seafarm

Macro algae

towards a bio-based society

The algae that live in our oceans are an untapped fountain of wealth whose value we have not fully understood. Not yet, at least. Algae are full of beneficial ingredients. If we were able to use them as a source of energy and as a raw material for the production of materials, it would be a step towards a bio-based society. Algae are also rich in many essential nutrients that can be used in the production of food and animal feed. What's more, the substances found in algae are different to those of land plants, which means that algal biomass can potentially be used to make unique products.

It goes without saying that we need to find alternative ways to produce energy and materials than using fossil resources. As the global population grows and more and more people around the world are encouraged to enjoy resource-intensive lifestyles, it becomes vital to find ways to create a global economy based on sustainable and renewable methods of production. One step in this direction might be the cultivation of macroalgae.

The Swedish coast is highly suitable for growing macroalgae. The long coastline has an archipelago of numerous islands which offer many protected areas. One of the major advantages of macroalgae is that they do not require any input of energy. In our latitudes, there is sufficient sunlight for them to grow a couple of metres in one season, which is enough for a harvest.

Seafarm is an interdisciplinary research project which grows and uses macroalgae for many different purposes in a closed loop system that produces zero waste. The goal is to use the full potential of the algae.

Marine biologists are becoming farmers of the sea...

There is not enough macroalgae growing in the wild for Seafarm's purposes. More needs to be cultivated. One of the many benefits is that the algae absorb nutrients from the water in which they grow and they form biotopes which provide an excellent habitat for small fish and crustaceans. The cultivation of macroalgae could therefore help reduce eutrophication of coastal bays and also increase biodiversity.

Compared with cultivating other kinds of biomass on land, macroalgal cultivation offers a host of advantages. Firstly, it doesn't take up any land space, which means it doesn't compete with forestry or agriculture. Secondly, the algae look after themselves. They don't need watering, fertilizer or any extra light or heat.

SEAFARM GROWS TWO SPECIES OF MACROALGAE: *Saccharina latsissima,* or sugar kelp and *Laminaria digitata,* These are common species found naturally along the west coast of Sweden. They grow quickly by as much as two metres in just one season. The amounts of proteins, lipids, carbohydrates and other substances that the algae contain vary as they grow. One of the tasks of the researchers is to determine the best time for harvesting the algae. In other words, at what stage of growth should it be cut to obtain the substances required.

The growth rate and the content of the algae are affected by their environment and exposure to waves. Wild algae from various locations are therefore being analysed. The greater the natural variation, the greater are the chances of being able to process the properties that are of interest. But unlike the processing of land plants, which mankind has been doing for a very long time, algae processing has barely begun.

CULTIVATION BEGINS IN THE LAB. Algae spores are sown on nylon strings. When the tiny plants have grown a couple of millimetres, the string is wound around a thicker rope which is then planted out in the sea. The algae can be harvested the following year. Trials are being conducted in a number of locations and at different depths in the Kosterhavet National Park.

It will be necessary to have more and larger farm sites in the future. One of the tasks of the project is to identify potential sites for the farms and how they could be designed to have as little impact on the environment as possible. It is important that they are able to coexist with other interests and, according to Henrik Pavia, that shouldn't be impossible.

FA 1 is being run by Henrik Pavia, Göran Nylund and Gunnar Cervin.

"This project is unique because we have taken an integrated approach from the start.The teams are working on every part of the chain. This is something of a pioneering project and I'm delighted to be on board."

Henrik Pavia, Professor, Department of Biological and Environmental Sciences, University of Gothenburg.

...who harvest and store...

There are some similarities between the cultivation of macroalgae and growing crops on land. You sow the seeds, wait for them to grow and when it's time to harvest the crop you do it all at once. That's about as far as the similarities go, but it might be possible to apply our knowledge of agricultural methods to algae cultivation too. When algae are harvested, they break down quite quickly and therefore have to be preserved and stored efficiently until the biomass can proceed to the refinement process.

THERE ARE VARIOUS WAYS TO PRESERVE THE HARVESTED ALGAE. One of the drawbacks of traditional techniques, such as drying and freezing, is that they are energy consuming. Silage is another alternative. Eva Albers can picture the algae being packed into silage bales whilst still on board the harvesting boat. She believes it would be a practical way to simplify the transportation of the algae. It is up to the project to investigate whether this can become a reality. Silage involves the addition of lactic acid bacteria to the biomass and the pH level decreases. The question is whether this alters or destroys any of the substances that should still be intact in the refining process. A certain type of preservation method could also simplify the refining process. It is therefore important for biorefineries and preservation facilities to have a regular exchange of knowledge so that the processes can be adapted to each other throughout the project. The storage time may also have an effect on the potential for further use. The sensitivity of the different substances may vary depending on how long the algal biomass is stored. This factor may need to be taken into account when planning the extraction of substances.

IN ORDER TO DETERMINE HOW DIFFERENT PRESERVATION METHODS AFFECT the algal biomass, the first thing to do is identify what is in the fresh algae from the start. Various chemical analysis methods are used to examine the content of substances, such as carbohydrates, proteins and lipids, and soluble substances, such as ammonium ions, monosaccharides and minerals. The same analyses must then be repeated on several occasions throughout the storage period. This makes it possible to determine how the content changes over time.

FA 2 is being run by Eva Albers.

"It is essential to have an agreed understanding about the sea. On land, we have fields and industrial sites where access is restricted. It needs to be the same in the sea. We need to set aside areas for cultivation."

Eva Albers, Associate Professor, Industrial Biotechnology at Chalmers University of Technology.

... refine the crop to extract maximum value...

An oil refinery distils crude oil to separate different fractions of hydrocarbons. In a similar way, Seafarm will purify macroalgae to extract substances, from large, complex carbohydrates to proteins, minerals and much more. To obtain maximum value from the algae, the process of extracting one substance must not make it impossible to extract further substances later on in the refining process. The goal is to extract as many of the high-value substances from the algae as possible using a gentle method and preferably without the use of organic solvents.

THE BIOREFINERY is where the substances are extracted. These will be used for a whole range of purposes. Ingredients for food and animal feed, substances that can be converted into bioethanol using yeast cells and substances that can serve as a raw material for the manufacture of materials such as plastic, rubber or textiles.

THE PRODUCTION OF PLASTIC requires polymers or, quite simply, very large molecules, such as large carbohydrates. Chemical engineering processes can then convert them to whichever type of plastic you want. Carbohydrates are needed for bioethanol production too but, in this process, it is through fermentation by yeast cells. With the proper pretreatment, the yeast cells grow as well on the algae-derived sugars as on other types of sugars. However, completely different types of molecules in the algal biomass might be of interest when it comes to food for human consumption. Proteins, lipids and antioxidants, for example.

THE DIFFERENT TYPES OF MOLECULES that you want to obtain differ significantly in structure and properties. This is what allows them to be separated into different fractions. The fact that so many of them are of interest poses a challenge for researchers. It is important to find fractionation methods

”There is an increasing demand for omega-3 fatty acids. These are produced in algae, which is why it would be good if these and high-value proteins could be used primarily for food purposes.”

Ingrid Undeland, Assistant Professor, Food Science at Chalmers University of Technology.

that are sufficiently effective, yet gentle too. And to find a smart fractionation sequence that extracts substances in the right order so that sensitive substances are not destroyed.

SOME CHEMICAL DETECTIVE WORK is then required to determine which substances are present in the fractions. It can be concluded from what we know today about the content of macroalgae that the potential to obtain considerable amounts of different substances is huge. However, an extra refining step is required for each component you want to extract. It might be better and more economically viable to settle for just a few valuable substances rather than spend large sums on extracting masses of them, says Ulrica Edlund.

Ingrid Undeland considers that it might not be necessary to extract completely pure substances but rather elegant combinations or, as she calls it, multi-valued food ingredients aimed at different uses. For instance, the combination of lipid and antioxidant where the antioxidant prevents the lipid going rancid, or a combination of protein, omega-3 fatty acids and glutamic acid, which is a flavour enhancer.

APART FROM MAKING OUR TRAFFIC GREENER, the production of bioethanol can also be seen as a model system for the fermentation of carbohydrates from macroalgae. Once the production of ethanol is working efficiently and we know that the yeast cells like the substrate, they can be used to produce other things, such as enzymes or high-value chemicals.

FA 3 is being run by Ingrid Undeland, Jenny Velde Vilg, Ulrica Edlund and Anders Höglund.

”The ideal product would be a completely renewable plastic. Numerous disposable products are made of plastic and if we could swap at least one oil-based plastic for an efficient algae-based plastic, it would be a major step in the right direction.”

Ulrica Edlund, Associate Professor, Department of Fibre and Polymer Technology, KTH Royal Institute of Technology.

... create biogas from the waste...

The parts of the algal biomass that do not continue for further processing in the biorefinery are to be digested to produce biogas. It is likely that more biogas would be produced if whole alga was digested without using it for other purposes too. But we can't be certain. The Seafarm research team will be investigating this. The question is therefore whether biogas production is most effective when the biomass consists of fresh algae, algae that has been pretreated in some way, or the waste product from the biorefinery?

Since the objective of the project is to achieve a closed loop system in which optimal use is made of the algae, it is necessary to find a balance between the value of the extracted substances and the value of the energy that can be produced. Digesting the waste to generate biogas might not be profitable, but then again it might be when you consider the whole chain, says Ulrika Welander.

BIOGAS is a mixture of methane and carbon dioxide which is produced when microorganisms break down the organic matter in the biomass in order to grow. A major focus of the project will be to optimise the conditions in the bioreactor, which is the vessel containing the microorganisms and substrates. To make it a profitable business, you need to get as much methane as possible per kilogram of substrate and the process has to be fast enough. The speed of the process depends on the temperature which is usually either 37 or 55 degrees in bioreactors.

The process may eventually be separated into two stages. The first, faster steps, in which large molecules are broken down into small organic acids, can then take place in one vessel, and the slower methane production process in another. The microorganisms can work there at their own pace without becoming stressed by having to take care of excessive levels of organic acids.

THE EFFICIENCY WITH WHICH BACTERIA break down different types of biomass varies from one strain to another. Several bacterial inoculants from active biogas plants will therefore be tested; from a treatment plant and from a biomass plant using agricultural waste. Marine biomass ought to be new for these bacteria and it remains to be seen how they react.

BIOGAS PRODUCTION ALSO CREATES WASTE. The waste contains a lot of nitrogen and phosphorus in a form that is easy for plants to absorb. Using it as fertiliser reduces the amount of nutrient salts that enter the sea. And so the loop closes in the same way as it started, with reduced eutrophication, but because the growing algae removed nutrient sales from the water.

FA 4 is being run by Ulrika Welander.

”We need all the renewable energy we can get. Biogas plants are almost fighting over biomass. We need new substrate and the sea is very interesting right now.”

Ulrika Welander, Associate Professor, Department of Civil and Energy Engineering, Linnaeus University.

...and finally evaluate the whole process in a sustainability assessment

Seafarm is a unique project because of its integrated approach to the cultivation and use of algae. It is not just about developing a method of cultivation. Or about extracting one substance from the algae, or about energy recovery. It's about all of this. The researchers will also evaluate whether the venture is worth undertaking at all. Is algae farming a sustainable business? For what purposes can algae farming justify the costs? Is it possible to motivate more expensive energy or chemicals in return for other things? A cleaner marine environment, for example. But how do you put a price tag on this?

THE DEVELOPMENT OF METHODS for the evaluation of a broad and interdisciplinary project like Seafarm is part of the research. As well as the actual algae project being evaluated, the methods can also be applied in future projects. Everything from environmental aspects to energy balances and socio-economic factors will be included in the system analysis of Seafarm. Fredrik Gröndahl thinks it is easiest to start by looking at the energy balance. It is relatively easy to put a price on that. What are the energy inputs and outputs? You then proceed with the next calculation.

There are a number of different scenarios. A small Seafarm with algae cultivation on a small scale for the production of small quantities of high-value products. Or a larger farm, to obtain a substantial amount of something that has less value. Whichever you choose, it has to be profitable. A previous project in Scotland showed that it was far too expensive to farm algae just for energy production. That's why Seafarm has placed a biorefinery in the middle of the loop and the energy that can be extracted at the end is really only a by-product.

WHAT THE ENVIRONMENTAL EFFECTS ARE WORTH in monetary terms is more difficult to calculate. There are now ways of calculating so-called ecosystem services. These are the services provided by nature. One way is to calculate what it would cost to replace one of nature's services with a man-made equivalent.

For example, the removal of nitrogen from water using a treatment plant or an algae farm. Or you could ask; what are people willing to pay for something that nature provides free of charge? How much are we prepared to pay for clean water?

One of the purposes of the socio-economic assessment is to investigate attitudes towards large-scale algae farming. Wind power and mussel farming are frequently discussed and it could well be the same with algae farming. Fredrik Gröndahl believes it is therefore a good idea to be well prepared. Dialogues with various parties need to be initiated in order to find suitable farming sites.

FA 5 is being run by Fredrik Gröndahl, Maria Malmström and Jonas Nordström.

"I hope we reach the stage where we have developed efficient and effective techniques and have solved all the other issues too, so that commercial powers can take over and construct an algae-based biorefinery."

Fredrik Gröndahl, Associate Professor in Industrial Ecology, KTH Royal Institute of Technology.

FOCUS AREA 1 – University of Gothenburg

- Establish cultivation of macroalgae
- Examine the variation between different populations of macroalgae in the wild
- Examine the ecological effects of algae farming
- Find suitable areas for macroalgae farming on a larger scale

FOCUS AREA 2 – Chalmers

- Make an inventory of preservation and storage methods and see which ones can be used for algae
- Find out how different methods of preserving the biomass affect its content
- Find out if and how different preservation methods affect the substances extracted at the biorefinery

FOCUS AREA 3 – Chalmers/KTH Royal Institute of Technology

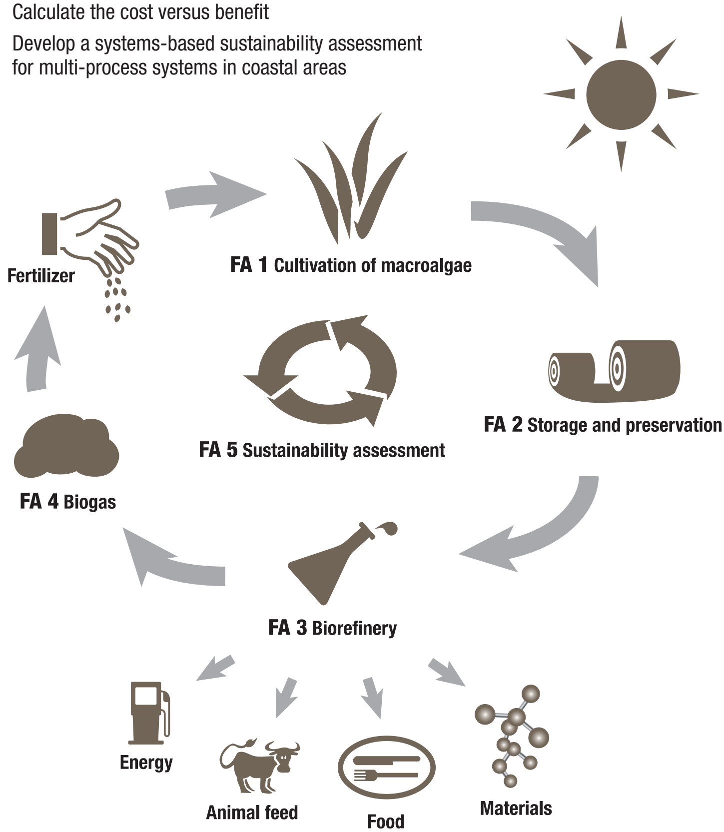
- Find out what the algal biomass contains
- Develop an effective fractionation method
- Purification of polysaccharides for the production of polymers that can be used to manufacture plastic
- Purification of fermentable sugars to produce bioethanol
- Purification of proteins and peptides to use for food and animal feed
- Purification of other high-value substances that have antioxidant, anti-inflammatory, weight-regulating and other properties

FOCUS AREA 4 – Linnaeus University

- Optimise the method of using macroalgal biomass to produce biogas

FOCUS AREA 5 – KTH Royal Institute of Technology/Lund University

- Analyse the project's sustainability and weak links
- Calculate the cost versus benefit
- Develop a systems-based sustainability assessment for multi-process systems in coastal areas



Seafarm is an interdisciplinary research project which grows and uses macroalgae for many different purposes in a closed loop system that produces zero waste. A key aspect of this project is to assess the sustainability of the system. Everything is to be assessed, from the impact of algae farms on the environment to the benefits relative to the costs. Seafarm is a joint collaborative project between five universities: KTH Royal Institute of Technology, Chalmers University of Technology, University of Gothenburg, Linnaeus University and Lund University. The project manager for Seafarm is Fredrik Gröndahl, KTH.

The Seafarm project is part of the Swedish Research Council Formas' targeted investment in the development of a bio-based economy. The project is being undertaken with industrial collaborators.

Find out more about Seafarm by visiting www.seafarm.se

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MACROALGAE FOR A BIO-BASED SOCIETY

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