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Production of Micro algae-based Products

A map of available production methods for micro algae and market opportunities for algae-based products as a basis for establishing commercial operations.



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In addition we have cooperated with a number of people and institutions in the Nordic countries in order to gather information on the subject.

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<p>Abstract:</p> <p>With the starting point that there is considerable knowledge about micro algae in the Nordic Region, Algetech Produkter AS has carried out a study to map available production methods for micro algae and market opportunities for algae-based products as a basis for commercial activity. Algetech Produkter AS has focused on creating an alliance of expert circles so that the necessary knowledge and competence would make it possible to achieve the objective of the project. Since there is relatively little experience of algae cultivation under Nordic conditions, trial production on an industrial scale has also been carried out to confirm that the climatic conditions are present for algae production in the Nordic Region.</p> <p>The study is therefore also a pilot project for a planned industrial project. During the project period the group has collaborated with participants from throughout the Nordic Region except Finland. Data has been collected on technical, market and economic matters which, together with the result of the trial production, will form the basis for continued progress and realisation of plant for production of micro algae.</p> <p>The study will in part be publicly available immediately, whilst part will be of a confidential nature for the present.</p> <p>Public part:</p> <ul style="list-style-type: none"> A. Mapping of available production methods to improve established technology if possible B. Market description (global for algae-based products and collection of information on Nordic industries that can employ or use algae-based raw materials) C. Overview of Nordic expertise and resource centres D. Report from trial production <p>Confidential part:</p> <p>Preparation of business plan that will build on results achieved from trial production and will contain technical description of the planned project, capital requirement, operating budget, financing plan and marketing and sales strategy.</p> <p>The study was carried out during the period 2004-2005 and the first half of 2006 and the long term objective was to show the probability of production of micro algae on an industrial scale in the Nordic Region.</p>		
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Executive summary

The purpose of the project

The purpose of the project has been to map available production methods for micro algae and market opportunities for algae-based products as well as to provide an overview of Nordic expertise and resource centres.

The study has achieved this aim by:

Having examined reports and available literature about existing production methods we believe the group possesses the information about which processes, given today's knowledge, can be established/used in Nordic conditions. We have also learned this in our own experience through our own trial production. Also, through conversations with external experts and the group's own knowledge, we have established which industries/markets may be relevant for supplies of micro algae-based biomass/products and which algae it may be advantageous to cultivate.

Knowledge about micro algae in the Nordic Region is found in university circles since there is little or no industrial experience at present. Previously there was commercial production of micro algae in Gustavsberg outside Stockholm.

How has the project been implemented?

Through previously planned collaboration with Bioprocess, Denmark, on production of the alga *Haematococcus* in Iceland we learned that production of this alga using fermentation and photobioreactors based on artificial light remains too expensive and insufficiently technologically advanced to make it likely that commercial production of Astaxanthin can compete on price with synthetic Astaxanthin. The same was found in Gustavsberg.

Other production processes like harvesting from the wild and production in open ponds are unrealistic because of climatic conditions and because they provide inadequate control of product quality.

However, closed photobioreactors installed in greenhouses, developed by IGV GmbH, have proved to be of interest in the Nordic Region. Large scale industrial production based on this technology is going on in Germany. The results of our trial production have confirmed that the technology can be optimised for Nordic climatic conditions by adding organic substrat and artificial light.

To obtain the widest possible information on the market opportunities for algae-based products we have also engaged external expertise.

What have been the most important results and conclusions?

The bioreactor technology trialled under our aegis provides us and others with an established technology that we now know will work in Nordic conditions. Production will be environmentally friendly since it is mainly based on exploitation of solar energy and at the same time CO₂ is consumed. It will also create the basis for research and development of new products in a range of industries. Algae biomass has many potential application areas

including farmed fish and animal feed. In addition to the algae's high protein and polyunsaturated fat content, the algae have probiotic qualities that may improve health and help reduce the use of antibiotics in livestock and the [fish] farming industry.

The following conclusions can be drawn from the results of the study:

Knowledge, technology, experience and confirmed results from trial production make investment in micro algae appear very interesting. Many possible products have been identified that can be developed from algae-based biomass and that may have great potential in the Nordic Region and internationally. However at the same time it is difficult to document many success stories from attempts that have succeeded.

However a large domestic market and now access to new technology that works mean that investment in micro algae should be intensified. Until now too little capital has been a problem, which has delayed and hindered commercial-scale investment.

Recommendations

Investment must be in products that have clear competitive advantage in Nordic conditions. Before production starts a network of collaborators should be established where good exploitation of each other's knowledge, resources and needs will create great synergy.

Algetech Produkter AS

Building Industry on Microalgae-based Products



August 2006

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SUMMARY

Algae culture technology appears to be an exciting and future-oriented business area. An increasing number of commercial operators has been identified globally and micro algae represent – globally – perhaps the largest remaining biological resource for development and industrial activity in the years ahead.

Micro algae are an untapped resource with more than 30000 species, of which fewer than 15 are in commercial production. Micro algae are one of nature's richest raw materials in vitamins, proteins and other nutrients. They have different characteristics with opportunities for different practical applications and trading goods. The majority of the products currently produced go to health foods and pharmaceuticals as well as some to the animal feed industry. In the future supplies of algae biomass to livestock and fish food producers will be an interesting area as well as production of hydrogen.

In the Nordic Region there is significant expert knowledge about micro algae and through its work in mapping this Algetech Produkter AS has carried out trial production of micro algae at an industrial scale where the effect of combined sunlight and artificial light on production was tested as well as the addition of organic materials. The process is called 'mixotrophic cultivation' and was conducted in a photobioreactor in a greenhouse. Grape sugar was used as the organic material. The trial production was carried out over a period of 6 months and resulted in significant production increase and confirmed previous assumptions that production on an industrial scale is possible in the Nordic Region.

As demonstrated algae need light and CO₂ to grow and the areas that appear most promising are where there is a lot of sun, CO₂ and waste heat. Such areas are found near oil refineries, gas power generators and other [plant] emitting a lot of CO₂. Areas that appear suitable are Slagentangen near Tønsberg and the areas around Vånern. Furthermore cheap energy is a competitive advantage.

A large domestic market and a situation in which the supply of raw materials for livestock and farmed fish [feed] is beginning to become critical give micro algae production increasing relevance as a source of raw materials.

1. INTRODUCTION

The purpose of the project has been to map available production methods for micro algae and market opportunities for algae-based products as a basis for establishing commercial operations.

The project has taken as its start point the mapping of algae culture technology operators in the Nordic Region and internationally. This has covered both research circles and commercial operators.

The project is divided into a public and a confidential part where the public part will illustrate opportunities for production and commercialisation under Nordic conditions, whilst the confidential part addresses actual micro algae production in the Nordic Region.

The study has been carried out to provide a basis for deciding whether cultivation of micro algae should be established in greenhouses on an industrial scale with the technology currently available.

Since there is little or no production (mainly production on laboratory scale) in the Nordic Region today Algetech ProdukterAS decided to carry out trial production outside Berlin at the premises of its collaborator, IGV GmbH, to show the probability of its theory that this is possible. The light conditions and other climatic conditions are the same there as south of the Nordic capital cities. [sic]

2. PRESENTATION OF THE PROJECT

2.1 Why produce micro algae?

Among micro algae, which belong to the plant kingdom, we find some of the most nutritious organisms in nature. Micro algae are an untapped resource with more than 30000 species, of which fewer than 10 are in commercial production. Micro algae contain natural pigments, have high protein, vitamin and carbohydrate content, and are rich in oil and fatty acids - including essential, polyunsaturated fatty acids. They have different characteristics with opportunities for different practical applications and trading goods.

Micro algae production requires sunlight, water and carbon dioxide. The most common production methods are:

- Harvesting from nature
- Open production systems in large containers or ponds
- Fermentation in the dark
- Closed photobioreactor systems in greenhouses.

The most common alga varieties in commercial cultivation are *Chlorella*, *Spirulina*, *Dunaliella* and *Haematococcus*.

Internationally there are many producers of micro algae. The majority of the products go to health food and cosmetics. In the future, supplies of algae biomass for livestock and fish feed will be interesting areas. Furthermore it seems of interest to mass-cultivate micro algae for use as products that can replace goods produced using fossil fuel as well as in production of hydrogen gas to use as motor vehicle fuel.

2.2 Background

Algae production appears to be an exciting and future-oriented business area. Based on the knowledge and competence in micro algae of the Norwegian Institute for Water Research (NIVA), Algetech Produkter AS has worked to create an alliance of collaborators with knowledge and competence on micro algae that can make it possible to establish industrial production of micro algae under Nordic conditions.

Since there is relatively little experience of large scale algaeculture in the Nordic Region, trial production has been carried out on an industrial scale to confirm viable production. The study is therefore also a pilot project for a planned industrial project based on production of micro algae.

Micro algae [production] is an established industry today, particularly in the Far East, but there is also some production in Germany.

2.3 The group's technological background

It has been agreed through agreements with the project participants that the participants will make available the necessary knowledge, competence, know-how and the technology on micro algae to such a degree that it is possible to meet the project objective. The participants will also practice mutual and open information development.

Project participants:

1. Algetech Produkter AS (N). Project coordinator and contributing financial and industrial expertise.
2. The Norwegian Institute for Water Research (NIVA) (N). Contributing with growth physiology and technical production knowledge. Has carried out research on micro algae for more than 30 years and has more than 600 alga cultures in its laboratory.
3. Billerud AB (S). Contributing with industrial process and technical production knowledge (computer automation).
4. Niels Henrik Norsker (D). Researcher and contributing with growth physiology and technical production knowledge. Has experience from planning and building the pilot plant for production of *Haematococcus* in Iceland.
5. IGV GmbH (IGV Institute for Cereal Processing Ltd.) (G). Contributing with results from its basic research as well as industrial and technical knowledge through experience from development and building of production plant currently producing micro algae on an industrial scale.

We have also linked up with a range of other individual resources in connection with the project, including Gavita (N) which has developed lighting systems specially designed for production of plants and vegetables in greenhouses. This technology and lighting systems that Gavita AS produces and sells internationally were used in our trial production. In addition the EWOS Group, the country's largest fish feed manufacturer has been engaged as an adviser and made available its research and development networks.

2.4 Project description

The company and the collaborators have collected and continue to collect data for analysis on technical and market conditions that will create the basis for commercialisation under Nordic conditions. The project will be publicly available in part, whilst a part regarding project planning will be of a confidential nature for the present.

The project comprises:

Public part:

Mapping of available production methods and results in existing plant with reference to climatic conditions. Description of the market for algae-based products and information on Nordic industries that may use algae-based raw materials. Overview of Nordic expertise and

resource centres. Information on completed trial production in a photobioreactor in a greenhouse at IGV GmbH.

Confidential part:

Detailed project planning with technical description of production plant, financial assessment and calculations for production, capital and investment requirements and a market description with product specification. For the present this will be available only to participants in the group and will provide the basis for final decision on realisation of production plant and the basis for investors' decisions on participation in the project.

3. PRODUCTION METHODS

3.1 Available production methods

Internationally there are many producers of micro algae. In the East, where most production is carried out, micro algae are produced in open systems (ponds). This form of production is not practical in the Nordic Region because of natural climatic conditions. It also provides limited possibilities of ensuring stable quality in the product.

Nor is harvesting from the wild on an industrial scale practical since climatic conditions limit the yield and density of natural stocks is low. Harvesting would therefore be much too resource-demanding to enable commercialisation.

Internationally there is considerable activity and research into commercial production of micro algae. The methods that may be practical in the Nordic Region are either fermentation processes or production in a photobioreactor in a greenhouse with a combination of sunlight and artificial light.

We have had access to information on two processes that may be practical in the Nordic Region.

The fermentation process has been used in Iceland in a pilot plant for production of *Haematococcus*. In Astacaroten's plant outside Stockholm the same alga was produced in a photobioreactor based on artificial light. IGV GmbH has developed a closed photobioreactor that uses sunlight as an energy source for the algae production. The knowledge and experience IGV GmbH possesses on photobioreactor technology will be available through a collaborative agreement. The process used by IGV GmbH will provide the basis for our project.

3.2 The fermentation process

This process involves production in the dark where organic substrat (for example acetate or glucose) is used as the source of energy and carbon. The process is usually used for cultivation of bacteria and fungi but can also be used in the production of certain types of algae that are able to exploit organic substrat. The fermentation is carried out in closed tanks in which the conditions can be controlled.

3.3 Process for photobioreactor production with artificial light

Closed photobioreactors are designed like fermentation reactors but with a light source placed in the culture so that the light energy can be utilised effectively. Most photobioreactors are designed as cylindrical containers with one or more built-in light sources. Closed artificial light reactors are the production technology that provides the best facility to control the cultivation conditions. This can be of interest in cultivating algae with special requirements. However, the costs of light energy are relatively high and large scale production is not currently very practical in the Nordic Region. Conversely small scale production of high cost products may be possible.

Both of the plants built in the Nordic Region based on fermentation and/or artificial light photobioreactors have been closed because of excessive energy costs.

3.4 Process for photobioreactor production in greenhouses

In recent decades several types of closed reactors for daylight-based production of micro algae have been developed. This development has been driven by the wish for better control of cultivation conditions than is possible in open pond plants. Daylight reactors require a large area/volume ratio to supply the culture with light energy. This is achieved by pumping the algae culture round in transparent pipes. The light –capturing part of the reactor can be oriented so that exploitation of the incoming rays is optimal. The reactor can be built with glass or plastic pipes. The algae culture is pumped through channels and CO₂ is added. Pumping for circulation of the algae culture can be expensive but in recent times favourable solutions have been developed.

Because of better protection of the culture and control of the growth conditions, closed reactors provide greater choice in the use of alga types and products than plant with open ponds. It has also proved possible to achieve higher production per unit of area in closed daylight reactors than in traditional open plant.

Artificial light

With production in greenhouses it is natural light that is the basis for production and it must therefore be exploited as well as possible. Even with installation of artificial light that will lengthen the growth period, natural light will still be the primary element. By supplementing the natural sunlight with growth lighting it is possible to establish good production conditions for growth 24 hours a day for much of the year. Temperature, light conditions and the supply of CO₂ can generally be optimised and thus provide efficient production. Use of artificial light as supplementary lighting has risen sharply over the last decade in the greenhouse industry. Both flowers and cucumbers have become year-round crops and it seems as though this may also be the case with micro algae production.

High pressure sodium vapour lamps are used today in greenhouse production as a source of growth light. These lamps have a high degree of effectiveness (30 %) compared to other types of lamp. This means that 30 % of the energy used is converted into photosynthetically active light.

Growth and reproduction

Micro algae reproduce like other microorganisms mainly by cell division. This means that the micro algae can multiply exponentially provided the growth conditions provide the opportunity. In optimal conditions the growth speed can be 1.5 – 2 per 24 hours, which means the number of cells is doubled 2 – 3 times a day. The exponential growth provides a formidable potential for production in a micro algae culture. With two doublings in 24 hours for example a biomass of 1 g will be able to increase to 1 kg after 5 days and 1 tonne after 10 days. This assumes however that the resources required for micro algae growth are supplied at adequate speed and in adequate quantity.

Photosynthetic growth of micro algae also requires adequate supply of carbon dioxide as a source of carbon, minerals in the form of salts dissolved in water and energy in the form of light.

Nutrition

The requirement for minerals that form part of the micro algae biomass is met through nutritional salts dissolved in the culture medium. Analyses of the algae show that a long list of elements is present, but in different quantities. Some are minimal factors like phosphorus and nitrogen, which are supplied in the form of phosphate and nitrate or ammonium. Another significant factor is iron, which is supplied together with complexing agents to avoid precipitation.

CO₂

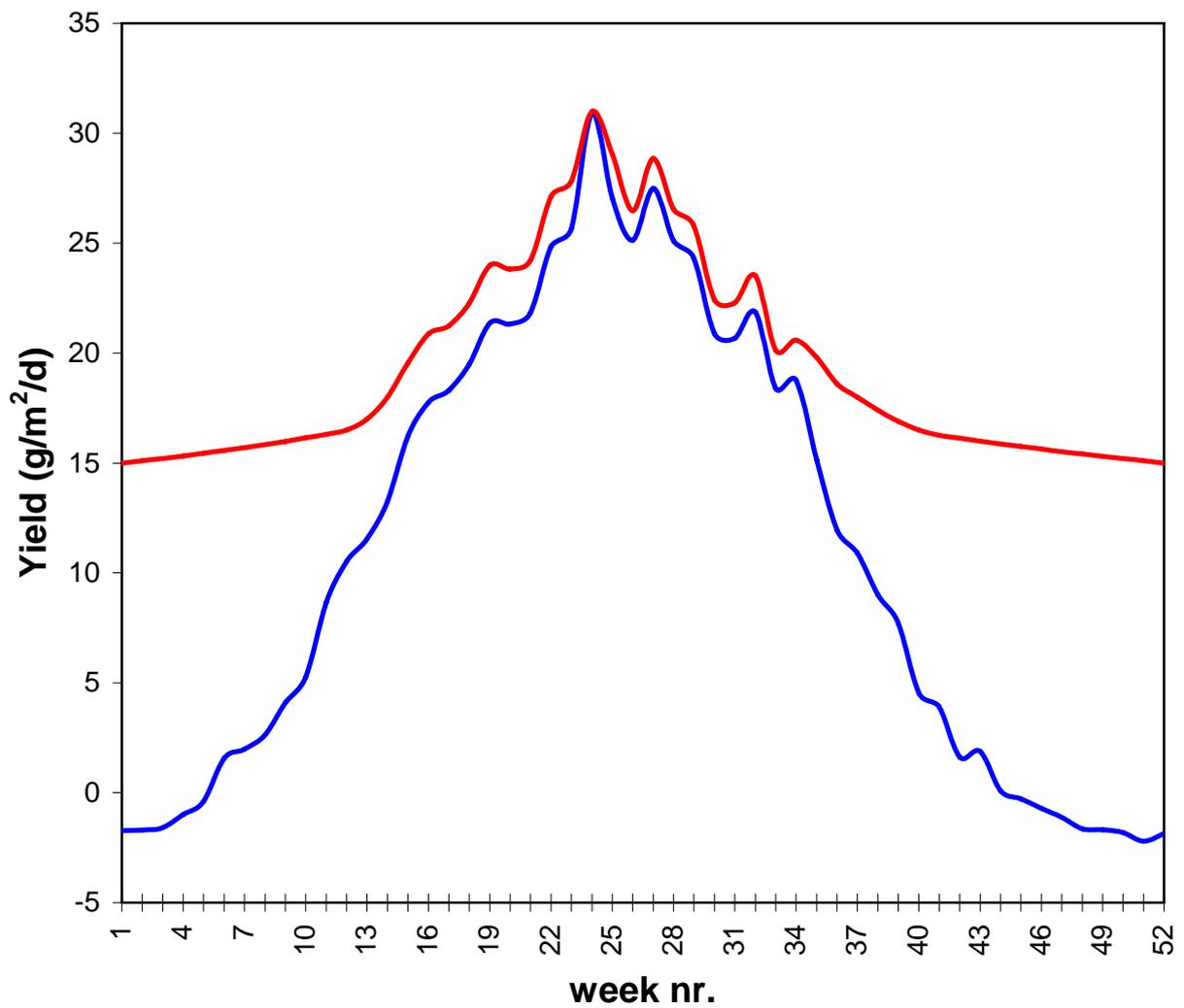
The micro algae's photosynthesis is done with CO₂ as the carbon source. Absorption is from dissolved CO₂ during the aqueous phase or from bicarbonate. To achieve high production in a micro algae reactor CO₂ must be supplied by bubbling CO₂-enriched air through the culture. Micro algae biomass contains about 45 % carbon, which means that production of 1 kg of algae by photosynthesis requires the supply of 1.65 kg CO₂.

Figur 1: Large Scale Production



Large scale production plant

Figur 2: Produksjons med naturlig lys og kunstig lys



— = Production with artificial light (red)
— = Production with natural light (blue)

3.5 Climate and location

Areas of interest for locating such an operation will be associated with gas power stations, oil refineries and other [plants with] large emissions of CO₂ and waste heat as well as areas with favourable sun conditions and proximity to the sea. Places that stand out as natural production sites are Slagentangen near Tønsberg in Norway and near Vänern in Sweden. These stand out because there [is] adequate emission of CO₂ and waste heat and because the number of hours of sun in these areas is among the highest in the Nordic Region and only insignificantly fewer than at the production plant in Klötze in Germany. Another advantage is cheap energy.

3.6 The degree of novelty of the project

- collects available information on biotechnology that is in rapid technical development
- as related to markets
- Contributes to the development of new production methods and improving the efficiency of existing ones
- Introduces environmentally friendly raw materials into different industrial products for example micro algae-based feed for livestock and the farming industry.
- Environmentally friendly since both CO₂ and waste heat will be utilised
- May reduce the use of antibiotics
- In time a range of synthetic raw materials for agriculture and the fish farming industry will be replaced.
- Providing access to technology that works

4. CHARACTERISTICS AND QUALITIES OF THE MICRO ALGAE

4.1 General

Photosynthetic micro-organisms represent a resource with significant potential for practical exploitation. Traditionally research on micro algae has been concentrated on their characteristics and function in natural waters. This has contributed to considerable knowledge about micro algae that can now be used to solve pollution problems, utilise waste products and produce important goods for society. The circumstances result in positive opportunities for economic exploitation of the micro algae and will at the same time provide environmental benefits.

Use of micro algae in a nutritional context has attracted increasing interest in step with research results that have emerged on their materials production and characteristics. The micro algae's chemical composition has been exhaustively studied in the case of some species that are used in industrial production.

4.2 Protein

The micro algae have in practice an interesting composition in regard to main components such as protein, fat and carbohydrates. The protein content is consistently high in micro algae. Blue-green algae have examples of species with the highest protein concentrations known in natural plants. But, for full utilisation of the protein, special treatment of the micro algae is generally necessary. Micro algae are excellent producers of essential amino acids. The micro algae in the genera *Spirulina* and *Chlorella* are for example used as high value protein supplements because of their essential amino acids content.

4.3 Lipids

Alga lipids generally comprise esters and glycerol and fatty acids with straight hydrocarbon chains with equal numbers of carbon atoms. Lipid production based on micro algae is among the most interesting possibilities for practical application of algae culture technology. For example silic algae and the blue-green algae can have high polyunsaturated fatty acid content, whilst the green algae are rich in linoleic acid.

4.4 Carbohydrates

The micro algae's carbohydrate content can vary between 20 % and 45 % on the basis of dry material. The chemical composition of the materials is linked inter alia to genetic circumstances, physiological factors and growth conditions. Production of glucose, fructose and galactose may have practical significance in the context of nutrition. However it is the polysaccharides substance group that receives most attention in the industrial context.

4.5 Pigments

Micro algae are important producers of a large spectrum of pigments. Their auxiliary pigments can in some cases be created in greater quantities than the primary pigments. In practical terms the pigments in micro algae are among the most financially interesting products.

4.6 Vitamins, aromatics

Micro algae represent a valuable resource for vitamins and aromatics of significance for use both for humans and for animals. Use of micro algae in connection with food/feed has demonstrated health effects of a probiotic nature. The practical potential of micro algae's vitamin production is large. Applications cover nutrition of humans and animals. Among the vitamins of particular economic interest are for example Vitamin B-12 and Vitamin E. Beta-carotene (Provitamin A) has its highest concentration in certain blue-green algae.

Exhaustive trials have been carried out that show that the micro algae represent an important source for virtually all nutritionally important vitamins. The vitamins are part of a group of substances that are inter alia handled administratively in the terminological category 'functional food'. Regular consumption may achieve special health effects or important specific bodily functions may be controlled.

4.7 Miscellaneous

Antibiotics

The blue-green algae appear as a particularly interesting resource of antibiotic effects and there is now strongly increasing research interest associated with new compounds produced by micro algae.

Probiotics

The term probiotic is a term that covers many applications of micro-organisms in the context of health/nutrition. Products of probiotics that are marketed are attributed with many different effects, for example strengthened immunity against infective diseases, improved growth and well-being for livestock and increased returns from commercial products .

Many types of micro-organisms are present in the preparations used, which are administered by way of powders, tablets or paste.

5. MARKET OPPORTUNITIES

5.1 Markets

Micro algae have a number of promising application areas and a significant growth market with great potential is foreseen.

The following application areas seem particularly interesting.

- Feed additives for animals and farmed fish, particularly production of fatty acids and astaxanthin.
Finished products in the market. Billions market.
- Health food and dietary supplements. Many products in the market. A market in significant growth.
Micro algae are used to a significant extent in health food products
- Pharmaceutical/medicinal products. Finished products in the market with great development potential.

Common to the markets mentioned above is that they are in significant growth globally and demand exceeds production.

In addition to the above mentioned markets great interest has been shown in production of micro algae as a new energy source. Both nationally and internationally and in the longer term, production of algae-based hydrogen gas and biodiesel will be able to replace fuels for example for motor vehicles and the market potential is enormous.

However it is as a supplier of feed supplements for livestock and farmed fish that micro algae production seems most interesting in the short term since possible resource shortage of feed components in existing production may be a reality shortly.

There is a professionally well established base of knowledge about micro algae as a resource for exploitation in feed and internationally there is rapid development in realising the potential for practical and economic solutions. Micro algae contain a range of the natural proteins, pigments, oils and fatty substances with essential fatty acids and vitamins in demand and in a short space of time will be able to represent an attractive alternative and supply the raw materials necessary to maintain quality and standards as well as replace a range of synthetic materials. This market is ripe for new alternatives since there is almost a monopoly on sales and thus the price.

5.2 Product opportunities

A careful assessment based on today's knowledge is that the following products will initially be relevant for algae culture technology.

- protein supplement for pig feed and poultry feed
- amino acid product with specially high amino acid content of the essential amino acids
- pigment for colouring egg yolks and farmed fish (a carotenoid that can be used to produce a good colour in farmed salmon will have a large market)

Selection of product areas should however be done in cooperation with industrial and financial partners. The above mentioned product possibilities are of potential major and commercial interest.

5.3 Competition conditions

There are many end users in the Nordic Region and competitive advantages will be proximity to the market and resource-friendly technology with sunlight and cheap energy: also, available and sufficient supplies of CO₂ and waste water. The area requirement and water consumption are also significantly lower than for example in production of protein in grain and meat.

5.4 Expertise and resource centres

Since there is little industrial activity [in] the Nordic Region all significant knowledge about micro algae is centred on university colleges and research institutes. The knowledge is world class.

6. TRIAL PRODUCTION

As part of the completion of the project it was decided to carry out trial production of micro algae in a photobioreactor in a greenhouse at IGV GmbH outside Berlin where the light conditions are in general the same as in those areas previously discussed under location.

To carry out the trial production a photobioreactor developed and constructed by IGV GmbH for industrial production was used. See brief presentation of the photobioreactor page. The purpose of the experiment was to test what effect artificial light as a supplement to sunlight would have on the production of micro algae. In addition trials were carried out on adding organic materials to further optimise production. This production process was called 'mixotrophic cultivation'.

The lighting system was supplied by Gavita AS (N) and the production of micro algae could thus be carried out at night, maintaining production at a high level when daylight was weak. The lamps were mounted between the photobioreactor's rows of pipes thus avoiding them shading daylight. The lamps used were high pressure sodium vapour lamps that provide high efficiency compared to other lamps.

Glucose was used as the organic material.

The trial production was carried out over a period of 6 months. The alga used was a green alga named *Nannochloropsis* which is a robust alga rich in fatty acids. Production was carried out both with and without artificial light (phototrophic cultivation) and mixotrophic cultivation with artificial light to see the effect of artificial light and the addition of glucose.

The result with mixotrophic cultivation proved to be a success. The increase in productivity or harvesting of algae biomass proved to be 245 % higher than compared to just use of sunlight. At the same time it was confirmed that such production methods can be used for other algae cultures with the same result, for example *Spirulina* and *Chlorella*.

Even although we basically have somewhat lower solar radiation exposure at our latitudes and are somewhat worse equipped to achieve optimal production per area unit, we have on the other hand the advantage of longer days and lower maximum light levels during the summer half-year and significantly cheaper electric power compared to other regions.

The trial therefore showed that production of micro algae on an industrial scale with such processes as described above is fully viable at our latitudes.

Figure 3: Input required for mixotrophic production of micro algae

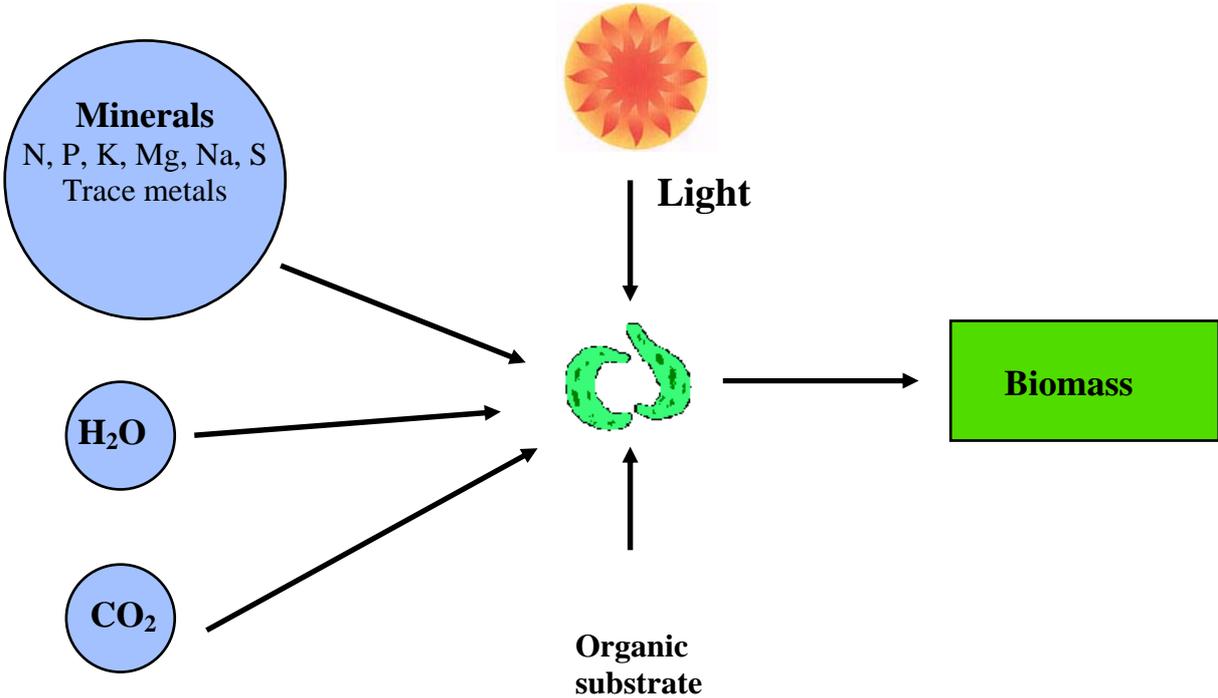
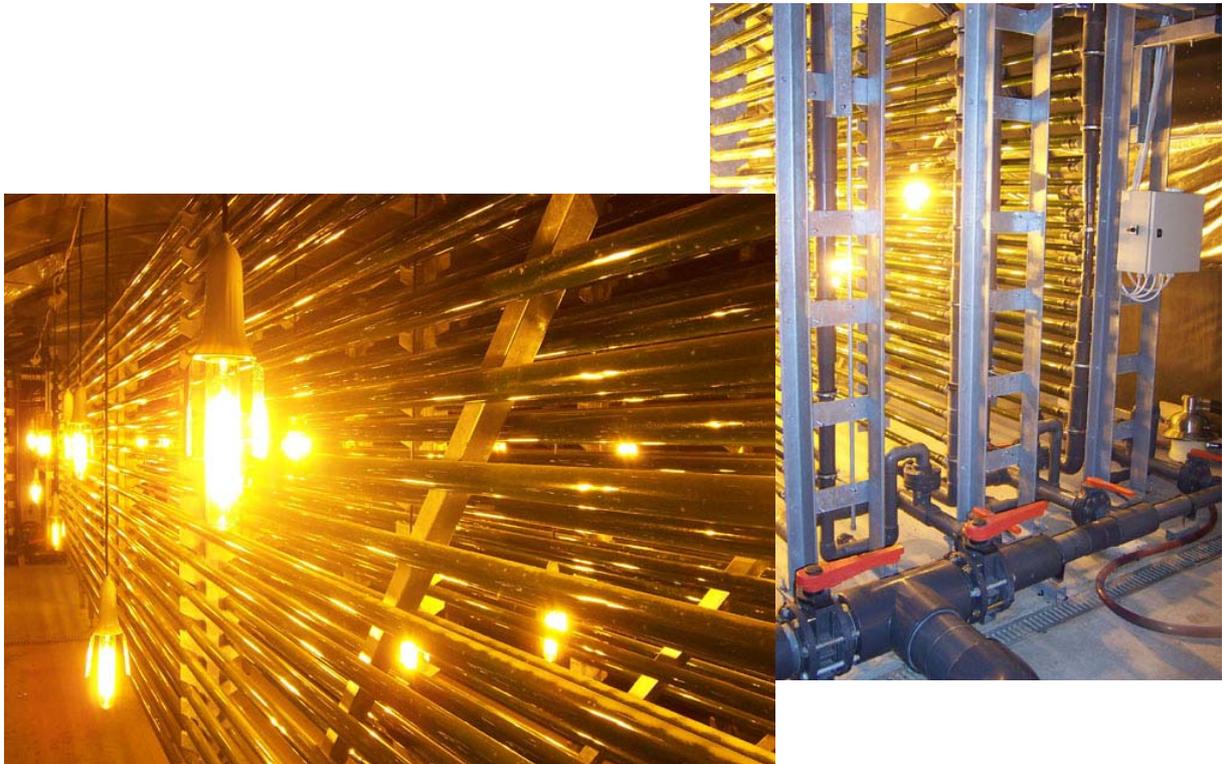


Figure 4: The cultivation in the PBR 4000 from 21.04.2006 to 21.05.2006 with sunlight and no artificial light



Figure 4: The mixotrophic cultivation in the PBR 4000 started on 31.05.2006 with artificial light, 12/24 h at night



7. CONCLUSION

Our own knowledge, access to technology that is in use and now confirmed positive results from our own trial production make investment in micro algae appear very interesting. A large domestic market and a situation in which the supply of raw materials for livestock and farmed fish [feed] is beginning to become critical give micro algae production increasing relevance as a source of raw materials.

Until now too little capital has been a problem, which has delayed and hindered investment in commercial production of micro algae

The following is recommended:

- Investment must be in products that have clear competitive advantage in Nordic conditions.
- Before production a network of collaborators must be established in which the synergy will be considerable through good exploitation of the parties' competencies, resources and requirements.
- Development of complete product concepts, in the first instance in agriculture and the [fish] farming industry.
- R & D projects in cooperation with research institutes and universities for development of concepts for algae-based hydrogen production.

8. LITERATURE

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