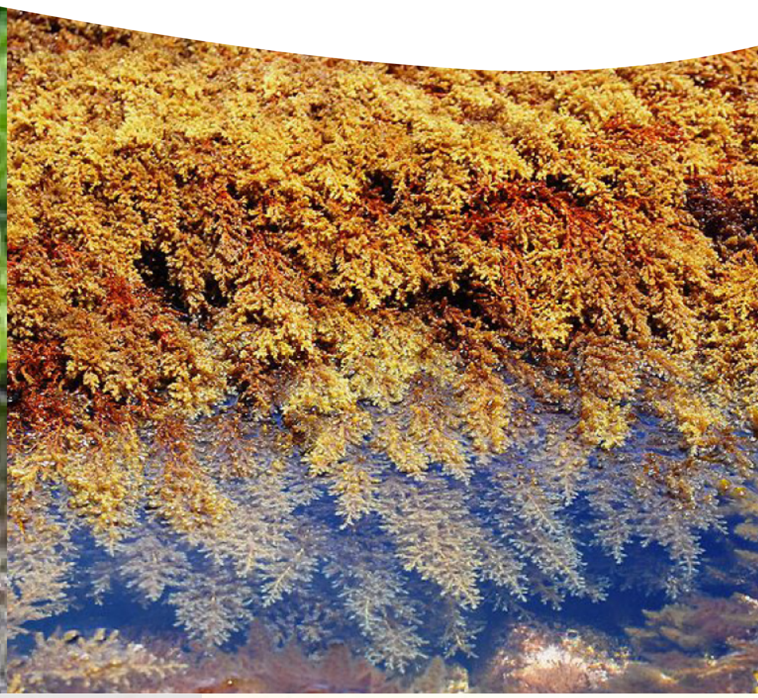
REPORT SNO 5895-2009

What is the potential of marine algae, in combination with sewage sludge, as a composite of bio-fertilizer?

Sewage sludge and marine biomass as innovative bio-solid composite (Black Sea, Romania)


Norwegian Institute for Water Research
– an institute in the Environmental Research Alliance of Norway

REPORT

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Title	Serial No.	Date
What is the potential of marine alga, in combination with sewage sludge, as a composite of bio-fertilizer?	O-29303	23.11.2009
	Report No. Sub-No. 5895-2009	Pages Price 30
Author(s) Smit, Anke Weber	Topic group Biodiversity and Eutrophication-Marine	Distribution Public
	Geographical area Norway, Black Sea	Printed CopyCat

Client(s)	Client ref.
ECOM	

Abstract
The report describes some features of the algae found in the Black Sea ecosystem. These algae are considered in a broader frame with respect to their potential usage as industrial products. A special focus is placed on their potential use, combination with sewage sludge, as bio-fertilizer. The present work is conducted based on available knowledge at NIVA and an internet search. Given the vast amount of references consulted, all references are generally only cited when referred to for the first time.

4 keywords, Norwegian	4 keywords, English
1. Marine alge	1. Marine algae
2. Norge	2. Norway
3. Alge bruk	3. Black Sea
4. Bio-gjødsel	4. Bio-fertilizer

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ISBN 978-82-577-5630-7

Grant Project KNRIN-2008/115241

Wastewater Treatment sludge and marine biomass from Romanian Black Sea Coast as innovative bio-solid composite

What is the potential of marine alga, in combination with sewage sludge, as a composite of bio-fertilizer?

Preface

The project is coordinated by ASSOCIATION OF PROTECTION OF THE HUMAN BEING AND THE ENVIRONMENT FOR A SUSTAINABLE DEVELOPMENT IN THE WORLD – ECOM with PhD Eng. Maria Nastac as president. ECOM Association of Constanta, based in 2004, is a professional-science organization, non-profit, with legal personality, operating in accordance with the Romanian legislation and with its own status. The purpose and the mission of the association is to promote the change in the economic operators mentality, state and public administration, civil society, in the direction of realizing a healthy life style in a friendly environment. The association objectives are oriented towards promoting and supporting the scientific activities of Research-Development-Innovation in medicine, industry and agriculture as a friendly alternative, non-harmful to humans and the environment.

The report at hand describes some features of the algae found in the Black Sea ecosystem. These algae are considered in a broader frame with respect to their potential usage as industrial products. A special focus is placed on their potential use, combination with sewage sludge, as bio-fertilizer. The present work is conducted based on available knowledge at NIVA and an internet search. Given the vast amount of references consulted, all references are generally only cited when referred to for the first time.

Trondheim, 20. November 2009

Anke Weber Smit

Contents

Summary

In this report, an overview is given about the state-of-the-art concerning the usage of marine algae, with focus on the species commonly found along the shores and on the beaches of the Black Sea: *Ulva lactuca*, *Cystoceira barbata* and *Ceramium rubrum*. What was thought to be *Ceramium rubrum* though appears to be *Phyllophora*, an arctic relict (chapter 2). This alga is found in large quantities in the Black Sea. *Phyllophora nervosa* is found in the top metre while *Coccotylus truncate* dwells in deeper layers. Both thrive on blue mussel.

Since the focus of interest was to produce a scientific study on the situation of algae in the Norwegian Sea in order to be able to undertake a comparative study with the situation in the Black Sea, a short overview about the ecology of Norway and of the Black Sea was included in order to illustrate the similarities and differences of the two ecosystems (chapter 1).

In the usability of the algae the focus was put on their potential usage, in combination with sewage sludge, as a bio-fertilizer. In order to provide some background information on this subject, a chapter each was dedicated to the pecularities of sewage sludge and the world of fertilizers, respectively (chapters 3 and 4). Chapter 5 gives some information about commercial use of algae in general and the industry in Norway in particular and in chapter 6 the conclusions and further suggestions are presented.

The report furthermore includes an extended list of references (chapter 7) in which also suggestions for further reading are given.

To complete this report, an overview of the possible usages of marine algae in industry is presented in the appendix.

1. Introduction

1.1 Marine algae in Norway and the Black Sea

Marine algae are aquatic non-vascular plants that form the basis of aquatic and marine food chains and habitats. They are major O_2 producers and also produce many other products useful to mankind. Their potential is just beginning to be appreciated.

Macroalgae (seaplants), commonly called 'seaweeds' are big enough to tie ropes from and can be chopped to mini size for other purposes. Minialgae are small seaplants that can be grown in slurry systems or seeded on substrate. They can grow in open ponds or in enclosed systems for pure cultures. Microalgae are too small to see with the naked eye. They are best grown in slurry systems Although they grow in open systems, to obtain a pure culture they must be cultured in closed systems.

1.2 Ecology of Norway

The Norwegian Shelf Large Marine Ecosystem (LME) is characterized by its Subarctic climate. It is a western boundary ecosystem situated off the West Coast of Norway. The Iceland-Faroe Ridge separates the relatively warm waters of the Northeast North Atlantic from the cold Arctic deep water of the Norwegian Sea. A boundary current flows along the edge of the Norwegian Shelf into the Arctic region. The cold and low salinity East Icelandic Current flows southeast towards the Norwegian Basin. Climate is the primary force driving the LME, with intensive fishing as the secondary driving force (http://www.eoearth.org).

Productivity

The Norwegian Shelf LME is considered a Class I, highly productive (>300 grams of Carbon per square meter per year) ecosystem based on SeaWiFS global primary productivity estimates. Its high productivity is probably linked to the nutrient rich, cold Arctic waters that characterize this LME (http://www.eoearth.org). A temperature and salinity anomaly occurring in the northern North Atlantic during the 1960s and 1970s has probably had a triggering effect on ecological events. It has had a major impact on Norwegian spring-spawning herring, the first large stock to be affected, and the International Council for the Exploration of the Sea (ICES). There was a change in feeding conditions for the herring stock, which had to shift further to the northeast. For more information on the effect of environmental factors on cod recruitment variability. A key species in this LME is the copepod *Calanus finmarchicus*, which is transported from the Norwegian Sea into the Barents Sea. For the life cycle and transport of *Calanus finmarchicus* from the Norwegian Sea into the Barents Sea. There is a need for better understanding of the climate system and its impacts on the LME.

Fish and Fisheries

The Norwegian Shelf LME has a complex fishery history with concomitant influences of ecological anomalies, high fishery mortality and early implementation of management measures. The Food and Agriculture Organization (FAO) 10-year trend shows an increase in the total catch, from 500,000 tons in 1990, to 1.8 million tons in 1999 (http://www.eoearth.org). The average yearly catch is 1.5 million tons. The average catch composition is dominated by 3 groups: herring, sardines and anchovies (almost half the catch); pelagic fishes (14% of the catch); and cods, hakes and haddocks (32% of the catch). In the 1960s and 1970s, fishing pressure increased as a result of purse seining technology. Herrings became depleted, which eventually led to a collapse. After two decades of very low abundance, herring stock has recently recovered to a total biomass of over 10 millions tons. The stock winters in the Vestfjord, and feeds all over the Norwegian Sea in the summer. Main spawning grounds are off Møre, with smaller populations spawning off of Iceland and southern Norway. The spawning areas of cod are located in the Norwegian coastal current, in coastal bays and near offshore banks. Temperature is an important factor affecting cod recruitment. The data strongly suggests that a high temperature is a necessary condition for the formation of a strong year-class. Capelin migrates out of the Barents Sea into the Norwegian Sea. The overriding goal of Norwegian fisheries management is the sustainable use of living marine resources.

Pollution and Ecosystem Health
Some pollution issues in this LME stem from Norway's offshore oil industry, and the risk of oil spills in Norwegian waters. Poor weather and substandard ships have caused groundings and losses. For more information about pollution control in Norway, see the Norwegian Pollution Control Authority (SFT), under Norway's Ministry of the Environment. This agency aims to promote sustainable development.

1.3 Black Sea ecology

The Black Sea Large Marine Ecosystem (LME) is characterized by its temperate climate. It is an almost completely enclosed sea located off of the Mediterranean Sea. It is surrounded by 6 countries, Romania, Bulgaria, Turkey, Georgia, Ukraine and Russia. It communicates with the Mediterranean Sea LME through the Turkish Straits (Bosporus and Dardanelles), and receives fresh water from the Danube, Dniepr, Dniestr, Don, and Kuban Rivers. Eutrophication is the primary force driving the LME, with intensive fishing as the secondary driving force. The Global Environment Facility (GEF) is supporting an LME project in the Black Sea, to address critical threats to the coastal and marine environment, and to promote ecosystem-based management of coastal and marine resources (http://www.eoearth.org).

Productivity
The Black Sea LME measures 330 miles from North to South and 630 miles from East to West. The LME has a narrow continental shelf, except in the productive Sea of Azov. It is strongly influenced by river runoff and the lack of rapid exchange with the adjacent Mediterranean Sea LME. The Black Sea Large Marine Ecosystem is considered a Class I, highly productive (>300gC/m2-yr) ecosystem based on SeaWiFS global primary production estimates. River inflows contribute to high phytoplankton production in this LME. In some places, the Black Sea reaches a depth of more than 2,200 meters. A distinctive feature of the Black Sea LME is the distribution of dissolved oxygen and hydrogen sulphide. Oxygen is nearly absent below 250 to 300 meters. Thus 90% of the LME's volume is anoxic, the world's largest such volume.

Fish and Fisheries
The Food and Agriculture Organization (FAO) 10-year trend shows an increase in the catch from 390,000 tons in 1990 to 500,000 in 1999. However, catch trends were irregular, with a peak of almost 600,000 tons in 1995, and two catch troughs, in 1991 and in 1998. The average catch is 500,000 tons. The most important species group in terms of shelf catches are clupeoids (herrings, sardines and anchovies). The combination of uncontrolled fisheries and eutrophication is causing important alterations in the structure and dynamics of this LME. The effect of uncontrolled fisheries and of the removal of predators on trophic interactions can be determined. The socalled trophic cascade is a reduction in apex predators leading to a higher abundance of planktivorous fish that feed on zooplankton biomass. Industrial fisheries began relatively early, especially for small pelagics such as anchovy. Demersal trawl fishery landings increased steadily after 1960. By the early 1970s, most of the demersal resources of the Black Sea were close to maximum sustainable yield (MSY). In recent

decades, landings of turbot, migratory pelagics, and anadromous species, especially sturgeon, have declined. The anchovy fishery has collapsed. There is now a decline for many demersal fish, for pelagic predators and for benthic invertebrates. Benthic systems are dominated by species such as *Mya arenaria*, better adapted to low-oxygen conditions. Increased salinity in the Sea of Azov, due to the reduction of freshwater inflow related to irrigation, appears to have affected species structure. This has changed the dominant species of ichthyofauna. There is a shortening of the food chain. Dolphins (common, harbor porpoise and bottlenose) are down to a population of 500,000 due to accidental killings, gill net fishing, the destruction of coastal ecosystems and various forms of pollution. Other marine mammals are critically endangered. The monk seal is virtually extinct. The productive fishery of the Black Sea Oyster, indigenous to the area, has been destroyed through the introduction of exotic species in ballast waters. The Global International Waters Assessment (GIWA) has issued a matrix that ranks LMEs according to the sustainable exploitation of fisheries and the predicted direction of future changes. GIWA characterizes the LME as severely impacted in terms of overfishing and destructive fishing practices. However, these impacts are decreasing. A fisheries convention is to be negotiated by the 6 Black Sea states to adopt an ecosystem based management approach. The University of British Columbia Fisheries Center has detailed fish catch statistics for this Large Marine Ecosystem.

Pollution and Ecosystem Health

The Black Sea area is a major industrial and agricultural region, with uncontrolled urban development. In coastal areas there are discharges from rivers, industry, agricultural pollution and domestic sewage. The LME has a huge drainage basin. There is an acceleration of eutrophication due to excessive levels of nitrogen loading. The combination of eutrophication and uncontrolled fisheries has caused important alterations in the structure and dynamics of this LME. The almost entirely enclosed nature of the LME contributes to the eutrophication problem. There is decreasing transparency of Black Sea waters. Beaches are littered, and there are regular beach closures due to sewage discharge problems. There is a growing risk of losing valuable habitats in these areas. While there is little data on toxic contamination and heavy metal accumulation, the Mussel Watch program in each of the six countries assesses areas with high pollution. A chemical pollution study for the Black Sea was completed by 98 Black Sea scientists. This resulted in the publication of a “State of Pollution of the Black Sea” report. Oil pollution comes from land-based sources, and from shipping. There has been a rapid increase in traffic in Black Sea ports, and an oil spill occurred in 1994 when the "Nassia" collided with an empty freighter. A report on Black Sea Pollution leading to the depletion of fishing stocks raised international concern. In the 1970s and 1980s there were frequent explosions of phytoplankton and jellyfish (*Aurelia aurita*). Blooms and red tides have been reported in the northern and western sections of the Black Sea. The Global International Waters Assessment (GIWA) has issued a matrix that ranks LMEs according to pollution. GIWA characterizes the LME as severely impacted in terms of eutrophication and ecotone modification. However, these impacts are not increasing, according to GIWA. A series of small GEF projects have focused on reducing nitrogen loadings from the 17 contributing nations of the Black Sea basin. Following the successful completion of a Transboundary Diagnostic Analysis (TDA) and a Strategic Action Programme (SAP) in the 1990s, there is a political commitment to reduce nutrients and abate persistent toxic substances being released from hotspots. Agriculture pollution is being reduced, and wetlands are being restored in the upstream basins to serve as nutrient sinks to protect the LME. A GEF Strategic Partnership is in place for 2001-2006, to assist the 17 nations.

The algae commonly found along the shores and on the beaches of the Black Sea are *Ulva lactuca*, *Cystoceira barbata* and *Ceramium rubrum*. What was thought to be *Ceramium rubrum* though appears to be Phyllophora (Pedersen, pers. com), an arctic relict. This algae is found in large quantities in the Black Sea (Lüning, 1990). *Phyllophora nervosa* is found in the top metre while *Coccotylus truncate* dwells in deeper layers. Both thrive on blue mussel.

2. Algae

Algal potential is just beginning to be realized. These plants bear great potential to humanity and to our environemt (http://www.dacnet.nic.in)

In the Black sea four species of algae are of main interest to the prestent study:

- *Ulva lactuca*, a green algae;
- *Cystoceira barbata*, a brown algae;
- *Phyllophora nevrosa,* a red algae
- *Coccotylus truncata*, a red algae.

2.1 Ulva lactuca

A green alga in the division Chlorophyta, is the type species of the genus Ulva, also known by the common name sea lettuce. The distribution is worldwide: Europe, North America - west and east coasts, Central America, Caribbean Islands, South America, Africa, Indian Ocean Islands, South-west Asia, China, Pacific Islands, Australia and New Zealand. This small green alga (up to 30 cm across) has a broad, crumpled frond that is tough, translucent and membranous. It is attached to rock via a small hold-fast (Pizzolla 2008). The sea lettuce is found at all levels of the intertidal, although in more northerly latitudes and in brackish habitats it is found in the shallow sublittoral. In very sheltered conditions, plants that have become detached from the substrate can continue to grow, forming extensive floating communities. The plant tolerates brackish conditions and can be found on suitable substrata in estuaries (www.wikipedia.org).

Figure 2: *Ulva lactuca* (www.wikipedia.org). Ulva are often able to thrive in polluted environments.

Ulva spp. are used as a sea vegetable, as aquarium feed or animal feed supplement, as an ingredient in nutraceutical mixtures and as an ingredient in wellness products such as skin lotions used in spas. At present, approximately 1,500 tons/year are harvested in the wild in Japan (http://www.seavegetables.com).

Nutrient requirements
The distribution of *Ulva* species can be limited by nitrogen concentrations. Due to their high nitrogen requirements, reduced ability to take up nitrogen, and limited ability to store it, *Ulva* need to be in nitrogen-rich environments. On the other hand, when nitrogen is available in particularly high

concentrations, *Ulva* is able to take up more than most species and use it to grow rapidly. This feature of *Ulva* makes it very successful in nitrogen-rich areas due to sewage pollution. Nutrient availability is known to influence reproduction in the microalgal species *U. fasciata*. Specifically, less nitrogen concentrations lead to enhanced gamete formation, while high nitrogen concentrations lead to vegetative growth and asexual reproduction. Nitrogen deficiency is known to suppress reproduction in many species, for example *U. lactuca,* in which high concentrations of ammonium have been seen to cause abundant zoospore formation. *Ulva* are found in abundance in areas with enhanced nutrient supplies, including anthropogenically altered areas where sewage is released into the water. Nuisance growths of *Ulva* can occur in such areas, especially if they are enclosed or semi-enclosed and experience little mixing. In these areas, *Ulva* comprise a large proportion of drift plants, which can smother the benthic communities below (http://www.mbari.org).

Bioindicators

Because many *Ulva* species thrive in high nutrient conditions, their abundance in an area may indicate eutrophication. In addition, there is a close correlation between the concentration of seawater inorganic nitrogen and phosphate and tissue nitrogen and phosphorous, respectively. *U. lactuca* and *U. expansa* are particularly good bioindicators of eutrophication. This close correlation between seawater concenctrations and tissue concentrations in *Ulva* implies that the relative amounts of tissue nutrients reflect the degree of eutrophication in the water where the algae grew. Even better than simply testing the water itself, the advantage of using *Ulva* as a bioindicator is that the levels of nutrients in the tissues result from long-term integration and accumulation from the surrounding water. Their cosmopolitan distribution, simple morphology and ease of growth assessment, along with a graded tolerance and response to stress induced by pollutants all make *Ulva* good bioindicators. *Ulva* species can be used as bioindicators of metal contamination as well. *U. lactuca*, for example, is a good indicator of Mn, Fe, Cu, Zn and Pb contaminations. The locations of high levels of metal contamination, for example in urban sites, can be reliably identified using *U. lactuca*. Metals can harm many forms of marine life, including algae. Metals may inhibit reproduction of *Ulva* by interfering with the ability of male and female gametes to find one another via phermones. Cadmium has been found to reduce growth uptake by about half in *U. lactuca* by inducing loss of pigments and thus decreasing the rate of photosynthesis. *Ulva* can also be used as indicators in areas that have been exposed to large concentrations of crude oil. The oil hurts algae by inhibiting DNA and RNA activities. It can cause damage simply by coating them or by disrupting cell metabolism and inhibiting photosynthesis through algal uptake of hydrocarbons. *Ulva* can be good algae to study in such cases due to their simple morphology, ease of growth assessment and graded tolerance and response to stress induced by pollutants.

2.2 Cystoceira

Cystoseira is a brown alga in the order Fucales. It is is characterized by highly differentiated basal and apical regions and presence of catenate pneumatocysts (air-vesicles). In *Cystoseira* old plants have an elongated main axis, and in time the primary laterals become proportionally elongated. Their lower parts are strongly flattened into 'foliar expansions' or basal leaves. Fertile regions which bear conceptacles are known as receptacles. These are normally found at the tips of the branches. Their basal and apical regions are highly differentiated. They have air vesicles. The aerocyst or air vesicles keep the organism erect, by causing it to float in strong currents. (www.wikipedia.org). *Cystoseira* is one of the most widely distributed genera of the Fucales order and provides an essential habitat for many epiphytes, invertebrates, fish, and even humans.


Figure 3: *Cystoseira* community (http://www.wikipedia.org).

Cystoseira osmundacea needs a hard, rocky substratum, a well-illuminated habitat, and cannot withstand much desiccation. Thus an ideal habitat for this alga would be the sublittoral rocky sea floor, although some specimens can be found in deep rocky tide pools. Several studies have observed the distributions of *C. osmundacea* in its environment, and the pattern that emerges is that of high abundances of *Cystoseira* between four and eight meters depth, with an abrupt drop in abundance past ten meters depth. Plants tend not to be abundant in the shallowest areas. Lower abundances in deep water may be a function of diminishing light, and the absence of *Cystoseira* in shallow waters may be a function of severe wave force during those violent winter storms. Although some plants do occur past ten meters, their growth tends to be stunted. (http://www.mbari.org). *Cystoseira* is found mostly in temperate regions of the Northern Hemisphere, such as the Mediterranean, Indian, and Pacific Oceans.

Bioindicators

Cystoseira depend on good water quality, and can be used for bioindication. Among seaweeds, *Cystoseira* can have a higher Pb levels relative to *Padina spp*, who in turn have higher Cr concentrations (Conti et al., 2009). The brown alga is also a known biosorbent for cadmium(II) and lead(II) (Lodeiro, 2005). *Cystoseira baccata* harvested along the Atlantic coasts of Morocco yielded seven new phytochemical structures (meroditerpenoids). Three of these compounds showed antifouling activities against growth of microalgae, macroalgal settlement, and mussel phenoloxidase activity, while being nontoxic to larvae of sea urchins and oysters (Mokrini, 2008). Furthermore, *Cystoseira* indica posseses sompounds that have potent antiviral activity against two herpes simplex virus types without being toxicity to other cells (Mandal, 2007). This offers interesting pharmacological perspectives for antiviral drug development.

2.3 *Phyllophora nervosa*

A bright red or pink seaweed. *Phyllophora nervosa* belongs to the 'red algae'. Each plant has a small disk-shaped base and erect fronds. The fronds consist of short cylindrical stipes (stalks) rarely longer than 1cm long and blades which may be up to 15 cm long and 10 mm wide. The fronds are dichotomously branched, with undulating margins and an indistinct midrib. The tip of each frond is distinctly rounded. The fronds are perennial and in some case 5 or 6 new periods of growth can be identified. Regeneration occurs following erosion or animal grazing. Continual regeneration leads to great variation in the appearance of individual plants as each new growth could come from the end, margin or surface of the blade. Fronds are frequently encrusted with the spiral tube worm *Spirorbis*

spirorbis or bryozoans (Heard, 2005). *Phyllophora crispa* grows on rock subtidally to depths of 30 m and is commonly found in shady pools in lower intertidal areas. The algae are an arctic relict that thrives on blue mussels.

In Norway, the *Phyllophora crispa* growth in the sublittoral on rocks or on calcareous sand/pebble and are distributed north of Trondheim (http://seaweeds.uib.no). Considered to be rare, it can sometimes occur in large numbers at the Norwegian west coast. Although this minor wild crop is used for food & galactans, it's main use is as food for animals, fertilizer, and food ingredient (http://www.seavegetables.com).

Figure 4: Specimen of *Phyllophora crispa*. (Photo by Francisco Arenas, http://www.mba.ac.uk)

2.4 *Coccotylus truncata*

Like *Phyllophora, Coccotylus truncata* belongs to the red algae. It is a common species in the subtidal zone along the entire Norwegian coast. It can be difficult to separate the species from the *Phyllophora* spp., in particular *Phyllophora pseudoceranoides* (http://seaweeds.uib.no). The species thrives on blue mussels.

Figure 5: *Coccotylus truncata* (Photo by Narve Brattenborg, http://seaweeds.uib.no/?art=735)

3. Sewage Sludge

The sludges accumulated in a wastewater treatment process must be treated and disposed in a safe and effective manner. The purpose of digestion is to reduce the amount of organic matter and the number of disease-causing microorganisms present in the solids. The most common treatment options include anaerobic digestion, aerobic digestion, and composting. Incineration is also used albeit to a much lesser degree (http://www.wikipedia.org).

Choice of a wastewater solid treatment method depends on the amount of solids generated and other site-specific conditions. However, in general, composting is most often applied to smaller-scale applications followed by aerobic digestion and then lastly anaerobic digestion

3.1 Anaerobic digestion

Anaerobic digestion is a bacterial process that is carried out in the absence of oxygen. The process can either be *thermophilic* digestion, in which sludge is fermented in tanks at a temperature of 55°C, or *mesophilic*, at a temperature of around 36°C. Though allowing shorter retention time (and thus smaller tanks), thermophilic digestion is more expensive in terms of energy consumption for heating the sludge. One major feature of anaerobic digestion is the production of biogas, which can be used in generators for electricity production and/or in boilers for heating purposes.

3.2 Aerobic digestion

Aerobic digestion is a bacterial process occurring in the presence of oxygen. Under aerobic conditions, bacteria rapidly consume organic matter and convert it into carbon dioxide. The operating costs used to be characteristically much greater for aerobic digestion because of the energy used by the blowers, pumps and motors needed to add oxygen to the process. However, since the recent advent of stone fiber filter technology which uses natural air currents for oxygenation, this no longer applies. Aerobic digestion can also be achieved by using jet aerators to oxidize the sludge.

3.3 Composting

Composting is also an aerobic process that involves mixing the sludge with sources of carbon such as sawdust, straw or wood chips. In the presence of oxygen, bacteria digest both the wastewater solids and the added carbon source and, in doing so, produce a large amount of heat.

3.4 Incineration

Incineration of sludge is less common due to air emissions concerns and the supplemental fuel (typically natural gas or fuel oil) required burning the low calorific value sludge and vaporizing residual water. Stepped multiple hearth incinerators with high residence time as well as fluidized bed incinerators are the most common systems used to combust wastewater sludge. Co-firing in municipal waste-to-energy plants is occasionally done, this option being less expensive assuming the facilities already exist for solid waste as well as no need for auxiliary fuel.

3.5 Sludge disposal

When a liquid sludge is produced, further treatment may be required to make it suitable for final disposal. Typically, sludges are thickened (dewatered) to reduce the volumes transported off-site for disposal. There is no process which completely eliminates the need to dispose of biosolids. There is, however, an additional step some cities are taking to superheat the wastewater sludge and convert it into small pelletized granules that are high in nitrogen and other organic materials. In New York City, for example, several sewage treatment plants have dewatering facilities that use large centrifuges along with the addition of chemicals such as polymer to further remove liquid from the sludge. The removed fluid, called centrate, is typically reintroduced into the wastewater process. The product which is left is called "cake" and that is picked up by companies which turn it into fertilizer pellets. This product is then sold to local farmers and turf farms as a soil amendment or fertilizer, reducing the amount of space required to dispose of sludge in landfills.

3.6 Treatment in the receiving environment

Many processes in a wastewater treatment plant are designed to mimic the natural treatment processes that occur in the environment, whether that environment is a natural water body or the ground. If not overloaded, bacteria in the environment will consume organic contaminants, although this will reduce the levels of oxygen in the water and may significantly change the overall ecology of the receiving water. Native bacterial populations feed on the organic contaminants, and the numbers of disease-causing microorganisms are reduced by natural environmental conditions such as predation or exposure to ultraviolet radiation. Consequently, in cases where the receiving environment provides a high level of dilution, a high degree of wastewater treatment may not be required. However, recent evidence has demonstrated that very low levels of specific contaminants in wastewater, including hormones (from animal husbandry and residue from human hormonal contraception methods) and synthetic materials such as phthalates that mimic hormones in their action, can have an unpredictable adverse impact on the natural biota and potentially on humans if the water is re-used for drinking water[2]. In the US and EU, uncontrolled discharges of wastewater to the environment are not permitted under law, and strict water quality requirements are to be met. A significant threat in the coming decades will be the increasing uncontrolled discharges of wastewater within rapidly developing countries.

4. Fertilizer

Fertilizers are chemical compounds applied to promote plant and fruit growth. Fertilizers are usually applied either through the soil (for uptake by plant roots) or by foliar feeding (for uptake through leaves). Fertilizers can also be applied to aquatic environments, notably Ocean fertilization. Fertilizers can be divided into the categories of *organic fertilizers* (composed of decayed plant/animal matter), or *inorganic fertilizers* (composed of simple chemicals and minerals). *Organic fertilizers* are 'naturally' occurring compounds, such as peat, manufactured through natural processes (such as composting), or naturally occurring mineral deposits; *inorganic fertilizers* are manufactured through chemical processes (such as the Haber process), also using naturally occurring deposits, while chemically altering them (e.g. concentrated triple superphosphate)(http://www.wikipedia.org).
Properly applied, organic fertilizers can improve the health and productivity of soil and plants, as they provide different essential nutrients to encourage plant growth. Organic nutrients increase the abundance of soil organisms by providing organic matter and micronutrients for organisms such as fungal mycorrhiza, which aid plants in absorbing nutrients. Chemical fertilizers may have long-term adverse impact on the organisms living in soil and a detrimental long term effect on soil productivity of the soil.

4.1 Chemical content

Fertilizers typically provide, in varying proportions, the three major plant nutrients: nitrogen, phosphorus, and potassium, known shorthand as N-P-K. Fertilizers may also provide secondary plant nutrients such as calcium, sulfur, magnesium and sometimes trace elements or micro nutrients with a role in plant or animal nutrition: boron, chlorine, manganese, iron, zinc, copper, molybdenum and in some countries selenium.

4.2 Organic and Non-organic

Both organic and inorganic fertilizers were called "manure", derived from the French expression for *manual* (or belonging to the hand) tillage, however, this term is currently restricted to organic manure. Though nitrogen is plentiful in the Earth's atmosphere, relatively few plants engage in nitrogen fixation (conversion of atmospheric nitrogen to a plant-accessible form). It is believed by some that 'organic' agricultural methods are more environmentally friendly and better maintain soil organic matter (SOM) levels. There are scientific studies that support this position.

4.3 Inorganic fertilizers (mineral fertilizers)

Naturally occurring inorganic fertilizers include Chilean sodium nitrate, mined rock phosphate, and limestone (to raise pH and a calcium source).

<u>Macronutrients and micronutrients</u>
Fertilizers can be divided into macronutrients and micronutrients based on their concentrations in plant dry matter. There are six macronutrients: nitrogen (N), phosphorus (P), and potassium (K), often termed "primary macronutrients" because their availability is usually managed with NPK fertilizers, and the "secondary macronutrients" — calcium (Ca), magnesium (Mg), and sulfur (S) — which are required in roughly similar quantities but whose availability is often managed as part of liming and manuring practices rather than fertilizers. The macronutrients are consumed in larger quantities and normally present as a whole number or tenths of percentages in plant tissues (on a dry matter weight basis). There are many micronutrients, required in concentrations ranging from 5 to 100 parts per million (ppm) by mass. Plant micronutrients include iron (Fe), manganese (Mn), boron (B), copper (Cu), molybdenum (Mo), nickel (Ni), chlorine (Cl), and zinc (Zn).

<u>Organic fertilizers</u>
Naturally occurring organic fertilizers include manure, worm castings, peat moss, seaweed, sewage and guano. Sewage sludge use in organic agricultural operations in the U.S. has been extremely limited and rare due to USA prohibition of the practice (due to toxic metal accumulation, among other factors). Cover crops are also grown to enrich soil as a green manure through nitrogen fixation from the atmosphere by bacterial nodules on roots; as well as phosphorus (through nutrient mobilization) content of soils. Processed organic fertilizers from *natural* sources include compost (from green waste), bloodmeal, bone meal, hoof and horn (from organic meat production facilities), hair, fur, wool, skin, leather and seaweed extracts (alginates and others).

<u>Mixed definitions of ‘organic’</u>
There can be confusion as to the veracity of the term 'organic' when applied to agricultural systems and fertilizer. The problem is related to the largely marketing and colloquial uses of the term. Minerals such as mined rock phosphate, sulfate of potash and limestone are considered *organic fertilizers*, although they contain no organic (carbon) molecules. This is but one of many ambiguities

in the usage of the term *organic*. Synthetic fertilizers, such as urea and urea formaldehyde, are considered organic in the sense of the organic chemistry, and can be supplied *organically* (agriculturally), but when manufactured as a pure chemical is not *organic* under organic certification standards. Naturally mined powdered limestone, mined rock phosphate and sodium nitrate, are *inorganic* (in a chemical sense) in that they contain no carbon molecules, and are energetically-intensive to harvest, *but* are approved for organic agriculture in *minimal* amounts. The common thread that can be seen through these examples is that *organic* agriculture attempts to define itself through minimal processing (e.g. via chemical energy such as petroleum), as well as being naturally-occurring (as is, or via natural biological processing such as the composting process). This is a contradictory stance however, because high-concentrate plant nutrients (in the form of salts) obtained from dry lake beds by farmers for centuries in a very minimal fashion are excluded from consideration by most *organic* enthusiasts and many governmental definitions of *organic agriculture*. One of the main tenants of *organic lifestyle* marketing is that *organic fertilizers* are completely different from *chemical fertilizers*. No such dichotomy exists. There is substantial overlap between the two.

Benefits of organic fertilizer
However, by their nature, organic fertilizers provide increased physical and biological storage mechanisms to soils, mitigating risks of over-fertilization. Organic fertilizer nutrient content, solubility, and nutrient release rates are typically much lower than mineral (inorganic) fertilizers. One study found that over a 140-day period, after 7 leachings: Organic fertilizers had released between 25% and 60% of their nitrogen content Controlled release fertilizers (CRFs) had a relatively constant rate of release. Soluble fertilizer released most of its nitrogen content at the first leaching.

Disadvantages of organic fertilizer
It is difficult to chemically distinguish between urea of biological origin and those produced synthetically. Like inorganic fertilizers, it is possible to over-apply organic fertilizers if one does not measure and distribute the required amounts according to the recommended amounts for the plot of land in question. Release of the nutrients may happen quite suddenly depending on the type of organic fertilizer used. Because of their dilute concentration of nutrients, transport and application costs are typically much greater for organic than inorganic fertilizers. Organic fertilizers from treated sewage, composts and sources can be quite variable from one batch to the next. Unless each batch is tested the amounts of nutrient applied are not precisely known.

4.4 Heath and sustainability issues

In many countries there is the public perception that inorganic fertilizers "poison the soil" and result in "low quality" produce. However, there is very little (if any) scientific evidence to support these views. When used appropriately, inorganic fertilizers enhance plant growth, the accumulation of organic matter, and the biological activity of the soil, thus preventing overgrazing and soil erosion. Studies in Australia show 'biodynamic' or 'organic' farms are less productive and less sustainable than conventional farms that used inorganic fertilizers. The nutritional value of plants for human and animal consumption is typically improved when inorganic fertilizers are used appropriately. Many inorganic fertilizers do not replace trace mineral elements in the soil which become gradually depleted by crops. This depletion has been linked to studies which have shown a marked fall (up to 75%) in the quantities of such minerals present in fruit and vegetables. However, a recent review of 55 reputable scientific studies concluded "there is no evidence of a difference in nutrient quality between organically and conventionally produced foodstuffs". In Western Australia deficiencies of zinc, copper, manganese, iron and molybdenum were identified as limiting the growth of broad-acre crops and pastures in the 1940s and 1950s. Soils in Western Australia are very old, highly weathered and deficient in many of the major nutrients and trace elements. Since this time these trace elements are routinely added to inorganic fertilizers used in agriculture in this state. There are concerns regarding arsenic, cadmium and uranium accumulating in fields treated with fertilizers. The phosphate minerals

contain trace amounts of these elements and if no cleaning step is applied after mining the continuous use of phosphate fertilizers leads towards an accumulation of these elements in the soil. High levels of lead and cadium can also be found in many manures or sewage sludges. Phosphate fertilizers replace inorganic arsenic naturally found in the soil, displacing the heavy metal and causing accumulation in runoff. Eventually these heavy metals can build up to unacceptable levels. Another problem with *inorganic* fertilizers is that they are now produced in ways which cannot be continued indefinitely. Potassium and phosphorus come from mines (or saline lakes such as the Dead Sea) and such resources are limited.
Innovative thermal depolymerization biofuel schemes are experimenting with the production of byproducts with 9% nitrogen fertilizer from organic waste.

4.5 Environmental risks of fertilizer use

High application rates of nitrogen fertilizers in order to maximize crop yields combined with the high solubility of these fertilizers leads to increased leaching of nitrates into groundwater. The use of ammonium nitrate in *inorganic* fertilizers is particularly damaging, as plants absorb ammonium ions preferentially over nitrate ions, while excess nitrate ions which are not absorbed dissolve (by rain or irrigation) into groundwater. Nitrate levels above 10 mg/L (10 ppm) in groundwater can cause 'blue baby syndrome' (acquired methemoglobinemia), leading to hypoxia (which can lead to coma and death if not treated). Nitrogen-containing inorganic fertilizers in the form of nitrate and ammonium also cause soil acidification. Eventually, nitrate-enriched groundwater makes its way into lakes, bays and oceans where it accelerates the growth of algae, disrupts the normal functioning of water ecosystems, and kills fish in a process called eutrophication. About half of all the lakes in the United States are now eutrophic, while the number of oceanic dead zones near inhabited coastlines is increasing. As of 2006, the application of nitrogen fertilizer is being increasingly controlled in Britain and the United States. If eutrophication *can* be reversed, it may take decades before the accumulated nitrates in groundwater can be broken down by natural processes. Storage and application of some nitrogen fertilizers in some weather or soil conditions can cause emissions of the greenhouse gas nitrous oxide (N_2O). Ammonia gas (NH_3) may be emitted following application of 'inorganic' fertilizers, or manure/slurry. Besides supplying nitrogen, ammonia can also increase soil acidity (lower pH, or "souring"). Excessive nitrogen fertilizer applications can also lead to pest problems by increasing the birth rate, longevity and overall fitness of certain pests. The concentration of up to 100 mg/kg of cadmium in phosphate minerals (for example, minerals from Nauru and the Christmas islands) increases the contamination of soil with cadmium, for example in New Zealand. Uranium is another example of a contaminant often found in phosphate fertilizers; also, radioactive Polonium-210 contained in phosphate fertilizers is absorbed by the roots of plants and stored in its tissues. Tobacco derived from plants fertilized by rock phosphates contains Polonium-210 which emits alpha radiation estimated to cause about 11,700 lung cancer deaths each year worldwide. For these reasons, it is recommended that knowledge of the nutrient content of the soil and nutrient requirements of the crop are carefully balanced with application of nutrients in inorganic fertilizer. This process is called nutrient budgeting. By careful monitoring of soil conditions, farmers can avoid wasting expensive fertilizers, and also avoid the potential costs of cleaning up any pollution created as a byproduct of their farming.

Environmental toxicity of fertilizer
Toxic fertilizers are recycled industrial wastes that introduce several classes of toxic materials into farm land, garden soils, and water streams. The consumption levels of toxic fertilizer are increasing lately in the U.S. from citizens who are purchasing the wrong chemicals for their gardens as well as choosing the wrong company to purchase it from. This is leading to major environmental problems due to the fact of toxic waste being processed and planted into our land and water. The most common toxic elements in this type of fertilizer are mercury, lead, and arsenic. Between 1990-1995, 600

companies from 44 different states sent 270 million pounds of toxic waste to farms and fertilizer companies across the USA. According to the United States Food and Drug Administration "Current information indicates that only a relatively small percentage of fertilizers is manufactured using industrial wastes as ingredients, and that hazardous wastes are used as ingredients in only a small portion of waste-derived fertilizers.", and "[the] EPA has continually encouraged the beneficial reuse and recycling of industrial wastes."

Heavy metal content of recycled fertilizer
Steel industry wastes, recycled into fertilizers for their high levels of zinc (essential to plant growth), wastes can include the following toxic metals:

- lead
- arsenic
- cadmium
- chromium and
- nickel

Toxic organic compounds
Dioxins, polychlorinated dibenzo-p-dioxins (PCDDs), and polychlorinated dibenzofurans (PCDFs) have been detected in fertilizers and soil amendments.

4.6 Biofertilizer

'Biofertilizers' are not fertilizers. Fertilizers directly increase soil fertility by adding nutrients. Biofertilizers add nutrients through the natural processes of fixing atmospheric nitrogen, solubilizing phosphorus, and stimulating plant growth through the synthesis of growth promoting substances. Biofertilizer is a substance which contains living microorganisms which, when applied to seed, plant surfaces, or soil, colonizes the rhizosphere or the interior of the plant and promotes growth by increasing the supply or availability of primary nutrients to the host plant. (http://en.wikipedia.org/wiki/Biofertilizer). Biofertilizers can be expected to reduce the use of chemical fertilizers and pesticides. The microorganisms in biofertilizers restore the soil's natural nutrient cycle and build soil organic matter. Through the use of biofertilizers, healthy plants can be grown while enhancing the sustainability and the health of soil. Biofertilizers are very similar to compost tea (http://www.dacnet.nic.in).They can be thought of as an engineered compost tea where only the microorganisms that are most beneficial are used. If algae are used in biofertilizers, the algal group supplies only nitrogen.

4.7 Marine algae and sewage as bio-fertilizer

In Norway, one Wastewater Treatment plant by the name of Hias, produces bio-fertilizer from part of its sludge. Hias is located in the Hamar area, in the municipality of Hedmark in south-eastern Norway. Hias supplies 49 000 persons with drinking water from lake Mjøsa. It comprises two Wastewater Treatment plants; Hamar wastewater treatment plant and Stange wastewater treatment plant.
Hias purifies the sewage from 50 000 persons from 4 surrounding communes. Sludge from the purification process is transformed to biomass which is concequently transformed to fertilizer and used to improve soil characteristics.

In order to improve the effectivity of the Constanta Wastewater Treatment Plants, which is the ultimate aim of this project, it is important to standardize the concentrations in the final effluent such that the water released in the adjacent environment does not lower the water quality there.

A guide for the water quality and concentrational thresholds for effluent released from a purification plant can, for example (www.pc.gc.ca/pn-np/ab/banff/plan/plan1_e.pdf), be:

- Phosphorus < 0.15 mg/L
- Fecal coliform bacteria: < 20/100 ml (end of pipe)
  < 2/100 ml (end of mixing zone)
- pH meet background levels of receiving waters
- BOD5 (Total) Summer < 10 mg/L, Winter < 20 mg/L
- Total suspended solids < 10.0 mg/L
- NH3N Summer < 1 mg/L, Winter < 5 mg/L

These values can be achieved by tertiary treatment of the plant effluent. Tertiary treatment includes filtration, lagooning, constructed wetlands, nutrient removal (http://en.wikipedia.org/wiki/Sewage_treatment).

The surplus of the aforementioned componets, which is not released with the effluent, will be condensed in the sewage sludge. It is probable, that high concentrations of heavy metals can present a challenge in the usage of sewage sludge in general, as in the sludge of the North and South Constanta Wastewater Treament plants. As we have learned previously, algae, as sewage sludge, can act as a bio-absorbent for heavy metals and posess higher concentrations of them than the surrounding water body. This may present a problem for the use of Bio-fertilizers if they were grown in areas with high ambient heavy metal concentrations. Algae are, in general, a valuable source of Nitrogen that is desirable in (bio-) fertilizer.

In order to combine marine algae with sewage sludge and use the product as a bio-fertilizer, some requirements have to be met. First of all, the content of crucial heavy metals and nutrients of the sludge and the algae have to be known. Both have to be under a certain threshold in order to be suitable as a bio-fertilizer. Secondly, sludge and algae have to be combined in such a way as to prevent negative interactions of their components. Thirdly, the product (Bio-fertilizer) has to have a constitution that can be easly stored, transported and applied on the target acreage.

5. Commerce

Seaweeds are used globally as a natural source for various raw materials (see appendix). Some figures from the global seaplant market (estimated annual) are presented in table 1. (http://www.surialink.com).

5.1 Global seaplant market

Over 2M dry tons or 7.5 M + wet tons are produced annually. This equals a value of 8B+USD/annum. Many seaplant products are exchanged in local markets. And therefore official statistics are scarce. The actual volumes may be many times the reported figures.

Table 1: Seaplant production by country. The 10 countries listed hold 96% of the **total harvest** (50% of which is harvested in Asia)) and ‹99% of the **farmed** production (96% of which farmed in Asia) (from:http://www.seavegetables.com)

Total harvest				**Farmed**		
Country	**Dry MT**	**%**		**Country**	**Dry MT**	**%**
China	698,529	32		China	675,229	61
France	616,762	28		Japan	107, 360	10
UK	205,500	9		Philippines	90,912	8
Japan	123,074	6		Korea, N	70,045	6
Chile	109,308	5		Korea, S	65,740	6
Philippines	95,912	4		Indonesia	46,894	4
Korea, N	71,435	3		Chile	34,218	3
Korea, S	67,050	3		Tanzania	5,000	+
Indonesia	46,894	2		Malaysia	4,000	+
Norway	40.632	2		Kiribati	496	+

It is expected that more production capacity is required and that the potential market is tenths of billions of USD /yr. The key to increased production is cultivation. Cultivation techologies range from low-tech seaweed farming til high-tech cell culture and blends between them. This means also, that small-to-medium enterprises (SME, such as family farms) can dominate the value chains.
Still, there is a very fuzzy line between where "raw material" ends and "extract" begins. It is often thought that "semi-refined" products and products subjected to post-harvest upgrading are still "Seaplants". We are developing as an information source for this important industry segment as well as lining up trade facilities to help buyers and sellers of these products do business with each other.

For specialised treatment of biopolymers in commerce, the following sites can be consulted as examples: Dennis Seisun's IMR International or to the sites of biopolymer producers such as BD Biosciences [Difco] ; Cambrex Bioproducts ; CP Kelco ; Degussa ; FMC BioPolymer ; International Specialty Products [ISP Alginates] ; Marcel Carrageenan ; TIC Gums Blenders .

5.2 Useage in Norway

In the coastal communities of Norway, seaweeds have been used for several hundreds of years, especially during hard times (Aasland, 1997). They were then used as nutritional supplements for man and beast, as healing herbs and as fertilizer. A more industrialized exploitation began when the ashes of seaweeds were used in the glass production process. In 1897 the foundations of the first factory producing algae products were layed in Norway, in the town of Kristiania (today known as Oslo). Alginat, a biopolymer that holds the same function in algae as cellulose in trees began to be produced.

Today, Alginat is being used in a great variety of industrial processes-from pharmacy to textile printing and welding (Aasland, 1997). In the 1990's, the exploration of the algae's medical potential has begun. Since then, every year brings new possibilities for the application of algal substances in various forms and disciplines.

The main areas of application in Norway today are:

- Technological use (swelling agent in textile printing and printing, binder in welding electrodes, water purification processes and a number of specialised applications in paperproduction industry). Among new innovations for application are enhancement of tea bag paper and development of rubber products with special properties (see also appendix).
- Food production (thousands of food products contain alginate. In the baking industry alginate is also used to prevent the diffusion of moisture between f.ex. cake and doug. In beer, alginate is used to enforce the froth; to re-assemble puder, f.ex. to produce onion rings, cocktail berries, or the filling of olives, see also appendix).
- Pharmaceuticals (alginate is used as the principal substance in acid regurgitation, impression, woundbandages and implant reinforcing; as a binding or high-pressure agent to ensure a controlled dispension of the agent in tablets; in cough syrup as a texture guard (see also appendix).
- Immobilizing living cells (alginate is used to encapsulate living cells; used f.ex. in diabetis treatment, champagne fermentation and purifying waste water from dairies)(see also appendix).

Three examples of companies exploiting seaweeds in Norway today are:

- Pronova BioPharma ASA and Pronova BioPharma Norge AS (biopharmaca; http://www.pronova.com)
- Protan (technical textiles; http://www.tech-textiles.com)
- FMC BioPolymer (food ingredients, pharmaceuticals, personal care; http://www.fmcbiopolymer.com)

6. Conclusion

The initial question of this study, ‘What is the potential of marine alga, in combination with sewage sludge, as a composite of bio-fertilizer?’ has been discussed in the light of some crucial background information. The characteristics of the algae present in the Black Sea were listed, and some general information on sewage sludge composition and risk of use were mentioned. No straight forward answer can be made as to weather or not the specific algae can be used in combination with sewage sludge to produce a bio-fertilizer. In order to do that, more detailed information about the composition of the sewage sludge produced in the Constanta Wastewater Treatment Plants is needed, along with some measurement of, in particular, heavy metal concentration in the thalli of the envisaged algae.

However, this report includes some other interesting and promising potential uses for both, algae and sewage sludge.
Sewage sludge has been successfully used as a biogas replacement for petrol and diesel (see Box 2). Marine algae are known to have a variety of usages (see appendix). Besides using the abundantly available algae from the Black Sea as component of bio-fertilizer, they could be used as, for example, water purifiers of alginat producers.

Areas suggested worth further investigation with respect to the challenges in Constanta are:

- Biosorption (to the benefit of the Black Sea ecosystem)
- Fertilizer: then the problem of high heavy metal content should be solved first
- Commercial usage as f. ex. described in chapter 5
- Biogas: use as a substitute for petrol/diesel (see the example from Sweden in Box 2)

Box 2: Biogas-Example Stockholm (http://www.biogasmax.eu)

The Municipality of Stockholm has an overall goal with regard to greenhouse gases, which is to become a fossil fuel free city by 2050. To reach this goal, the City is working on several activities related to energy and transport. One example in the transport field is the City's Clean Vehicles project in Stockholm. The objective of the project is to increase the number of clean vehicles in the Stockholm area. A support program for companies that use clean vehicles has also been launched. Sales of biomethane have been a success in Stockholm over the last year. Volumes have increased considerably and developments are extremely positive. However, this success has generated some problems related to fuel supply. In 2006, the demand exceeded supply. The Biogasmax project will aim at increasing the supply to meet the demands of biomethane customers. This involves producing more biomethane and expanding the infrastructure for filling stations. The breakthrough for biomethane has already started. The next step is further expansion.
Some numbers:

Input

- Organic Waste: 15 000 t/a
- Grease Trap Removal Sludge: 2 000 t/a
- Ley Crop (Silage): 4 000 t/a
- Biogas from Sewage Treatment Plant: 8 000 MWh/a

Output

- Solid Digestate: 4 000 t/a
- Liquid Digestate: 16 000 t/a
- Purified biogas: 25 GWh/a (Equivalent to 2,8 million liters of diesel/petrol)

Usage:

- ✓ Delivers biogas to buses and cars since October 2004
- ✓ Deliver biogas to public filling stations in Stockholm since 2008
- ✓ Treating bio-waste since July 2005
- ✓ Using ley crop (silage) for biogas production since 2007

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8. Appendix

Disciplines of use of marine algae

8.1 Agriculture

Various algae have been used as food among various worldwide aborigines since old eras (even before 300 BC,. The use of marine plants in terrestrial agriculture probably goes back as far as the history of agriculture among coastal people. As far as we know raw seaweeds and seaweed products (e.g. liquid hydrolysates; products of composting; ash from burnt seaweeds) have been used for millennia (and are still used today) as animal feeds, supplements to animal feeds, soil conditioners, mineral sources and fertilizers or plant foods. One very large use of seaplants in agriculture is the use of coralline algae (maërl) such as *Phymatolithon calcareum* and *Lithothamnion corallioides* as soil conditioners, trace element and mineral sources. They can also replace bone meal in some feed applications and ground maërl is useful for water filtration. These algae contain calcium and magnesium carbonates that comprise up to 80% of the wet weight. Maërl is dredged off the coasts of France (Brittany), England, and Ireland. Over 600,000 tons are harvested each year from live and dead deposits. The dried, ground product is favoured by organic farmers and horticulturists.

8.2 Agronomy and Biotechnology

Marine algae are used as raw materials for extracts food and other useful products. One of the highest-profile and economically significant uses of marine algae is in their role as raw materials for extraction industries that modify, extract and purify the chemical constituents known as biopolymers (e.g. carrageenan, agar and alginates). Marine algae serve as raw material for products utilised directly as human foods and also as the basis for a variety of well-being and personal care products. Finally, seaweeds are a source of hydrolysates other ingredients products that serve as plant foods and animal feeds (www.seavegetables.com).

8.3 Animal nutrition

Also in animal nutrition algal meals, powders and extracts are used as nutraceutical feed components. Microalgae are important aquaculture hatchery feeds whilst macroalgae are feed for herbivourous fish. Algal bioplymers are used as pet food and farm feed stabilizers (www.seavegetables.com).

8.4 Biopolymer

Seaplant biopolymers are an important extract from seaplant raw materials. The significance of these products to the Raw Materials Community is Carrageenan and agar bearing seaplants as raw materials for red algal galactans. One of the highest-profile and economically significant uses of several species of red algae is in their role as raw materials for extraction industries that modify, extract and purify the chemical constituents known as red algal galactans (RAGs) that comprise useful seaplant biopolymers.

8.5 Biosorption and waste treatment

Algae can remove heavy metals from water through biosorption. They can also be used to remove nitrogen and other nutrients from water. In polyculture systems algae can convert sea animal wastes to useful biomass (www.seavegetables.com).

Box 1: Biosorption

Biosorption is the passive removal of toxic heavy metals such as Cd(2+), Cu(2+), Zn(2+), Pb(2+), Cr(3+), and Hg(2+) by inexpensive biomaterials. It requires that the substrate displays high metal uptake and selectivity, as well as suitable mechanical properties for applied remediation scenarios . The biosorptoin of stable cesium can be increased even more by treatet with specific chemical agents. In recent years, many low-cost sorbents have been investigated.

The brown algae have proven to be the most effective and promising substrates for biosorption. It is their basic biochemical constitution that is responsible for this enhanced performance among biomaterials. More specifically, it is the properties of cell wall constituents, such as alginate and fucoidan, which are chiefly responsible for heavy metal chelation. The biochemical properties of the brown algae that set them apart from other algal biosorbents are outlined in a comprehensive review. He offers a detailed description of the macromolecular conformation of the alginate biopolymer in order to explain the heavy metal selectivity displayed by the brown algae. The role of cellular structure, storage polysaccharides, cell wall and extracellular polysaccharides is evaluated in terms of their potential for metal sequestration. Binding mechanisms are discussed, including the key functional groups involved and the ion-exchange process. Quantification of metal-biomass interactions is fundamental to the evaluation of potential implementation strategies; hence sorption isotherms, ion-exchange constants, as well as models used to characterize algal biosorption are reviewed. The authors summarize the sorption behavior (i.e., capacity, affinity) of brown algae with various heavy metals and evaluate their relative performance.

Conclusively, brown algae present an interesting possibility in biological sewage treatment.

8.6 Energy

Algae can be used as feedstock for energy producing bioreactors. Green algae such as *Chlamydomonas* can be stimulated to produce significant amount of hydrogen instead of oxygen during photosynthesis (www.seavegetables.com).

8.7 Environment

Seaplants are essential to life as we know it. Big and small seaplants (macrophytes and phytoplankton) represent a major proportion of the biomass of photosynthesizing organisms that provides the essential oxygen in the air that we breathe and that consumes gases such as carbon dioxide that are toxic to us in high doses. Seaplants provide the basis for all of the oceans' production of living organisms including the fish, shellfish and other animals that much of humanity depends on for food. Sea grasses stabilize the shorelines of our land masses and provide habitat for many of the seafood species that we depend on. Seaplants have a multitude of direct and derived uses that benefit humanity in our role as primary users of seaplants and seaplant products. The importance of seaplants to global ecosystems is such that members of all seaplant communities must take a serious interest in seaplant environmentalism.

8.8 Industrial process aids

Biopolymers and seaplant flour are used in brewery fining, oil field completion fluids, as slurry stabilizer for pigments in ceramics and textile applications, textile sizing and dyestuff (www.seavegetables.com).

8.9 Nutraceuticals and pharmaceuticals

Bioactive and nutritional compounds and extracts from seaplants are attracting an increasing amount of attention as people throughout the world seek natural sources of nutritional supplements, nutraceuticals and pharmaceuticals. Seaplant constituents such as fucoidan, myostatin, carrageenan and a variety of others are attracting attention for their apparent efficacy as anti-inflammatory, anti-coagulant or anti-viral agents. Algae are 'drugs from the sea' but ther use is still in their infancy. Moreover, algae can host genetic material which allows exciting new technologies. For example energy and antibodies from *Chlamydomonas*, antibodies, vaccines, antioxicants, omega-3 fatty acids form genetic transformation of macroalgae (e.g. *Porphyra*) and others.

8.10 Plant nutrition

Algal products serve as cource of plant biostimulants, trace elements and other nutrients. They can be used as mulch or spray for soil conditioning and biopolymers are used as stabilizers for seed emulsions and as culture media for specialty crops (e.g. orchids) (www.seavegetables.com).

8.11 Seavegetables

Seavegetables have been an important food item in several human societies for hundreds of years; if not for millennia. Such has especially been the case among the Celtic cultures of Europe, the Island nations of Oceania and the countries of East Asia; especially Japan, Korea and China. In these latter countries seavegetables are a daily food item that forms the basis for a multi-billion USD business that is a major employer of seaplant farmers and processors. The spread of Japanese and Chinese cuisine and of health foods throughout the world has brought new attention to seavegetables. There is immense potential for increasing the consumption of seavegetables as food items, dietary supplements, food texturisers, flavouring, colouring and condiments especially among "mainstream" markets.
One market driver for sea vegetables, food ingredients and nutraceuticals is the shift toward 'natural' nutraceuticals and there is a massive potential for expansion. The use is spreading from traditional markets to global markets.

8.12 Wellbeing

Seavegetables are finding ever-expanding uses as aids to peoples' well-being and personal care. They have long been used as sources of vitamins, minerals and other nutrients both for internal consumption as food and supplements and as topical formulations for external application. Algae naturally synthesize anti-bacterial, anti-thrombic and other compunds which make them higly wanted in well-being sector. Therefore they are for example, used in Thalassotherapy, aroma therapy, lotions and potions for spa treatment, 'cosmeceuticals', nutritional benefits and personal care products.

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