- Process for production of algae enriched rapeseed-based feed for pigs;
- Report on process development for algal based food product;
- Report on biorefinery approach based on sample composition;
- Protocol for production of alginate-rich fraction;
- Protocol for production of fucoidan-rich fraction;
- Protocol for production of mannitol and laminarin;
- Protocol for production of protein-rich fraction;
- Protocol for production of polyphenol;
- Report with the techno economic analysis;
- Knowledge and data repository provided to relevant European platforms (incl. standards, norms, certifications and regulations relevant for MACRO CASCADE).

Project-related publications:

Allahgholi, L.; Sardari, R.R.R.; Hakvåg, S; *et al.* Composition analysis and minimal treatments to solubilize polysaccharides from the brown seaweed *Laminaria digitata* for microbial growth of thermophiles. Journal of Applied Phycology, 2020, 32: 1933–1947. https://doi.org/10.1007/s10811-020-02103-6

Ara, K.Z.G.; Månberger, A.; Gabriško, M; et al. Characterization and diversity of the complete set of GH family 3 enzymes from Rhodothermus marinus DSM 4253. Scientific Reports, 2020, 10; 1329. https://doi.org/10.1038/s41598-020-58015-5

Jönsson, M.; Allahgholi, L.; Sardari, R.R.R.; Hreggviðsson, G.O.; Nordberg Karlsson, E. Extraction and Modification of Macroalgal Polysaccharides for Current and Next-Generation Applications. Molecules, 2020, 25: 930. https://doi.org/10.3390/molecules25040930

Månberger, A.; Verbrugghe, P.; Guðmundsdóttir, E.E.; Santesson, S.; Nilsson, A.; Hreggviðsson,G.O.; Linares-Pastén, X.A.; Karlsson, E. N.Taxogenomic assessment and genomic characterisation of *Weissella cibaria* strain 92 able to metabolise oligosaccharides derived from dietary fibres, Scientific Reports, 2020, 10: 5853. DOI:10.1038/s41598-020-62610-x

Pilgaard, B.; Wilkens, C.; Herbst, F.A. et al. Proteomic enzyme analysis of the marine fungus Paradendryphiella salina reveals alginate lyase as a minimal adaptation strategy for brown algae degradation. Scientific Reports, 2019, 9, 12338, https://doi.org/10.1038/s41598-019-48823-9

Ron, E.Y.C.; Sardari, R.R.R.; Anthony, R. et al. Cultivation technology development of Rhodothermus marinus DSM 16675. Extremophiles, 2019, 23: 735–745. https://doi.org/10.1007/s00792-019-01129-0

Sardari, R.R.R.; Nordberg Karlsson, E. Marine Poly- and Oligosaccharides as Prebiotics. Journal of Agricultural and Food Chemistry, 2018, 66, 44: 11544–11549. DOI: 10.1021/acs.jafc.8b04418

Sardari, R.R.R.; Prothmann, J.; Gregersen, O.; Turner, C.; Nordberg Karlsson, E. Identification of Phlorotannins in the Brown Algae, Saccharina latissima and Ascophyllum nodosum by Ultra-High-Performance Liquid Chromatography Coupled to High-Resolution Tandem Mass Spectrometry. Molecules, 2021, *26*, 43. https://doi.org/10.3390/molecules26010043

Vuillemin, M.; Silchenko, A.S.; Cao, H.T.T.; Kokoulin, M.S.; Trang, V.T.D.; Holck, J.; Ermakova, S.P.; Meyer, A.S.; Mikkelsen, M.D. Functional Characterization of a New GH107 Endo-α-(1,4)-Fucoidanase from the Marine Bacterium Formosa haliotis. *Marine Drugs* 2020, *18*, 562. https://doi.org/10.3390/md18110562

12. MacroFuels – Developing the next generation Macro-Algae based biofuels for transportation via advanced bio-refinery processes

Project website: https://www.macrofuels.eu/

Funding source: European Union, Horizon 2020 programme

Coordinating beneficiary:
Danish Technological Institute, Denmark

Partners:
Energy Center of the Netherlands (ECN), Netherlands
Wageningen Food & Biobased Research (WFBR), Netherlands
The Scottish Association for Marine Science, Scotland
Avantium, Netherlands
SIOEN Industries NV, Belgium
Environmental Resources Management Limited (ERM), United Kingdom
Aarhus University, Denmark
EURIDA, Germany
Matis, Iceland
Fermentation Experts AS, Denmark

Project start – 2016-01
Project end – 2019-12

Project type – RIA

Aim of the project:
To produce advanced biofuels from seaweed or macro-algae. The targeted biofuels are ethanol, butanol, furanics and biogas [21].

Objectives:
- Increasing biomass supply by developing a rotating crop scheme for cultivation of seaweed, using native, highly productive brown, red and green seaweeds, in combination with the use of advanced textile substrates resulting in a year-round biomass yield.

- Improving the pre-treatment and storage of seaweed and to yield fermentable and convertible sugars at economically relevant concentrations (10-30%).
- Increasing bio-ethanol and bio-butanol production to economically viable concentrations by developing novel fermenting organisms, which metabolize all sugars at 90% efficiency.
- Increasing biogas yield to convert 90% of the available carbon in residues by adapting the organisms to seaweed.
- Developing thermochemical conversion of sugars to fuels from the mg. scale to the kg. scale.
- Performing an integral techno-economic, sustainability and risk assessment of the entire seaweed to biofuel chain.
- MacroFuels will develop technology for the production of fuels, which are suitable as liquid fuels or precursor thereof for the heavy transport sector as well as potentially for the aviation sector.

Results:
MacroFuels reached significant breakthroughs on the way to a sustainable seaweed production industry, which in Europe is still in its infancy. Results achieved include a proved novel year-round cultivation approach for seaweeds at test sites in Scotland and Denmark under different cultivation conditions (Fig. 10):

- 200 kg of seaweed were harvested in Denmark;
- 10 t of seaweed were harvested in Scotland;
- Cultivation of 4 species of seaweed was investigated;
- 20 l of seaweed derived fuel compound were produced;
- A test car drove 80 km on a seaweed fuel mix;
- The biofuel production from cultivated seaweed was brought from Technology Readiness Level 3 to 5;
- Market readiness of seaweed-based fuels or fuel additives is envisaged for 2030.

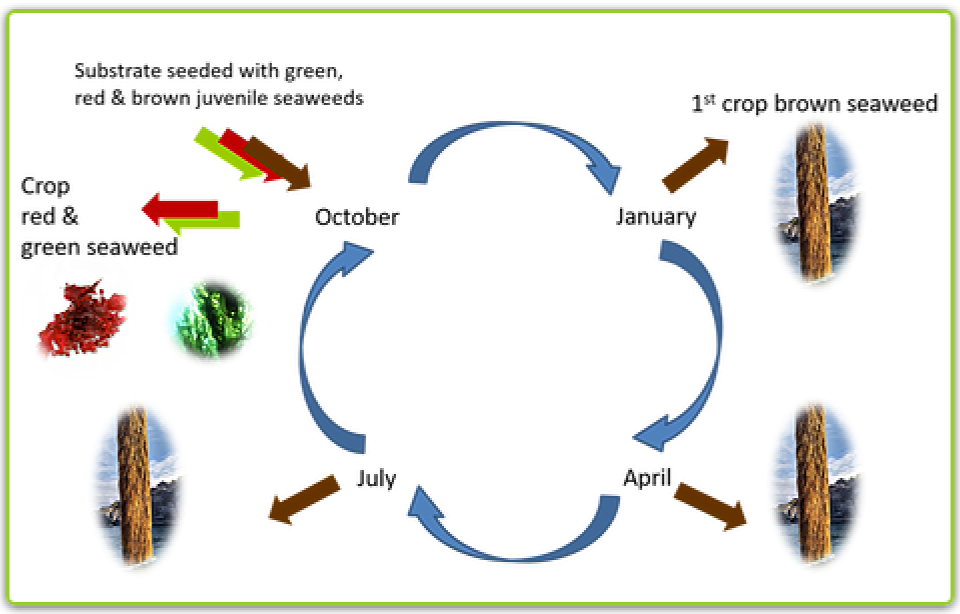

Figure 10: The MacroFuels rotating crop concept (figure by TNO, edited by Eurida)

MacroFuels tested chemical and biological ensiling via lactic acid fermentation processes. Results showed great potential of ensiling as a biomass preservation method for industry-scale operations due to the low energy input required. Processes were optimized including combining biological and chemical ensiling. All ensiling processes and their combinations could represent cost-effective options for future business operations, especially when combined with novel storage concepts. It was determined that fermenting sugar kelp by using lactic acid bacteria seems to improve its sensory properties and significantly reduces the tissue content of cadmium and mercury, while sugar and protein contents remain nearly unchanged [22].

A promising fermentation protocol for the production of ethanol from seaweed by meso-yeast fermentation using algal polysaccharide laminarin was established. The pilot production of ethanol was demonstrated, and 8 l of distilled ethanol was tested in a real engine.

8 g/l butanol from desalted Saccharina latissima hydrolysate with addition of sugars was produced. Glucose and mannitol were metabolized at 95% efficiency. A novel strain of Clostridium beijerinckii for the direct conversion of algal biomass to ABE was constructed. The pilot production of ABE was performed.

MacroFuels developed routes to produce furanics by dehydrating carbohydrates from seaweed. Producing a diesel additive proved most promising from red seaweeds via their conversion to a fuel precursor, which can react with butanol to a fuel mixture. Furfural was selectively produced via pyrolysis from alginate in low yields (<2% wt). A furanic fuel additive (at kg scale) produced from red seaweed for engine testing was implemented.

The fuels developed in MacroFuels project were tested in a real car. The four cylinder 1.2 TSI engine from Volkswagen golf was used in the tests and three different fuels (ethanol, ABE and furanic fuels) were investigated. The produced fuel blends were tested for engine performance both on an engine dynamometer, and on a chassis dynamometer in the laboratory and during real driving emission test on a 80 km route according the European PEMS procedures. The tested biofuels and additives demonstrated excellent engine performance, fully equivalent to commercial petrol. The results indicated that the measured emissions (NO_x, CO, CO_2, SO_2) were similar as for commercial fuels.
The entire value chain addressed in MacroFuels has been assessed. Results showed that the costs for biomass production and automated harvesting are currently too high for fuel applications unless integrated in a cascading biorefinery in which seaweed compounds are valorized for high value applications. The project implementers indicated that the seaweed cultivation areas of 369 km^2 (are needed for one single seaweed-to-fuels biorefinery.

Policy recommendations:

- Support the development of a European open and usable knowledge base on potential economic, environmental and social impacts resulting from large-scale seaweed production.
- Establish a robust policy framework as orientation for European and national licensing bodies for large-scale seaweed cultivation sites.

- Co-create European best practice models and standards for seaweed cultivation sites, based on latest findings from research projects and pilot sites.
- Work towards agreements on acceptable levels of environmental change caused by large-scale seaweed production and suitable management options, instead of following a zero-change approach. Introduce appropriate benchmarks and thresholds for monitoring and risk assessment needs to avoid over-specification of monitoring and data collection by seaweed cultivators that could prove too costly and deliver 'data-rich, information poor' (DRIP) data.
- Initiate and facilitate dialogues between various users of the marine space to counteract competition and instead promote synergies via multi-use marine energy infrastructures, ecosystem-based approaches and/or Integrated Multi-Trophic Aquaculture (IMTA).
- Incentivise long-term investment in the seaweed-based bioenergy sector in Europe by industries, potentially through subsidies of biofuels derived from aquatic biomass.
- Reinforce dialogues with societal stakeholders, such as local residents and fishermen in future seaweed cultivation areas, by making social licenses a mandatory part of each seaweed cultivation site license [22].

Project-related publications:

Bruhn, A.; Brynning, G.; Johansen, A.; Lindegaard, M.S.; Sveigaard, H.H.; Aarup, B.; Fonager, L.; Andersen, L.L.; Rasmussen, M.B.; Larsen, M.M.; Elsser-Gravesen, D.; Børsting, M.E. Fermentation of sugar kelp (Saccharina latissima)—effects on sensory properties, and content of minerals and metals. Journal of Applied Phycology, 2019, 31(5): 3175–3187. DOI: 10.1007/s10811-019-01827-4

Bruhn, A.; Janicek, T.; Manns, D.; Nielsen, M.M.; Balsby, T.J.S.; Meyer, A.; Rasmussen, M.B.; Hou, X.; Saake, B.; Göke, C.; Bjerre, A.B. Crude fucoidan content in two North Atlantic kelp species, Saccharina latissima and Laminaria digitata - seasonal variation and impact of environmental factors. Journal of Applied Phycology, 2017, 29: 3121-3137. DOI: 10.1007/s10811-017-1204-5

Campbell, I.; Macleod, A.; Sahlmann, Ch.; Neves, L.; Funderud, J.; Øverland, M.; Hughes, A.D.; Stanley, M. The Environmental Risks Associated With the Development of Seaweed Farming in Europe - Prioritizing Key Knowledge Gaps. Frontiers in Marine Science, 2019, 6: https://doi.org/10.3389/fmars.2019.00107

Clancy, R. Policy *Brief,* Seaweed as sustainable biomass for a European bioenergy sector - Findings and recommendations from the MacroFuels Horizon 2020 research and innovation project (2019).

Diallo, M.; Hocq, R.; Collas, F.; Chartier, G.; Wasels, F.; Wijaya, H.S.; Werten, M.W.T.; Wolbert, E.J.H.; Kengen, S.W.M.; van der Oost, J.; Ferreira, N.L.; López-Contreras, A.M. Adaptation and application of a two-plasmid inducible CRISPR-Cas9 system in Clostridium beijerinckii. Methods, 2019, 172: 51–60. https://doi.org/10.1016/j.ymeth.2019.07.022

Diallo, M.; Simons, A.D.; van der Wal, H.; Collas, F.; Houweling-Tan, B.; Kengen, S.W.M.; López-Contreras, A.M. L-Rhamnose Metabolism in Clostridium beijerinckii Strain DSM 6423. Applied and Environmental Microbiology, 2019, 85(5): e02656-18 DOI:10.1128/AEM.02656-18

Duarte, M.; Wu, J.; Xiao, X.; Bruhn, A.; Krause-Jensen, D. Can Seaweed Farming Play a Role in Climate Change Mitigation and Adaptation. Frontiers in Marine Science, 2017, 4. DOI: 10.3389/fmars.2017.00100

Hou, X.; From, N.; Angelidaki, I.; Huijgen, J.J. W.; Bjerre, A. Butanol fermentation of the brown seaweed Laminaria digitata byClostridium beijerinckii DSM-6422. Bioresource Technology, 2017, 238: 16–21. DOI: 10.1016/j.biortech.2017.04.035

Lopez-Contreras, A.M,; Harmsen, P.F.H.; Hou, X.; Huijgen, W.J.J.; Ditchfield, A.K.; Bjornsdottir, B,; Obata, O.O.; Hreggvidsson, G.O.; van Hal, J.W.; Bjerre, A.B. Biorefinery Approach to the use of Macroalgae as feedstock for biofuels. Algal Biofuels, 2017: 103 - 139. ISBN 9781498752312. https://doi.org/10.1201/9781315152547-4

Parjikolaei, B.R.; Bruhn, A.; Eybye, K.L; Larsen, M.M.; Rasmussen, M.B..; Christensen, K.V.; Frette, X.C. Valuable Biomolecules from Nine North Atlantic Red Macroalgae: Amino Acids, Fatty Acids, Carotenoids, Minerals and Metals. Natural Resources, 2016, 7(4): 157-183. DOI: 10.4236/nr.2016.74016

Wasels, F.; Jean-Marie, J.; Collas, F.; López-Contreras, A.; Ferreira, N. A two-plasmid inducible CRISPR/Cas9 genome editing tool for Clostridium acetobutylicum. Journal of Microbiological Methods, 2017, 140: 5–11, DOI: 10.1016/j.mimet.2017.06.010

13. Netalgae – Inter-regional network to promote sustainable development in the marine algal industry

Project website: http://www.netalgae.eu/netalgae-project.php

Funding source: European Union, European Regional Development Fund

Coordinating beneficiary:

Indigo Rock Marine Research Limited, Ireland

Partners:

The University of Algarve, Portugal
Syndicat Mixte pour l'Equipment du Littoral, France
University of Brest AMURE, France
Mutrikuko Institutua, Spain
Institute For Innovation In Basque Technical And Vocational Education And Training (TKNIKA), Spain
Bord Iascaigh Mhara, Ireland
Agrocampus Ouest, the Fisheries and Aquatic Sciences Cente, France
Viking Fish Farms, Ardtoe Marine Laboratory, United Kingdom
The Norwegian Institute for Agricultural and Environmental Research (BIOFORSK), Norway

Project start – 2010-10
Project end – 2012-12

Project type – CSA

Aim of the project:

To establish a Europe-wide network of the key stakeholders within the European marine macro algae sector. Creating a set of best practice guidelines for the management of macro algae resources into the future, based on an assessment of the existing regulatory and administrative systems across the project area [24].

Objectives:

- General baseline study of all national algae industries across the project area.

- Assessment of algae regulation, administration and management systems.
- Development of best practice guidelines for management and sustainability of algae resources.
- Development of a European algal industry database.
- Creation of a European- wide algae industry portal and business tools.

Results:

European network of relevant stakeholders within the marine macroalgae sector was created. Compilation of information from different regions has resulted in a wide-ranging policy study of existing practices within the macroalgae industry.

Analysis of the results has established a best practice model and suggested policies for the successful, sustainable and commercial utilization of marine macroalgae resources. The diverse network of developing industrial, commercial and scientific links between the project partners was established.

A series of business tools have been developed: web-based communication portal, trade directory, training and development manuals [24].

The project has established technology transfer initiatives and supported the formation of a European representative body for entities trading in macroalgae resources and products.

At present, there are problems in Ireland, the United Kingdom, France (Bretagne and Normandy) and Spain (Galicia and Pais Vasco) with a lack of policies and administrative tools to support the necessary environmental research, sustainability management, industry representation and commercial development tools to support macroalgae industries. Therefore, national and regional development policies and regulatory environments were studied, in order to identify a development model of good practices for regions to adopt as standard procedure to develop strong industries, environmentally sustainable and economically viable, based on the utilization of native marine macroalgae resources.

General recommendations for seaweed harvesting in Europe:

- To ensure the sustainability of algae resources and harvesting activities, the total amount of seaweed harvested should be set in accordance with the availability of wild seaweed resources
- The harvesting techniques employed must be those that offer a low impact on the ecosystem and are adapted to the species biology (to encourage regeneration of resources post removal)
- In order to improve the likelihood of resource sustainability it is recommended that some species be cut at a certain size defined by scientists and according to species biology. For some species, the use of ripping as a means of harvesting may be authorized
- Impact assessment of the harvesting activity should be made not only on the target species but also on the associated communities.

14. SeaGas – Using seaweed for the generation of sustainable energy

Project website: http://seagas.co.uk/

Funding source: InnovateUK programme (national source)

Coordinating beneficiary:
Centre of Process Innovation (CPI), United Kingdom

Partners:
The Crown Estate, United Kingdom
Queen's University Belfast, Northern Ireland
Newcastle University, United Kingdom
The Scottish Association for Marine Science (SAMS), Scotland
Cefas, United Kingdom

Project start – 2015-04
Project end – 2018-06

Project type – RIA

Aim of the project:
To utilize farmed seaweed (*Saccharina latissima*), non-food, sustainable resource in the UK. As a farmed resource, seaweed could potentially be used instead of land biomass to produce both bioenergy and a digestate suitable for use as fertilizer [25].

Objectives:
Develop a novel storage system to support a 12-month AD operation – to counter seaweed availability and variability.
Support exploitation of seaweed across other applications which were not viable, e.g., fermentation to bio-fuel.
Meet the cost targets of commercial seaweed farming.
Assess community responses and attitudes to seaweed farming *per se* and its use for energy production.

Results:

A novel storage system for seaweed was investigated to counter variability in seaweed production, and through that support continuous 12-month operation of an AD plant. Auto-fed seaweed digestors were developed in 2016. The project was innovative in its provision of a scalable, industrial AD process for seaweed. A unique UK implementation plan will be developed, directed by environmental and socio-economic assessment and economic modelling, to facilitate uptake by AD end users and initiate the building of a viable supply chain for farming and storage of seaweed. It will be the platform for further exploitation of seaweed across other applications.

As part of this project, Queen's Marine Laboratory was able to upscale seaweed production on test site to 20 t of harvested seaweed in one year, a UK record in 2018. This significant milestone gives a perspective for the case that bioenergy could be produced from seaweed using AD at a commercial scale [25].

15. Seamatter – Revalorization of coastal algae wastes in textile nonwoven industry with applications in building noise isolation

Project website: http://www.seamatter.com/

Coordinating beneficiary:
Textile research institute AITEX, Spain

Partners:
Ecology Coastal Institute (IEL), Spain
Material Science and Technology Laboratory, University of Perugia, Italy
ATEVAL, Spain

Project start – 2012-09
Project end – 2015-02

Project type – CSA

Aim of the project:
The project aims to demonstrate and validate the reuse of algae and coastal seaweed accumulations as raw material in the composite industry by demonstrating and applying wet technology to convert these materials into structures reinforcement for composites of nonwovens by the wet-laid technology. Also, it is expected to improve the systems of marine waste disposal [26].

Objectives:
- Contribute to the development and demonstration of innovative approaches policy, technologies, methods and instruments;
- Consolidate the contribution to the knowledge base for the development, assessment, monitoring and evaluation of environmental policy and legislation;
- Support the design and implementation of approaches to monitoring and assessment of the state of the environment and the factors, and responses that impact pressure on it;
- Facilitate the implementation of European Union environment policy, with particular emphasis on implementation at regional and local level.

Results:

The following results have been obtained:

- A study of the current situation of the management of algae and seaweed deposition wastes from the coast involves specific knowledge of the environmental function with eleven algae, sea grass specifically, in the ecological balance within biological interaction of the marine environment.
- IEL have developed activities aimed at collecting information involving technological guidance regarding the management of marine biological waste.
- Studies have been made of the amounts deposited and withdrawn from the Spanish coast, and analysis of waste management, from the analysis of them, harvesting, transportation and most common uses. Also detailed studies on storage, their use and application, machinery and accessories used in the cleaning of beaches as primary actions of the process.
- Environmental costs of using these management systems for the collection / transport of marine debris. Studies of the effects caused by the removal of sediment dynamics wrack on beaches. Some conclusions:
  - Loss of temporary protection
  - Elimination of the base of boulders with the clean-up
  - The loss of grassland the erosive power of the storms on beaches.

In terms of legislation, orders, memoranda, and best practices guides are conducted a detailed study of current legislative options regarding waste management and beach cleaning [27].

It was confirmed how, from a socio-economic base point, the diverting of algae waste from the landfill and the subsequent reusing may be considered significantly advantageous in comparison to the mere disposal. Detailed cost analysis for cleaning, shredding, manufacturing of wet-laid products and adding all of the above estimated costs for the manufacturing process of nonwovens by the wet-laid technology at laboratory scale, the final cost of manufacturing the nonwoven was considered equal to 1.9 EUR/m^2 was obtained. This cost was substantially higher than full-scale production costs, due to slower output times and smaller capacity available in the laboratory.

After the dissemination campaign in beaches and once the results of the surveys obtained, IEL has had some dissemination meetings with Coastal city councils in order to provide them the Best Practices Guidelines and also to inform them about the results [27]. The city councils visited were San Javier (Environmental Department), Altea, Guardamar del Segura, Xábia, Villajoyosa, Santa Pola.

16. SeaRefinery – The Seaweed Biorefinery – for high value added products

Project website: http://www.marinebiotech.eu/seaweed-biorefinery-%E2%80%93-high-value-added-products-searefinary

Funding source: European Union the 7th Framework Programme

Coordinating beneficiary:
Danish Technological Institute, Denmark

Partners:
Centexbel, Belgium
Cork Institute of Technology, Ireland
Marinox ehf, Iceland
CyberColloids Ltd, Ireland
Sionen Industries NV, Belgium
Hortimare AS, Netherlands
ViVoX ApS, Denmark

Project start – 2015-11
Project end – 2018-10

Project type – RIA

Aim of the project:
To develop and test an innovative biorefinery approach for seaweed exploitation in Northern Europe, led by industrial key players and specifically aimed at producing algal bioactive molecules for nutraceuticals, functional foods, cosmetics, pharmaceuticals and bio-based materials [28], [29].

Objectives:

- Develop an integrated biorefinery process;

- Using eco-friendly chemical and enzymatic step-wise extraction and purification steps;
- Produce high value-added components from cultivated brown seaweed (Sccaharina latissima, Alaria esculenta) including antioxidants (phlorotannins), hydrocolloids (alginate), and other bioactives (laminarin, fucoidan and protein);
- Evaluate these extracted components for use in neutraceutical & functional food ingredients, cosmetic & medical products and bio-based materials;
- Demonstrate the biorefinery concept at pilot scale.

Results:

- Robust processes for lab scale biorefinery of Saccharina latissima & Alaria esculenta;
- Multi stream extraction of fucoidan, laminarin & alginate;
- Polyphenol levels too low to be of interest in this project;
- Demonstrated transfer of biorefinery to pilot scale (600 kg);
- Development of alginate rich seaweed fibres with commercially interesting properties;
- Demonstrated functionality in targeted food and cosmetics and applications.

Impact

- SeaRefinery is an industrially driven project, with the aim to enhance the competitiveness of the marine high-value bio-industry:
  - Improving Breeding and cultivation techniques for seaweed culture;
  - Improving Harvesting and storage technologies;
  - Development of new processes and products;
  - Raise awareness in the public and industrial sector as well as policy makers.
- Ultimately this is expected to create jobs and generate income especially in coastal areas of Europe
- Contribute to mitigate eutrophication and improve the ecological status of the marine environment in accordance with the EU Marine Strategy Framework Directive (Directive 2008/56/EC).

Future directions and needs

- Lacking Regulatory framework for seaweed cultivation is an obstacle and barrier for the development of the industry;
- Standardization of seaweed-based products is a requirement for the development of this business area
  - Specifications for food/feed and non-food sector applications;
  - Develop standards determination methods for algae and algae-based products;
  - Technical committee has been established in Oct 2017 (CEN TC 454).
- Improving awareness for seaweed-based products in public.

17. SOLROD – Solrød Biogas Plant Investment Project

Plant website: https://solrodbiogas.dk/en/forside/

Funding source: Co-funded by the Intelligent Energy Europe Programme

Coordinating beneficiary:
Solrød Biogas A/S Company, Denmark

Partners:
CP Kelco, Denmark
Chr. Hansen, Denmark
VEKS, Denmark
Roskilde University, Denmark
Bigadan, Denmark
Solrød Bioenergi ApS, Denmark
local farmers
EU-MLEI project
Region Zealand, Denmark
Growth Forum Zealand, Denmark

The first plant construction phase began in 2014. The plant started operating in in 2015 and runs till now [30].

Project type – RIA

Aim of the project:
To reduce Solrød community's coastline odour problem, caused by seaweed washed to the beach, as well as mitigate climate change by generating green energy (biogas), thus reducing the CO_2 emissions. Later, the project's idea has expanded and incorporated local authorities, industry and agriculture. It allowed to build up a biogas plant and generate energy from collected seaweed, industrial organic residues and livestock manure, with this solving several local problems [30].

Objectives:
Increase the level of renewable energy in heat and power generation
Replacing fossil fuels in the process
Securing of significant greenhouse gas (GHG) reductions
Establishing the biogas plant is to achieve multilateral advantages [30]:

- **Renewable energy:** Production of renewable energy and thus the contribution to the changeover of the energy system, which enjoys national and local political support.
- **Obnoxious smell:** Contribute to solving the odour issues stemming from washed-up seaweed and brown algae on Solrød beach by using seaweed and brown algae in the biogas plant.
- **Climate efforts:** The use of by-products and seaweed for the production and use of power and heat from the biogas production replace fossil fuel and contribute to reducing the emission of greenhouse gases.
- **Plant nutrients:** The removal of seaweed from the coast contributes to reducing the aquatic environment’s pollution. By removing seaweed and brown algae, it will almost be possible to reduce the nitrogen and phosphorous quantities corresponding to the first water environment action plan’s objectives, stemming from the EU Water Framework Directive.
- **Manure:** The raw material composition of the biogas plant and the optimisation of this composition mean that a well-qualified natural fertilizer is developed. A product that can replace fossil produced fertilizers.
- **Waste issues:** The design and the raw material composition of the plant also contribute to solving a waste issue, including cheaper and more environmentally safe waste handling in the participating industrial companies.
- **Conversion of district heating:** The objective of the district heating company VEKS is to generate fossil-free heat supply no later than in the year 2025. The use of the excess heat from the biogas plant’s gas engine will contribute towards this conversion.

Results:
The collection of seaweeds from the coastline of the beach caused the reduction of odour problems [30]. Also, the Solrød Biogas Plant Investment Project activities improved seawater quality and induced higher recreational value of the maritime coastal area.

Moreover, the project has caused the decrease of nitrogen leaching to the aquatic environment by 62 t/year. Also, project’s implementation induced reduction of phosphorus leaching to the aquatic environment by 9 t/year [30].

Figure 11: The Solrød biogas plant (Solrød Biogas A/S, 2018)

The Solrød Biogas plant (Fig. 11) targeted to reduce greenhouse gas emissions by approximately 40,100 t/year, which represent 51% of the municipality target for 2025. The reference published in 2019 stated that the Solrød Biogas plant reduced greenhouse gas emissions by approximately 45,000 tons of CO_2 per year [30].

The Solrød biogas plant caused a decreased dependency on fossil fuels as well as foreign energy sources and guaranteed the production of renewable energy from sustainable and local sources (seaweed, pectin residues, lactic acid and yeast slurry, manure) (Fig. 12). Consequently, 23.8 GWh of electricity, 34.7 GWh of heat and 6,279,131 m^3 of methane were produced in 2017 [31]. The similar tendency remained in 2018, when 24.7 GWh of electricity, 33.4 GWh of heat and 6,966,085 m^3 of methane were produced [32].

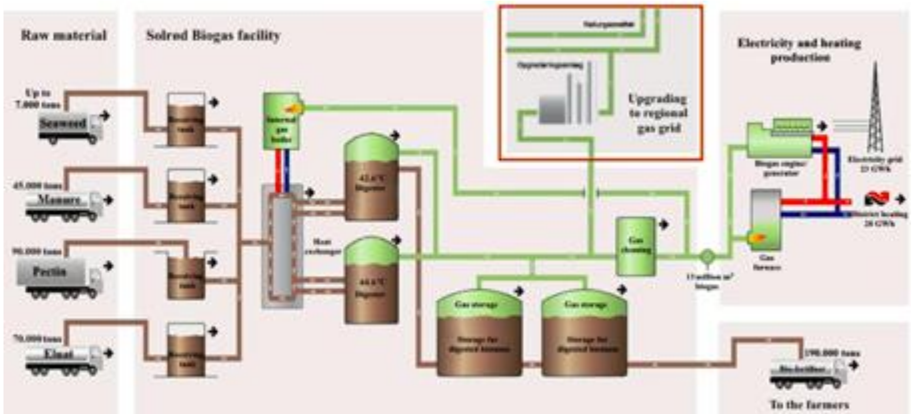

Figure 12: The scheme of biogas and organic fertiliser production in the Solrød biogas plant [33]

The Solrød biogas plant produces digestate (190,000 t/year), which is used as organic fertiliser (suitable for all types of crops) in the agricultural sector [34]. Digestate (organic fertiliser) replaces artificial fertilisers (commercial fertilisers) and other organic fertilisers (manure). Thus, the number of fossil resources used for the production of artificial fertilisers as well as greenhouse gas (GHG) emissions are reduced.

Furthermore, the plants rapidly absorb organic fertiliser. Accordingly, the crop uptake to nitrogen increases by 10-25% and the risk of nitrogen leaching into the environment decreases. Also, organic fertiliser results in a higher crop yield compared to manure [34]. Moreover, the farmland owners get a homogeneous fertiliser that covers a large part of the plant's nitrogen (N), phosphorus (P) and potassium (K) needs [35].

18. RBR – The Reviving Baltic Resilience

Project website: https://chem.pg.edu.pl/rbr/main-page

Coordinating beneficiary:

Gdansk University of Technology, Poland

Partners:

Klaipeda University, Lithuania
Linnaeus University, Sweden
Industrial Development Center South, Sweden
Pomeranian Special Economic Zone Ltd., Poland
Nordvästra Skånes Renhållnings AB, Sweden
Municipality of Palanga, Lithuania

Project start – 2017-07
Project end – 2020-06

Project type – RIA

Aim of the project:
The project aims to highlight the proactive approach when working with environmental projects by showcasing successful proactive methods and technologies to prevent hazardous and unwanted particles from reaching the Baltic Sea and at the same time to disseminate this knowledge to the South Baltic region by having a cross-border approach [36].

Objectives:
The initial phase of the project looked at the technical analysis of this, i.e., how is each solution prepared optimally (type of equipment/economic viability etc.) and which technology providers were available in the region to take part in the pilot cases. A broad audience of stakeholders such as SME´s, decision makers and potential future implementing municipalities/regional authorities were invited to give their input to this analysis [37].

Once the initial phase was completed, the project continued with the actual installation and running of the pilot cases. During this segment of the project also invited relevant stakeholders to showcase the solution as well as have technical study tours and training session to broaden the understanding and knowledge about the solutions. It is also during this stage setting of the framework for the South Baltic Proactive Resilience institute/cluster started.

The third and final stage of the project was the evaluation of the pilot installations and further development of the dissemination of results by having cross-border knowledge exchange seminars; there the institute/cluster was promoted as well. These seminars were open for stakeholders from the entire Baltic region and promoted through the broad network of partners and the associated organizations.

Results:
Due to the tightening of the MARPOL Convention, the emissions of ships and vessels needs to be decreased constantly. The Department of Process Engineering and Chemical Technology, Gdansk University of Technology proposes to partially substitute diesel by dimethyl ether (DME) as fuel. The pilot comprises the modification of diesel ship engine of the swimming research yacht "Photon" (Fig. 13). The combustion of DME is characterized by a complete lack of particulate matter and Sulphur oxides (SOx) emission and a reduced emission of nitrogen oxides (NOx), carbon oxide (CO) and unburnt hydrocarbons [38].

Figure 13: research yacht "Photon" (photo by Prof. Jan Hupka)

Technical solution was developed, which allows to operate the diesel engine in two modes. In the first mode the engine is fuelled by diesel, whereas in the second mode the engine will be fuelled by a mixture of diesel and DME. Applying the mixture improve the physical properties of the DME and at the same time decrease the noxious emissions.

NSR is responsible for the post-treatment of five landfills in southern Sweden. In two of these, the issue of PFAS substances in leachate has been investigated. Relating to the expansion of nutrient purification systems at Höganäs, it is therefore interesting to investigate the possibility to expand the treatment with facility for purification of Perfluorooctanesulfonic acid (PFOS) substances, mainly PFOS. In Sweden, there are a couple of full-scale purification plants for PFAS substances in leachate. The plants consist of sand filters for particle purification followed by two series activated charcoal filters. This type of facility has a high investment cost and a high operating cost. NSR's goal is therefore to see if any other technology for purifying PFOS is more economically justifiable. For example, one looks at the possibility of cleaning PFOS with ash from coal power plants [39].

Ecopiling is a modification of traditional passive biopiling (technology in which excavated soils are piled and typically constructed in a treatment area that consists of a leachate collection and aeration system) in that, instead of enclosing the biopile with black plastic, the pile is planted with suitable phytoremediation plants. The selection of appropriate plant species is critical to optimize the phytoremediation and co-planting is often used for a simultaneous removal of multiple contaminants [40].

The biopile can be lined with a polyethylene waterproof membrane to prevent the leachate from draining into the ground and ensure the correct inflow-outflow water balance. A drainage layer made of gravel and sand must be laid on the bottom.

19. WAB – Wetlands Algae Biomass

Project website: not available anymore

Funding source: The European Commission and the South Baltic programme

Coordinating beneficiary:

Municipality of Trelleborg, Sweden

Partners:

Municipality of Sopot, Poland
Institute of Oceanology Polish Academy of Sciences (IOPAS), Poland
Pomeranian Agriculture Education Center (PAEC), Poland
The River Basin District Authority for the South Baltic Sea, Sweden
Linnaeus University, Sweden
The Skåne Association of Local Authorities – BiogasSyd, Sweden
Community Union 'Dolina Redy i Chylonki' (CU), Poland
Pomeranian Center for Environmental Research and Technology (POMCERT), Poland
Royal Institute of Technology (KTH), Sweden
Self-Government of the Pomorskie Voivodeship, Poland

Project start – 2010-02
Project end – 2012-12

Project type – RIA

Aim of the project:
To establish a full-scale nutrient reduction cycle based on a holistic approach to extract nutrients from the sea. This was achieved by combining the reconstruction of wetlands, the collection of algae from shores and the utilization of the biomass for biogas production [41].

Objectives:

- Improve recreational value of the coastal area, and in the long term the regional economy
- Stimulate biodiversity

- Decrease nutrient leakage from farmlands through the harvesting of wetlands
- Make shallow coastal waters available for juvenile fish and other important organisms
- Remove phosphorus and nitrogen from the Baltic Sea and recycle it to arable land [41].

Results:
Since there is not enough information on the natural resource potential of macroalgae in the Baltic Sea, the implementers of the WAB project offered simplified algae coverage model. The model was applied to two case study areas – Trelleborg (Sweden) and Kassari Bay (Estonia). According to project promoters, the model may constitute a useful and cost-efficient tool for estimating available macroalgae biomass for coastal regions in the Baltic Sea after its further development and testing. Also, this model can be used as a harvesting management tool [42].

Furthermore, during the WAB project an evaluation of the biogas plant's economic possibilities using feedstocks such as marine algae, wetland plants and other local waste in Pomerania was performed. This feasibility study assessed the potential for excess water biomass (microalgae, wetland plants) in Pomorskie and neighbouring municipalities. Also, it proposed the handling system for the water biomass, which contributed to the decrease of nutrient outflows to the Baltic Sea. Further, the evaluation of the technical possibilities to produce biogas from abundant water biomass was carried out. Finally, the estimation of the economic performance of a large-scale biogas plant using water biomass was performed [42].

The investigation of current biodiversity in the wetlands within Tullstorp stream catchment area (Fig. 14) was performed during the WAB project in cooperation with the Tullstorp stream project. The theoretical potential for high biodiversity in the 13 wetlands was compared with the practical results obtained via inventory. More detailed results can be found in the final report of the WAB project [42].

Figure 14: The Tullstorp stream in the Trelleborg (photo by Trelleborg Municipality)

Additionally, the algae cultivation in wetlands can be one of the solutions seeking to reduce the leakage of nutrient from farmland to Baltic Sea and at the same time used to gain biomass for biogas production. The obtained results demonstrated good nutrient reducing capacity. 137 kg of nitrogen (N) and 2.3 kg of phosphorus (P) were reduced in the 200 m^2 cultivation site. The uptake of nutrients in the algae (*Cladophora sp.)* biomass was only 0.5 kg N, and 0.06 kg P. Meanwhile, microorganisms conducted most of the nitrogen removal in the pond. Under optimal conditions, this site could bind 150 kg N/ha/year and 10.5 kg P/ha/year in the algae (*Cladophora sp.*) biomass. Further, algae could be used for biogas production, and nutrients bound in the algae could become bio-fertilizer, which could be used in the farms once again.

Trelleborg municipality investigated the effect of filamentous algae, which occur along the shoreline in Trelleborg, on fauna and oxygen levels. The obtained results showed that oxygen levels and the quantity of living organisms were significantly lower in the areas with algae compared to territories without algae. More precisely, the areas without algae had an oxygen level of around 100%, while the oxygen level was only 14%, and living organisms were not found at one location with the algae. Also, at the other two areas with a lower oxygen level, some living organisms were found. However, a higher number of species and individuals were found in the territories without algae [42].

During the WAB project implementation, the Institute of Oceanology Polish Academy of Science (IOPAS) mounted and maintained an in-situ eutrophication control system in the Sopot pier (Fig. 15). This system enabled the following of eutrophication trends and allowed the possibility to alarm the beach managing services in case of an imminent algae bloom. Also, permanent measurements of air. Thus, eutrophication control system became integral to all town [42].

Figure 15: Monitoring station in the Sopot pier (photo by Trelleborg Municipality)

Also, the IOPAS performed determination of nutrients – in macroalgae (green, brown and red algae) and seagrass (*Zostera marina*) collected at the Sopot beach (Fig. 16). Moreover, to compare results, the identification of nutrients in macroalgae collected at the beach near Trelleborg was performed [42].

Figure: 16 Macroalgae species found at the Sopot beach [photo by Trelleborg Municipality]

Additionally, the WAB project implementers aimed to remove algae from the beach and use it for biogas production and formed residues use as fertilizers in the agriculture sector. The opportunity to use algae as a feedstock for biogas production and residues as fertilizers depended on the heavy metal (mainly Cadmium (Cd)) content in the algae. The promoters of the project presented various metal removal methods, including ones which use chemicals. Researchers concluded that such methods could be questionable with respect to sustainability. Also, they suggested untreated residues use to fertilize energy crops (willows) which are distinguished as fast-growing plants capable of accumulating metals. Finally, project promoters proposed a way of diluting Cd rich algae by co-fermentation with another substrate (house waste, manure). Such a way would help increase the production of biogas and gain algal residues with metal concentrations below threshold values regulating sludge usage in the agriculture sector [42].

a) b) c)

Figure 17: Equipment used for the collection of algae: a – the DM Truxor 4700B, b) –BioMarine/Limnoteknik Prototype III, c – grip claw loader (photo by Trelleborg Municipality)

In the WAB-project various algae collection techniques including grip-claw loader, power-rake and beach cleaner, the DM Truxor 4700B and BioMarine/Limnoteknik Prototype III were tested in Poland and Sweden (Fig 17). The evaluation of collection equipment showed that the most efficient method to collect algae is the grip-claw with a dumper when there are significant algae amounts. However, the sand content in such a way collected algae can be too high. In this case, a Truxor front fork is an option since the algae collected with this equipment is almost wholly free of sand. Furthermore, Prototype III is a good alternative when the algae are spread in shallow water [42], [43].

Moreover, a pilot biogas plant was designed and operated in Smygehamn (Trelleborg municipality) within the WAB project. This biogas plant used algae as a feedstock. The testing of the biogas plant has consisted of three periods. The first test period revealed that the natural methane process already starts when the algae are stored in an anaerobic environment. Further, it was found that high hydrogen sulfide (H_2S) production competes with methane (CH_4) production, thus inhibits the methane process. Also, tests performed via the first period showed that 50% of the cadmium (Cd) was released and 95% of the phosphorus (P) remained in the algae residue [42].

The second period was dedicated to pH tests. The provided results showed that usage of whey lowered the pH and increased methane production. The test with acetic acid was also performed to identify the system tolerance for pH around 3.8 – 4.2. The peak of produced gases (2800 l/day) was obtained in this period of tests compared to all project period [42].
In the earlier two stages, algae were collected from the beach. The algae used for the third-period tests were directly collected from the sea. The test results showed that algae collected from the sea are tough to ferment since there is no spontaneous hydrolysis. Consequently, it is beneficial to dry algae before its use as a feedstock for biogas production [42].

The realization of the WAB project allowed evaluating the possibility to use renewable sources for energy production in Sopot. It was determined that the renewable resources, including plant biomass (e.g., algae), manure and organic waste could be used as a feedstock for energy production. The analysis indicated that it is possible to generate biogas from algae found in Sopot. Nevertheless, the yield of algae is insufficient. Thus, the use of additional feedstock such as horse manure and green biomass is required [42].

Conclusions & Future outlook

The reviewed finished or still ongoing projects intending to mitigate negative eutrophication consequences around the Baltic Sea and other regions (the Curonian lagoon, rivers running into the Baltic Sea, etc.) or catchment areas (Tullstorp and Albäcken stream catchment areas, Sweden), summarize different approaches and experiences, e.g. growing mussels, installing floating wetlands, collecting and removing seaweed from beaches and rivers/lakes, producing biofuels, revolarizing coastal seaweed into textile nonwovens, etc. One type of projects (coordination and support action, CSA) are mostly based on providing some recommendations or guidelines to the stakeholders, whereas research and innovation action (RIA) projects are dedicated to technological advances or prototypes to be created and applied to tackle eutrophication or reduce water pollution. This combination between the CSA and the RIA projects funded by Interreg, H2020, LIFE or other programmes cover the whole value chain from supporting measures to practical implementation. However, most of the summarized projects, including the COASTAL Biogas, attempt to address negative eutrophication consequences instead of taking direct actions of prevention in advance.

The Baltic Sea is the biggest water body/catchment area in North and Central Europe, which suffers from the negative anthropogenic impact of overnutrification starting from rivers, lakes and other water sources as well as each human's home. In addition, the Baltic Sea has a special 'position' in comparison to other water bodies, e.g. North Sea, Mediterranean Sea as the fresh water exchange is reduced. As a consequence, the excess of nutrients originating from intensively farmed areas, wastewater treatment plants, industry or other anthropogenic activities runoff in the river basins, which finally enter the Baltic Sea. Therefore, the actions should include education as well as adjustments and implementation of national and/or EU laws. Regulations should limit the use of mineral fertilizers on farmland and the use of domestic cleaners, detergents, as well as chemicals usage by industry and other sectors and improvement of wastewater treatment etc. Only joint efforts and understanding that the final recipient is the Baltic Sea of any human action taken on the above-mentioned activities could lead to positive impacts. In the end, this will directly affects not only the sea with its biodiversity, but also humans' quality of life as well.

The numerous presented projects implemented over the past decade on utilization of marine resources show the importance of the eutrophication topic. More action should be taken in forthcoming projects or initiatives, firstly by building more balanced and diverse consortia of different types of stakeholders from municipalities, ministries, NGOs, industry, research, SMEs, etc. This would help to have mature discussions and take coordinated actions looking from different perspectives of stakeholders. Secondly, the development of demonstration prototypes/pilots (>TRL 6), with strong involvement of business or industry, would increase public and decision-makers awareness by demonstrating the solutions to reduce eutrophication in a circular way. Thirdly, education starting from the youngest age up to mature (kindergarten, school, academia, adults) should also be taken into consideration. Finally, recommendations, which are addressed to decision-makers (municipalities, ministries), environmental agencies, utility companies responsible for beach cleaning, based on reviewed projects' results would help to improve, adopt and implement various strategies, laws and regulations on reduction of pollution, i.e. water, air, soil.

The COASTAL Biogas project seeks to provide updated knowledge and concrete solutions to coastal regions (of the Baltic Sea) to tackle eutrophication, contribute to the transition to a circular bio-economy and improve prosperity by cross-border cooperation. This will be achieved through trainings of stakeholders (coastal municipalities, ecologists, AD plant operators, utility companies cleaning beaches, environmental agencies), organisation of conferences, preparation of case studies, and demonstration of a cast seaweed handling chain from substrate collection, storage and pre-treatment to co-digestion with other feedstocks, biogas production and digestate utilisation as well as energy recovery through thermochemical pathway and, most importantly, closing nutrient cycles.

One should have take into consideration that the final goal of each identified project in this report, including the COASTAL Biogas project, is mitigation of eutrophication. This could be done through various paths mentioned above and therefore it was complicated to make a proper comparison between the COASTAL Biogas project's results with other results obtained in the identified projects.

References

[1] "AlgaeService for LIFE." https://algaeservice.gamtostyrimai.lt/lt/ (accessed Aug. 14, 2020).
[2] "BalticBlue growth." https://www.submariner-network.eu/balticbluegrowth (accessed Sep. 20, 2020).
[3] Z. Ozolina, "Mussel farming costs in the Baltic Sea," 2014. [Online]. Available: https://www.submariner-network.eu/images/201810_MF_cost_report_2.pdf.
[4] "Biomara." http://www.biomara.org/meet-the-team.html (accessed Oct. 18, 2020).
[5] "Biomara." https://www.keep.eu/project/3465/biomara-sustainable-fuels-from-marine-biomass (accessed Oct. 18, 2020).
[6] "Biomara." http://www.biomara.org/downloads/brochure 1.pdf/at_download/brochure 1.pdf (accessed Oct. 18, 2020).
[7] "Biomara." http://www.biomara.org/Celebrating BioMara.pdf/at_download/Celebrating BioMara.pdf (accessed Oct. 19, 2020).
[8] "BUCEFALOS - BlUe ConcEpt For A Low nutrient/carbOn System –regional aqua resource management," [Online]. Available: https://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=4182.
[9] "LIFE11 ENV/SE/839, Final Report Covering the project activities from 01/09/2012 to 31/08/2015.," 2005.
[10] "CONTRA - Conversion of a Nuisance to a Resource and Asset." https://www.beachwrack-contra.eu/ (accessed Nov. 04, 2020).
[11] "EUALGAE: European Network For Algal-Bioproducts." https://www.energy.imdea.org/research/projects/eualgae (accessed Nov. 25, 2020).
[12] "GRASS - Growing algae sustainably in the Baltic Se." https://www.submariner-network.eu/grass (accessed Dec. 09, 2020).
[13] "Assessing the PanBaltic potential of macroalgae cultivation and of harvesting wild stocks," 2005. [Online]. Available: https://www.submariner-network.eu/images/grass/GRASS_OA2.1_pan-Baltic_map_depicting_potential_of_macroalgal_cultivation_and_harvesting.pdf.
[14] "GREATER BIO." http://www.gate21.dk/greater-bio/ (accessed Dec. 17, 2020).
[15] "Live Lagoons." http://www.balticlagoons.net/livelagoons/ (accessed May 19, 2020).
[16] "Live Lagoons." http://www.balticlagoons.net/livelagoons/?page_id=14 (accessed May 19, 2020).
[17] "Live Lagoons." http://www.balticlagoons.net/livelagoons/?page_id=18 (accessed May 20, 2020).
[18] "MAB4." http://www.oceanrainforest.com/mab4 (accessed Mar. 14, 2020).
[19] "MacroCascade." https://www.macrocascade.eu/ (accessed Jun. 01, 2020).
[20] "MacroCascade." https://www.macrocascade.eu/outcomes/deliverables/ (accessed Jun. 01, 2020).
[21] "MacroFuels." https://www.macrofuels.eu/ (accessed Aug. 15, 2020).
[22] "MacroFuels." https://www.macrofuels.eu/events (accessed Aug. 15, 2020).
[23] "Netalgae." http://www.netalgae.eu/netalgae-project.php (accessed Jan. 06, 2021).
[24] "Netalgae." http://www.netalgae.eu/publications.php (accessed Jan. 06, 2021).
[25] "SEAGAS." http://seagas.co.uk/ (accessed Jan. 27, 2021).
[26] "SEA-MATTER." http://www.seamatter.com/ (accessed Feb. 12, 2021).
[27] "LIFE11ENV/ES/000/600 FINAL Report Covering the project activities from 01/09/2012 to 28/02/2015." [Online]. Available: http://www.seamatter.com/images/final_report_SEAMATTER_para web.pdf.
[28] "SeaRefinery." https://www.dti.dk/projects/project-searefinery/36883 (accessed Mar. 14, 2021).
[29] "SeaRefinery," [Online]. Available: http://www.marinebiotech.eu/sites/marinebiotech.eu/files/public/2-16 SeaRefinery.pdf.
[30] "Solrød Biogas – conception, project development and realisation." [Online]. Available: https://solrodbiogas.dk/wp-content/uploads/2016/10/8.-Rapport-om-Solrød-Biogas_uk.pdf.

[31] "Solrød Biogas A/S." https://solrodbiogas.dk/ (accessed Nov. 25, 2020).
[32] "Solrød Biogas fortsætter succesen - Solrød Kommune."
[33] "Start undervisningen - Solrød Biogas – Scheme." https://solrodbiogas.dk/undervisningsmateriale/start-undervisningen/ (accessed Nov. 25, 2020).
[34] "Start undervisningen - Biogødning til landbruget - Solrød Biogas." https://solrodbiogas.dk/undervisningsmateriale/start-undervisningen/til-landbruget/ (accessed Nov. 20, 2020).
[35] "Velkommen til Solrød Biogas' undervisningsmatriale." https://solrodbiogas.dk/undervisningsmateriale/ (accessed Dec. 02, 2020).
[36] "Reviving Baltic Resilience." https://southbaltic.eu/-/rbr-reviving-baltic-resilien-1 (accessed Feb. 20, 2021).
[37] "Reviving Baltic Resilience." https://chem.pg.edu.pl/rbr/main-page (accessed Feb. 20, 2021).
[38] "Reviving Baltic Resilience." https://chem.pg.edu.pl/rbr/less-particulates-emission-from-diesel-engine (accessed Feb. 20, 2021).
[39] "Reviving Baltic Resilience." https://chem.pg.edu.pl/rbr/landfill-leachate-cleaning (accessed Feb. 20, 2021).
[40] "Reviving Baltic Resilience." https://chem.pg.edu.pl/rbr/ecopile-phytoremediation-plant (accessed Feb. 20, 2021).
[41] "Wetlands Algae Biomass." http://wabproject.pl/en.aimsgoals.html (accessed Jun. 14, 2020).
[42] "Wetlands Algae Biogas." [Online]. Available: http://www.wabproject.pl/files/WAB_FinalReport inet.pdf.
[43] "Evaluation of machines for the collection of algae." [Online]. Available: http://wabproject.pl/files/evaluation of algae machines.pdf.