# Seaweed and Algae as a Natural Resource and a Renewable Energy Source, Step 1

**Abstract**
Seaweed and algae that accumulate on beaches and along our coasts is an environmental nuisance. The plant material prevents the use of the coastline, of the beach and emits odors into the environment.

The increased nitrogen load in the sea has led to a greatly increased growth of some species of algae. This threatens biodiversity as important nursery habitats disappear, both for fish and birds.

Accumulation of seaweed and algae is therefore a multifaceted problem.
Seaweed and algae take up heavy metals, especially cadmium. This means that precautions must be taken when plant material is removed from the coast so as to not contribute to an increased load of cadmium in the environment.

On behalf of Trelleborg Municipality Detox has produced a development which involves an investment in new environmental technologies for the management of seaweed / algae from beaches and coastal waters.

The management includes a comprehensive concept of pretreatment, purification and production of biogas through anaerobic digestion. Grading and cleaning is done to allow for digestion and to obtain a high quality of residue. Production of biogas through anaerobic digestion is done by breaking down the organic material in an oxygen-free (anaerobic) environment. The residual product is to be reused for soil or fertilizer. An initial survey of conditions in the assignment was made to provide a basis for evaluating technical, environmental and economic parameters of the project. In particular, this step included characterizations of seaweed and algae, and studies of relevant technologies for the concept.

Materials to be digested into biogas can be initially assessed on content of organic matter, nutrients, and retardants.

The results of the analysis of seaweed / algae from Trelleborg beaches show that the organic content is significant but the content of inorganic materials, primarily sand, are high.

The test results show a carbon / nitrogen ratio of around 10-14, i.e. the carbon content is slightly lower than what is optimal. Metals found to inhibit the digestion process in other studies were compared with the analyzed algae samples from Trelleborg. The results show that the cadmium content should not inhibit methane production and the same for copper and zinc content. Sodium and chloride concentrations in the samples were on the verge of inhibitory when compared with previous studies, although some studies indicate that salt does not negatively affected the digestion of algae.

A comparison of metal content in the samples analyzed shows that the levels of all metals, except cadmium, are well below maximum levels. Therefore the residue could be useful as soil or fertilizer if the cadmium is removed.

Cadmium poses a serious threat to agricultural land, on which it is easily taken up and accumulated by plants and can remain in the plant for a relatively long time after discharge to the ground. Cadmium also has high toxicity to animals and humans.

Further studies into the potential for nutrient recovery should be made in the future.

A biological characterization of seaweed / algae from beaches in Trelleborg shows that the variation is small geographically. All samples were dominated by the filamentous red algae Polysiphonia fucoides with a range of other filamentous algae also occurring.
About 2000 m3 of algae and seaweed collect annually on the general beaches in Trelleborg. The total amount of algae, collected annually all along the Trelleborg coastal strip that could be used for biogas production was estimated at about 10 000 m3. Possibly higher amounts could be collected with different collection techniques. A study of different collection techniques should be undertaken as a separate related project.
A very rough estimate of potential annual methane production from seaweed / algae has been made based on the methane yield of the algae.
An aggravated estimated, with a low methane production (200 Nm3 CH4/ton organic content), would be the equivalent to 1,3-1,4 GWh / yr of biogas that could be produced from seaweed / algae in Trelleborg.

Laboratory experiments designed to determine the methane potential of seaweed / algae from Trelleborg with adapted technology will be made in the continuation of the project.
Examination of existing technology shows that there are a number of proven purification methods for cadmium, which could be applied to the seaweed / algae before or after digestion. Treatment requires only a resolution of cadmium in the aqueous phase and then separating cadmium ions. To further explore what techniques are appropriate for this concept requires further laboratory tests.

The choice of anaerobic digestion technology to apply to the seaweed / algae is dependent on several factors.
Based on experience of the current situation (analysis of seaweed / algae in Trelleborg, experience from other studies of similar materials, etc.) a review of various process parameters in the digestion of seaweed / algae has been made. Further study and validation of the technique will be made in laboratory experiments in the continuation of the project.
The survey in Stage 1 of the project shows that the purification and digestion of seaweed / algae has good potential. There are techniques for purification and digestion, which should be combined to give good results from this material. The results from other studies have shown that seaweed, algae and similar materials can be digested.

Abbreviations used:

VS Loss on ignition (measure of organic content)
TS Dry matter
COD Chemical oxygen demand

On behalf of the Municipality of Trelleborg Environmental Department, Detox AB has carried out the Stage 1 development project:
“Seaweed and Algae as a Natural Resource and a Renewable Energy Source”.

## 1.1 Background

There is an environmental nuisance caused by the algae and seaweed that accumulate on beaches and along our coasts in Sweden, as well as internationally. Algae smells bad and is an obstacle to the enjoyment of the coastline and beach. Filamentous algae are also a cause of an increased nutrient load in our oceans and the accumulation of algae is a threat to the biodiversity of shallow coastal waters. Removing the algae from the water's edge can reduce the impact of eutrophication and contribute to the maintenance of important nursery habitats for both fish and birds.
At the same time heavy metals, especially cadmium, accumulate in plant material. The bioavailability of cadmium increases with decreasing salinity levels. This means that a certain level of cadmium is more environmentally powerful in the Baltic Sea than for example in the North Sea.
Heavy metal content means that precautions must be taken in order to not contribute to an increased burden of cadmium in nature.

On behalf of Trelleborg Municipality DetoxAB has produced a concept which involves an investment in new environmental technologies for the management of seaweed / algae from beaches and coastal waters.
The management includes a comprehensive concept of gathering, sorting, purification and production of biogas through anaerobic digestion.
Sorting and cleaning is done to allow digestion and to obtain a high quality of residual product. Production of biogas through anaerobic digestion is done by breakdown of the organic material in an oxygen-free (anaerobic) environment. The residual product that remains after digestion is a clean, nutritious and soil-like product that can be reused for soil or fertilizer.
The concept means that the algae is able to be used a resource for producing energy and using nutrients, while the inconvenience to nature is reduced.

The decomposition is carried out by the microorganisms that use organic matter and they convert it to biogas in the form of methane and carbon dioxide. The energy-rich methane gas can be used for the production of heat, electricity and vehicle fuel. In addition to the biogas, digestion residue is also obtained. This digestion residue contains nutrients in a more plant available form than before digestion.
The digestion is a delicate process that requires a certain balance between organic matter and nutrients, while the levels of inhibitory substances are low. A thorough characterization of the algae is therefore needed to assess its suitability for anaerobic digestion.

Since algae contains some heavy metals, especially cadmium, it is important to examine how the nutrient content can be returned to agricultural land without polluting the soil with undesirable contaminants.
An important part of the project is to develop technology to remove heavy metals that can be reconciled with the sensitive biogas process so that undesirable substances are destroyed during purification.

## 1.2 Approach & Objectives

### 1.2.1 Step 1 - Identification, Objectives and Technology Choices

As an initial step, a survey of conditions in the project was made. The survey was carried out in consultation with the client and authorities and aims to provide a basis for evaluating the technical, environmental and economic parameters. In the initial stage there has also been a characterization of seaweed and algae, and a study of relevant technical solutions.

### 1.2.2 Next Step 2 - Technology Adaptation and Budget

The suitability of different technology solutions are assessed objectively based on knowledge from Step 1 "Identification, objectives and technology choices."
The chosen process solutions are verified on a laboratory scale with operating parameters such as dosage and streams, reduction rate, processing times and gas production optimization.
Parameters to be studied include collecting seaweed, pretreatment, treatment effectiveness, control of the digestion process and energy exchange.

## 2 Catergorisation of Seaweed/Algae

Samples of seaweed / algae have been collected from various beaches in Trelleborg and subsequently characterized with respect to chemical content, digestion potential and the potential for nutrient recovery. Samples were also characterized in terms of biological species and composition. In addition an assessment of the amount of seaweed / algae has been made.

### 2.1 Chemical Analysis

Samples from six different beaches (see photos in Appendix 1) were analyzed with respect to particular heavy metals, macro-and micronutrients and some other parameters. The results of the analysis are shown in Table 1.

Table 1. Contents of micronutrients, nutrients, metals, etc. in algae samples from various beaches in Trelleborg June 2007.

| Material | Site: ------> | Skåre | Östra stranden | Dala-badet | Gislövs strandmark | Smyge (Åspö) | Smyge (Fyren) |
|---|---|---|---|---|---|---|---|
| TS | % | 11,5 | 16,6 | 16,4 | 10 | 8,8 | 9,7 |
| Al | mg/kg TS | 819 | 517 | 910 | 1740 | 464 | 1250 |
| As | mg/kg TS | 6,04 | 1,29 | 1,72 | 3,81 | 4,05 | 6,21 |
| B | mg/kg TS | 372 | 163 | 76,5 | 189 | 273 | 227 |
| Ba | mg/kg TS | 36,3 | 9,43 | 13,3 | 15,9 | 23 | 40 |
| Ca | mg/kg TS | 20900 | 5040 | 6060 | 16400 | 46600 | 12800 |
| Cd | mg/kg TS | 1,1 | 0,563 | 0,525 | 1,28 | 1,45 | 1,71 |
| Co | mg/kg TS | 0,964 | 0,563 | 0,646 | 1,07 | 0,657 | 0,985 |
| Cr | mg/kg TS | 1,78 | 1,19 | 1,68 | 3,73 | 1,08 | 2,61 |
| Cu | mg/kg TS | 9,02 | 5,47 | 4,95 | 9,97 | 7,77 | 10,7 |
| Fe | mg/kg TS | 1900 | 1500 | 1650 | 3890 | 1300 | 2810 |
| Hg | mg/kg TS | 0,0273 | 0,0287 | 0,0208 | 0,0506 | 0,0451 | 0,0442 |
| K | mg/kg TS | 12100 | 2430 | 3660 | 14600 | 23100 | 24900 |
| Mg | mg/kg TS | 9850 | 3180 | 2230 | 7300 | 10800 | 9750 |
| Mn | mg/kg TS | 62,2 | 16,9 | 33,1 | 63,6 | 70,5 | 36,2 |
| Mo | mg/kg TS | 1,15 | 0,375 | 0,28 | 0,548 | 0,663 | 0,914 |
| Na | mg/kg TS | 30700 | 8870 | 5410 | 20400 | 27500 | 35200 |
| Ni | mg/kg TS | 9,05 | 3,61 | 3,8 | 7,8 | 5,99 | 8,17 |
| P | mg/kg TS | 3540 | 884 | 1230 | 2930 | 3130 | 3210 |
| Pb | mg/kg TS | 3,36 | 2,48 | 3,04 | 6,3 | 2,25 | 5,2 |
| Si | mg/kg TS | 179 | 96,8 | 106 | 235 | 337 | 536 |
| Ti | mg/kg TS | 23,2 | 18 | 26,3 | 42,9 | 13,7 | 30,8 |
| V | mg/kg TS | 2,55 | 1,69 | 2,32 | 4,27 | 1,65 | 3,92 |
| Zn | mg/kg TS | 92,5 | 50,2 | 36,4 | 73,4 | 84,2 | 108 |
| Cl | mg/kg TS | 25850 | 14810 | 10180 | 10230 | 18360 | 38940 |
| C | % TS | 28,5 | 12,9 | 16,1 | 29,6 | 34,4 | 33,6 |
| H | % TS | 3,9 | 1,7 | 2,2 | 4,2 | 4,7 | 4,7 |
| N | % TS | 2,8 | 1,1 | 1,6 | 2,2 | 2,6 | 3,1 |

### 2.1.1 Anaerobic digestion Characterization

The suitability of a material to decay into biogas can be assessed initially on its content of organic matter, nutrients, and retardants.

#### 2.1.1.1 Organic Content

Some of the algae gathered was analyzed to determine VS content, which is the commonly used measure of organic content. VS content expressed as % of TS was around 55-70%. These results show that the organic content is significant, but the need to test the content of inorganic material, probably mostly sand, is great.

#### 2.1.1.2 Nutrient Substances

The microorganisms involved in anaerobic decomposition have specific requirements regarding the availability of nutrients and the balance between various contents. The carbon content of the substrate to be digested should be in balance with the nitrogen content. The microorganisms that produce enzymes needed for anaerobic digestion require nitrogen, but too much nitrogen can also inhibit the process. An optimum carbon to nitrogen ratio should be around 20-30. The nitrogen is most suitable if it is in ammonium form.

Analytical results (Table 1) show a C / N ratio around 10-14, i.e. the carbon content is slightly lower than optimal and there is a risk of ammonium accumulating in the digestion chamber. In addition to carbon and nitrogen small amounts of vitamins are needed, S, Fe, Ni, Mg, Ca, Na, Ba, Mo, Se and Co.

Some of these are analyzed and presented in Table 1.

#### 2.1.1.3 Biological Characterization

High sulfur content can affect the digestion process, if the substrate which is digested contains too much sulfur (as sulfate ions) it may sulphate the activated bacteria. These bacteria compete for methanogenesis (Zehnder, 1988). The result of this competition leads to the formation of hydrogen sulfide (H2S) instead of methane. Besides giving reduced methane production, it is not desirable because hydrogen sulfide is very corrosive and toxic.

#### 2.1.1.4 Quantities

A lot of substances can inhibit microbiological activity in the digestion process. While some substances are inhibitory at high concentrations, they could stimulate at lower concentrations. Reported toxicity values from various studies are available but can be misleading. The effect obtained at a certain concentration is also influenced by environmental factors: pH, temperature, alkalinity and concentrations of other substances. The most frequent inhibiting factors however are volatile fatty acids (VFA), pH, ammonium and hydrogen sulphide. Other inhibitory substances are salt and environmental contaminants.

In the case of seaweed / algae, it is possible that the content of sulfur, salt and heavy metals can inhibit digestion. The table below provides inhibitory heavy metals from a study by Hickey et al. (1989). A comparison of the inhibitory concentrations in Table 2 with the concentrations measured in the seaweed samples analyzed (Table 1) shows that the cadmium content should not inhibit methane production and that the same is true of the copper and zinc content.

Table 2. Amount of various heavy metals (expressed as mg per g biomass), which provides 50% inhibition of methane production (*Hickey et al., 1989*)

| Heavy Metal | mg $Me^{+}$/g $VS^{*}$ |
|---|---|
| Copper, $Cu^{2+}$ | 13,5 |
| Zinc, $Zn^{2+}$ | 65 |
| Cadmium, $Cd^{2+}$ | 27,5 |

VS - loss on ignition (measure of organic content)

The concentrations of sodium and chloride are high as measured values, see Table 1. (5,4-35,2 g Na / kg DM respectively. 10-39 g Cl / kg DM). According to scientific studies the sodium content should not be inhibiting to the digestion, while the chloride content may be inhibitory. However, similar chloride concentrations examined during laboratory digestion of algae and seaweed are not shown to inhibit the process. (Briand & Morand,1997; Melin, 2001).

### 2.1.2 Characterization of Nutrient Recovery

Assessment of the digestion residues potential as a fertilizer can be made from the analyzes (see Table 1). The residual product that remains after the digestion of algae has good potential to be used as fertilizer in agriculture, in terms of nutrients (N, P, K). The ratio N: P: K is on average 1:0,11:0,54 for the undigested algprover analyzed (Table 1).

In Table 3 are crops that need fertilizer as quotas in relation to nitrogen. Assessed for content of N, P and K it appears that algae and seaweed have good potential to be used as fertilizer. Further studies of the potential for nutrient recovery should be done in the future.

The concentrations of metals can limit the use of fertilizers. The limits that exist for the use of sludge on green areas and in agriculture are below in Table 4 (SNFS 1998:944; SNFS 1994:2), together with the Environmental Protection Agencies proposed new limits. A comparison of metal content in the samples analyzed with the values below show that the concentrations of all metals except cadmium are well below maximum levels.

The content of cadmium in alga / seaweed samples is below the threshold of 2 mg / kg dw in all samples (1-1,7 mg / kg DM). However it must be considered that after digestion, which reduces the amount of TS, the cadmium content in mg / kg DM in the digestion chamber may increase and reach or go just above the limit. Cadmium in soil is not desirable because the cadmium is taken up by and remains in plants for a long time after introduction to the ground. Cadmium can be taken up lightly and can accumulate in various crops, allowing further transport of the Cadmium up the food chain (Malgerd et al, 1998).

Table 3. Some crops (top to bottom: cereals, oilseed, sugar beet & peas) that need fertilizer as quotas in relation to nitrogen.
The table also contains an indication of the nutrient content in sewage sludge ("slam").

| | N | P | K | S |
|---|---|---|---|---|
| **cereals** | 1 | 0.16 | 0.17 | 0.06 |
| **oil seed** | 1 | 0.17 | 1.50 | 0.36 |
| **sugar beet** | 1 | 0.17 | 1 | 0.10 |
| **peas** | 1 | 0.11 | 0.28 | 0.05 |
| **sludge** | 1 | 1.03 | 0.10 | 0.33 |

Table 4. Current and proposed new limits for metals in the effluent supplied to arable land. Concentration limit, maximum input per hectare(ha) and total content limit in the soil. The current limit in force is shown in bold.
(SNV Report 5214)

| | Concentration Limit in Sewage Fractions (mg/kg TS) | Concentration Limit in Sewage Fractions (mg/kg P) | Maximum Input to Farmland (g/ha per yr) | Concentration Limit in Soil (mg/kg TS) |
|---|---|---|---|---|
| Cadmium | **2** 1.7 (2005) | 71, 61 (2005) | **0.75**, 0.55(2010), 0.45(2015), 0.35(2020) | **0.4** |
| Chromium | **100** | 3600 | **40** | **60** |
| Copper | **600** | 21000 | **300** | **40** |
| Lead | **100** | 3600 | **25** | **40** |
| Mercury | **2.5,** 1.8(2005) | 89, 64 (2005) | **1.5**, 1 (2005) | **0.3** |
| Nickel | **50** | 1800 | **25** | **30** |
| Silver | 15 (2005) | 540 (2005) | 8 (2005) | - |
| Tin | 35 (2005) | 1200 | - | - |
| Zinc | **800** | 29000 | **600** | **100** |

Another limitation of the use of the digestion residue as fertilizer is the salt content of algae. Some crops have a low salt tolerance (e.g. strawberries, green beans, and red clover), and can therefore can find it difficult to grow in saline soil. Crops with high salt tolerance (e.g. spinach, kale, cabbage, rapeseed, barley and sugar beet) and crops with a moderate salt tolerance (e.g. tomato, broccoli, lettuce, carrot, onion, rye, wheat and oats) should be of primary interest to grow in soil fertilized with algae digestion residue.

**2.1.3 Biological characterization**

As part of the biological characterization (Annex 3- Biological characterization) samples from five different beaches in Trelleborg were analyzed in terms of species composition and geographic variation.
Samples were collected in early June 2007. The results show that the variation is small geographically. All samples were dominated by the filamentous red algae Polysiphonia fucoides, with a range of other filamentous algae occurring. There were some larger red algae Furcellaria lumbricalis present but it was never dominant. Polysiphonia fucoides are one of the most abundant species in the Baltic Sea, which sometimes causes some problems particularly around Öland.

In late summer, large quantities of these algae become detached from the sea bottom and set up rotting clumps that stains the water red, and smell bad. Many studies have shown that the water around these algae contain large amounts of bromphenol which can be very toxic. (Andersson, 2007)

### 2.1.4 Quantities

Annually about 2000 m3 of algae and seaweed collect on the general beaches in Trelleborg (see Table below). There are nine municipal beaches in Trelleborg and these represent approximately 17% (about 5 km) of the total 30 km long coastal strip of the municipality. The beaches can be divided into mainly rock / gravel beaches (about 13 km) and sand beaches (approximately 17 km) (Case study Trelleborg, 2007). The beaches that are cleared of seaweed are mainly those of sand. The current situation results in the collection of around 2,000 m3 of algae per year. All the points of seaweed and algae reception along the Trelleborg coastline could potentially contribute approximately 10 000 m3 of algae per year, that could be used for biogas production. It is possible that the current collection method for the seaweed / algae would be difficult to apply to the entire coastal strip. To exploit the full potential it is possible that another collection method may be required, for example some form of assembly in the water. Collection in the water could also lead to larger quantities of seaweed and algae being collected. A study of such techniques should be carried out in connection with this project.

Table 5.
Amounts of algae collected (m3) in the Trelleborg area in recent years (data from Leisure Management, Trelleborg).

| Year | Quantity of Seaweed Collected (m3) |
|---|---|
| 2004 | 2040 |
| 2005 | 2000 |
| 2006 | 1300 |

### 2.1.5 Possible Options for Disposal

Another form of waste treatment other than anaerobic digestion for biogas production could be incineration, landfill or composting. Incineration is a possible way to get rid of the mass and also recover some energy by using the organic content. However, the nutrient content of the seaweed and sand are lost in the process. The deposit of seaweed into landfill is not a viable option today because there is a ban on the land filling of organic waste.
Composting is a viable treatment method. But the use of the composted material is limited due to the cadmium content. In addition composting is an aerobic treatment process and therefore the profits of anaerobic digestion, in the form of high energy biogas, are not present.

## 3 Purification Techniques for Heavy Metals

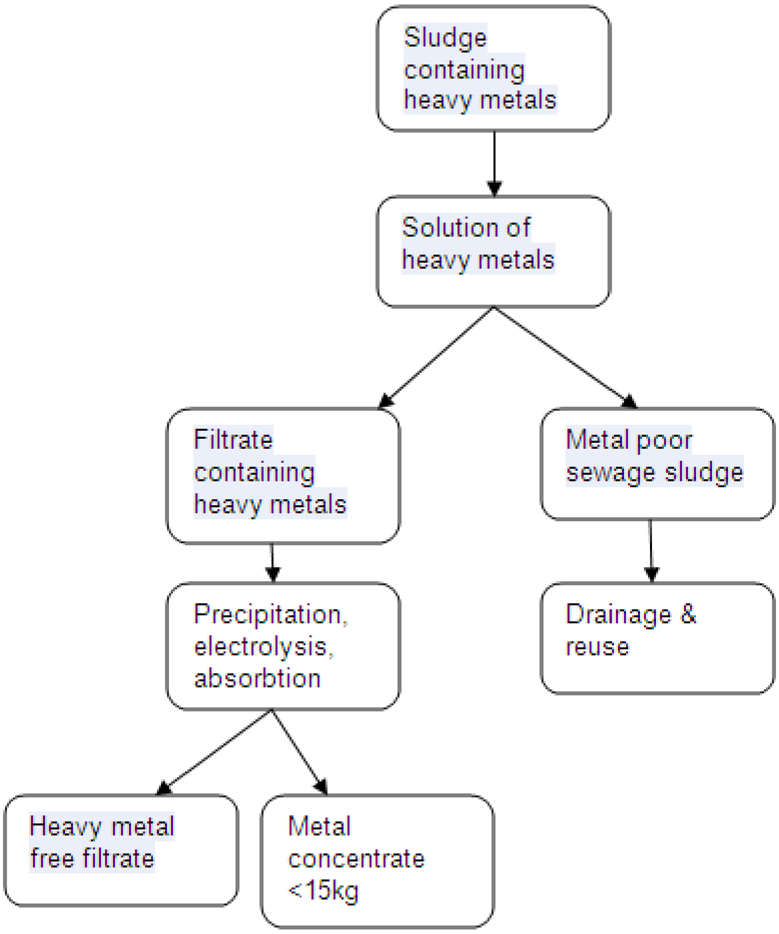
Heavy metals are the commonly used name for the metals having a density above 5 kg/dm3. Heavy metals occur naturally in our environment, but in some areas they have increased considerably due to anthropogenic emissions, i.e. the result of human activity. Some heavy metals are vital in lower concentrations (e.g. Zn, Cu, Cr and Mn), while others are toxic and hazardous (e.g. Cd, Pb and Hg).
Heavy metals never degrade but accumulate in the cycle. Heavy metal mobility in soil increases at low pH. A low content of organic matter and a low clay content in the soil also increases the movement. Cadmium is highly mobile, while Cu, Zn and Ni are only slightly mobile, and Pb, Cr and Hg are among the most immobile metals.

According to the results of the analysis, there are high levels of cadmium in the algae studied (see Table 1). The cadmium content is generally higher than the existing limits for the recycling of nutrients onto agricultural land.
A certain reduction of the cadmium is therefore necessary to use the residue in this way. Furthermore, cadmium (Cd) is of high toxicity to animals and humans and is very highly mobile in the soil. Cadmium is readily taken up and can accumulate in plants over a relatively long time after discharge to the ground (Malgeryd et al. 1998). In humans cadmium accumulates in the kidneys and can cause damage to them. In addition, cadmium increases the risk of prostate cancer. Most of the cadmium that non-smokers have may in itself be derived from their diet. The average Swede's kidney contains 30-40g Cd / g which is not so far from the critical threshold for renal damage considered to be 50-70 g Cd / g (Ottosson, 1997). It is therefore of great importance to reduce cadmium levels in the environment.

## 3.1 Purification of the Digested Material

Purification of heavy metals must be selective in the sense that nutrients must be maintained if you want to use the residue as a nutrient. Similarly, if treatment is performed prior to digestion, it is important not to remove nutrients which microorganisms need to be present the solution. If treatment is performed before digestion it must also be ensured that the solution is not added to substances that may inhibit  the microbial process.
This compilation of techniques are based primarily on experiences from the purification of heavy metals in sewage sludge, waste water (industrial or municipal),stormwater, leachate and ash.
Sewage sludge contains more heavy metals compared to original emissions from industry, households and trade as well as from stormwater and water. Purification of heavy metals in the sludge can be done by first dissolving the precipitated metals and then separating the dissolved metals from the solid sludge. To get a more concentrated amount of the metal, liferous filtrate can be treated with various methods such as precipitation, electrolysis or adsorption so that a low metal content is obtained. Any metal concentrates that are derived are then further processed or disposed of in a controlled manner. (Levlin et al. 1996)

Figure 1. Technology for removing heavy metals from sewage sludge (Levlin et al., 1996)




As regards the treatment of heavy metals in algae / seaweed that has or is to be digested, it is probably easiest to carry out treatment when in the liquid phase in a one-step process at usually around pH 7 as then the solubility of metals is low.
A two-step digestion with different pH will result in the solubility of the metal that is affected.
In the first stage and methane formation in the subsequent step, some metals from the biomass go into solution. Where the pH drops and they are transported with the liquid to the methane phase, where the pH rises, resulting in an accumulation of metals.

### <u>3.2 Methods to Solve Metals in Aqueous</u>

There are several ways to further transfer the metals to the liquid phase, for example:

- Extraction of water
- Extraction with acid medium - heavy metals solubility is generally improved with decreasing pH.
- Extraction of alkaline solution
- Extraction by formation of metal complexes
- Extraction with supercritical fluids
- Microbial metal dissolution

The methods deemed most interesting in releasing metals and especially cadmium in algae or digestion residues from algae digestion are described in more detail in Chapters 3.1.1 - 3.1.4.
When metals are dissolved into the aqueous phase a separation method is required (see chapter 3.3) and the metal-rich concentrate must then be dealt with in a controlled manner.

### 3.2.1 Extraction by Acidic Solution

Since the solubility of metals increases at low pH metal dissolution can be achieved by adding acid. Cadmium in solution at pH 4.2 allows for the aerobic conditions to prevail. Under anaerobic conditions heavy metals such as cadmium, copper, nickel, lead and zinc are in the sludge in the form of sulphides. Possible acids to use for acidification are hydrochloric acid (HCl), nitric acid ($HNO_3$), sulfuric acid ($H_2SO_4$) or organic acids.
An acidic leachate can also be achieved by certain bacterial types, e.g. sulfur-oxidizing bacteria (Thiobacillus strains).
A method for removing the metals from the ash consists of several steps (Mercier et al, 1999). After an initial washing with an alkaline aqueous to remove lead, the slurry is acidified to pH 4 with sulfuric acid. Then adding it to the bacterial culture and ferric chloride. After several washes and an addition of calcium phosphate the pH is raised before the final filtration is done.

### 3.2.2 Extraction by Complexation

There are a large number of compounds that form soluble complexes with metal ions. Common complexing agents are chloride ion and ethylenediaminetetraacetic acid (EDTA). These chloride ions will form complexes with dissolved metals in a aqueous solution. This has the effect of shifting the chemical equilibrium so that more of the heavy metals can be leached than the solubility of the original heavy metal compounds indicate. Many of the complex-forming compounds have their own equilibrium, within the aqueous phase, and this equilibrium is often pH-sensitive.
Some organic acids act both as acid, which produces a low pH in solution, and that of complex binders. For example, EDTA, in addition to these, there are a number of compounds that are based on organic ions. In principle it is possible to design a Ligand to bind a specific metal. To do so the ion (that is to bind to the metal ion) must have an appropriate number of places in its structure in which binding to the metal ion can take place.

### 3.2.3 Extraction with Supercritical Fluid

At sufficiently high pressure and temperature fluids and gases are released into a super-critical state that could be characterized as both gas and liquid simultaneously.
The molecules are moving almost as a gas, which diffuses rapidly. At the same time it has the ability to dissolve materials like a liquid. This can be exploited in extraction. Extraction efficiency has been shown to increase with increasing pressure.
Carbon dioxide ($CO_2$) can be used as a solvent and has the advantage that it can easily be regenerated. For heavy metals to be extracted with $CO_2$, they must be in the form of neutral complexes. Therefore, we are using organic ligands to make appropriate metal complexes. (Bjurström & Steenari, 2003)

#### 3.2.4 Microbial Metal-Resolution

The cost of the acidification of the metal dissolution can be reduced by using sulfur-oxidizing bacteria, Thiobacillus. The bacteria can dissolve metals by oxidizing metal sulphides to form soluble sulfates:

$$MS + 2O_2 \rightarrow M^{2+} + SO_4^{2-}$$

These bacteria oxidize sulfur to sulfate. They are Autotroph's, i.e. they can synthesize organic matter from carbon dioxide and water and they are aerobic, which means that aeration is required. Studies have been made with the addition of Thiobacillus to the anaerobic sludge, acidified to pH 4 (Wong & Henry,1984).
A comparison of heavy metal dissolution in sewage sludge using three different methods has been made by Blais et al (1992). Chemical acidification with sulfuric acid was compared to microbial leaching (with the addition of sulfur) and microbial leaching with addition ferrous sulphate. The dissolution of metallic cadmium was greatest for microbial method with sulfur (82%), then the microbial method with ferrous sulphate (74% dissolution) and acidification with sulfuric acid (59% dissolution).

### 3.3 Methods for Separating Heavy Metals from Aqueous Solutions

When heavy metals are treated so that they exist in the aqueous solution you must separate them from the solution. It can be done by chemical precipitation, ion exchange, membrane filtration, electrochemical treatment and adsorption. (Kurniawan et al., 2006).

#### 3.3.1 Chemical Precipitation

When precipitation is added, chemicals form insoluble compounds with metal ions. The common way to precipitate heavy metals as hydroxides is by pH adjustment and the addition of precipitation chemicals. For example, Ca (OH) 2 and Fe (OH) 3 proved to give high separation of cadmium (99% resp. 96%) at optimum pH 11 (Charerntanyarak, 1999; Tünay & Kabdasli, 1994).
Heavy metals can also fall as carbonates, sulphides, carbamates or other organic salt. The precipitated unions must be separated from the solution, which can be done by combining the precipitate with coagulation and flocculation. The precipitation method generates large amounts of sludge that must be disposed of.

##### 3.3.1.1 Coagulation and Flocculation

By setting up a coagulant that reduces the repulsion force between particles they may then coagulate and settle. To increase the particle size may be a done through subsequent flocculation. The technique involves pH adjustment and the addition of iron or aluminum salts.

##### 3.3.1.2 Flotation

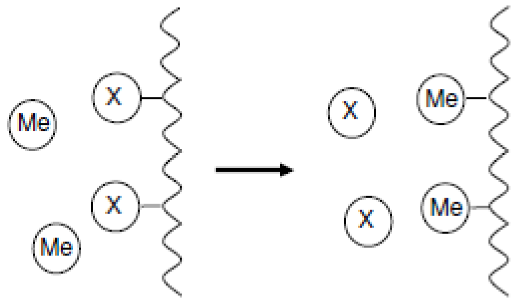
Flotation is a method of separation for particles and dissolved substances.
Air bubbles attach to particles and allow these to rise and they can then be separated at the surface. There are different types of flotation, but the DAF (dissolved air flotation) is the most common for treating metal contaminated water.

#### 3.3.2 Ion Exchange

The core of the ion exchange process consists of the ions in a given medium, such as water, are exchanged for ions bound to an ion-exchange resin.
Metal Ions in solution may be separated by ion exchange under the principle in Figure 2.

However, it must then be separated from the resin in some way. The amount of exchange resin is small in comparison with the sludge obtained from chemical precipitation. The general structure of the ion exchanger consists of a network of small balls covered with mobile ions for the exchange of ions that we want. Some resin is amphoteric, which means that the surface charge depends on the pH of the solution that the resin is in. Resin materials are divided into natural and synthetic materials. The so-called natural inorganic materials include zeolites (Analcime, chabazite, clinoptiolite and mordenite) as well as clay and mica minerals, these can also be produced synthetically. Two selective materials have been tested by Álvarez-Ayuso & García-Sánchez (2003) for the capture of cadmium. The tested materials, Clinoptilite and synthetic zeolite (Naples), gave 90% and 100% efficiency for Cd (II). Heavy metals may be separated efficiently by ion exchange at pH 2-6, depending on the nature of the resin. Ion exchange method requires a pretreatment in the form of separation of suspended solids.

Figure 2.
Metal Separation by ion exchange in a simplified sketch




**3.3.3 Membrane Filtration**

Several different types of membrane filtration can be used to remove heavy metals in liquids, such as ultrafiltration, reverse osmosis and nanofiltration. Ultrafiltration uses a permeable membrane to separate heavy metals, macromolecules and suspended solids from an inorganic aqueous solution.
For ultrafiltration with an inorganic membrane ($ZnAl_2O_4$-$TiO_2$) efficiency of 93% Cd (II) was obtained (Saffaj et al, 2004)

Reverse Osmosis is a membrane process in which pressure is used to separate water from heavy metals. The water passes through the membrane, while heavy metal is retained. In general, reverse osmosis is more effective for separation of heavy metals than ultrafiltration and nanofiltration (Kurniawan et al., 2006). Reverse osmosis with a polyamide membrane has obtained a 99% g degree of purification for Cd (II) (Qdais & Moussa, 2004)

Nanofiltration is a cross between ultrafiltration and reverse osmosis.
The separation mechanism involves sifting and electric power. The membrane has a small pore diameter and a surface charge. This makes the loaded dissolved substances smaller than the membrane pores. Nanofiltration with a polyamide membrane has obtained a 97%-ig degree of purification for Cd (II) compared with the 99%-iga purification rate of reverse osmosis (Qdais & Moussa, 2004).

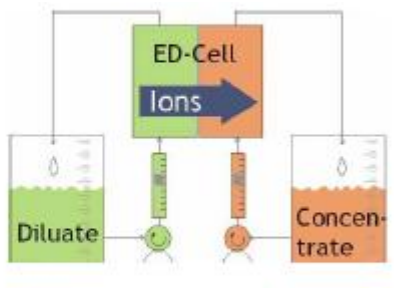
Both methods seem to have a high potential for separation of cadmium, however Nanofiltration requires less pressure than reverse osmosis.

### 3.3.4 Electrochemical Treatment

The following describes three different electro-chemical treatment methods: electro dialysis, membrane electrolysis and electrochemical precipitation.

Electro dialysis is a membrane separation method with ion exchange. Ions in aqueous solution pass the ion exchange membrane by using electric potential. The membranes consist of thin plastic sheet with either anionic or cationic character. When a solution containing ions pass through the cell compartment anions will be drawn towards the anode and cations towards the cathode. The method is suitable for lower heavy metal content (<20mg / l).

Figure 3. Electro dialysis (figure is taken from www.wikipedia.org)




Membrane Electrolysis is a chemical process, driven by electric potential. The method can be used to remove heavy metals from water. The ion exchange membrane allows oxidation (anode) and reduction (cathode). Unlike electro-dialysis, membrane electrolysis works both at low and high metal concentrations. However this approach requires high energy consumption.

Electrochemical Precipitation is a modification of the conventional chemical precipitation which uses electric potential to maximize the cleaning rate. The method can be used for very high metal concentrations.

### 3.3.5 Adsorption

Adsorption is a mass transfer process by which a substance is transferred from a liquid to the surface of a solid material in which it is bound chemically. Activated carbon is a material that can absorb heavy metals as it has a large surface area, high adsorption capacity and efficiency. Also other materials that are cheaper (e.g. residues from industry, natural materials or materials derived from agriculture) can be well-functioning adsorbents. Adsorbents for pollution reduction can be categorized in different ways depending on their content of various substances or their origin. The following list is taken from Färm (2003):

Natural materials
- opoka (calcium silicate), lime, zeolite, peat, bark chips, clay

Manufactured materials
- LECA and LWA (Light Weight Aggregate) products
- iron oxide coated sand
- activated charcoal (which proved to be an effective cadmium absorbent)

Industrial wastes
- blast furnace slag

In experiments in which treatment of stormwater was carried out with different sorbents (natural opoka, burned opoka and zeolite in various mixtures) obtained high separation (Cd 99% removal efficiency) at low hydraulic load. At the raising of the load the decreased rate of purification was more pronounced for Cd than for

other metals.
The explanation for this was due to the column becoming quickly saturated with cadmium. (Farma, 2003)
In a study by the Swedish Agricultural University, adsorption of hydroxyl groups by filter materials proved to give good separation of cadmium in the leachate.

### 3.4 Purification of Cadmium in Seaweed / Algae

Examination of existing technology showed that there are several proven purification methods for cadmium, which could be applied to the seaweed / algae before or after digestion. It is important that the preferred treatment technology is sustainable economically and environmentally, that it does not require large chemical consumption or high energy consumption. The amount of cadmium contaminated waste to be finally deposited must also be restricted with the use of economically viable technology.
Methods that provide large amounts of waste, that cannot be disposed of appropriately, should be avoided. The technology must also be selective so that nutrients that can be used for digestion are not removed unnecessarily.
In addition, a smooth operation along with a digestion technique is needed so that the amount of biogas recovery at the digestion process does not deteriorate.
Thus, several requirements must be met for the whole concept if it is to be economically and environmentally viable. The suitability of different purification techniques and laboratory tests on how they fit together with the digestion will be discussed and tested in more detail in step 2.

## 4 Anaerobic Digestion Techniques

### 4.1 Technology / processes

There are many different processes for reactor-based digestion. The following parameters differ for different techniques: moisture, temperature, stirring, feeding, step-and phase separation and substrates.

#### 4.1.1 Moisture in the Digestion Chamber

There are three kinds of processes with regard to moisture in the digestion chamber: dry processes, wet processes and semi-dry processes.

<u>Dry processes</u>: substrate with solid content of 25% is supplied without water additive. Most dry processes occur in Central Europe (Germany, Switzerland, Holland and Belgium), these are the digestion of large elements of household waste and garden waste. The residue is used particularly as soil improvers after treatment (sometimes by composting).

<u>Wet processes</u>: any dry substrate is mixed with wet substrates or water to keep the solid content below 10%. Sludge digestion as part of the municipal wastewater treatment plant is running as a wet process.

<u>Semi-Dry processes</u>: substrate and any water are mixed to achieve a solid content in the digestion chamber of between 10-25%. However only a few facilities are available for such methods.

#### 4.1.2 Temperature of the Digestion Chamber

There are different groups of microorganisms that can convert organic material to methane gas. These groups have different optimum operating temperatures and in a controlled process it is usual to seek and maintain the temperature at any of these optimums.

Psychrophilic digestion (<20 º C): slow degradation, requires a long residence time and thus large volumes. Not normally commercial.

Mesophilic digestion (~ 35 º C): most common in sludge digestion, is considered stable.

Thermophilic anaerobic digestion (~ 55 º C): higher degradation rate than mesophilic digestion. Considered less stable and more sensitive to nitrogen-rich substrate.

Hyperthermophile (> 70 º C). High energy consumption. Not normally commercial.

### 4.1.3 Mixing

Depending on the nature of the material being digested various stirring principles apply. Usually the processes are divided into the total stirred process and the plug flow process.

Total stirred process is the most common. Stirring of material made by propeller stirrer, recycle retted material or by returning pressurized biogas.

Plug flow is used mainly used in a dry process, e.g. digestion of municipal and garden waste.

### 4.1.4 Feeding of the Digestion Chamber

The digestion chamber can be fed in different ways. In a batch digester any material is eradicated, i.e. have the same residence time. For a continuous supply the residence time becomes averaged over all materials entered into the digestion chamber and some materials pass the digestion chamber in a very short time. Most common is a form of semi-continuous feeding, which means that all the material is broken down to some extent before it exits the chamber.

Batch: digestion chamber filled with a great rate, charged on completion of treatment, approximately 10-40 days.

Semi-Continuous: Feeding the subset to / from the digestion chamber, e.g. once a day etc.

Continuous: Feed to / from the digestion chamber is continuous.

### 4.1.5 Number of Steps

The digestion process can be divided into different stages. There are different processes from simple digestion (one step) to something more advanced (two-step) and further complex multi-step processes.

The one-step process is the most common for sludge digestion  and requires only one tank.

Multi-step processes breakdown the normal two-step process (and sometimes even three steps) that requires multiple tanks to be able to improve the digestion process. Through division, conditions of the various micro-organisms are optimized. Methanogenesis (methane formed) and acetogenesis (acetic acid formed) have other demands on pH (optimum around pH 7) than for example acidogenesis (optimum around pH 6). Optimized conditions can result in increased degradation and a more efficient process which results in shorter residence times and reduced volumes. Multistage processes usually require more complex management and the operating personnel to have greater knowledge.

**4.1.6 Splitting up Phase**

The digestion process is sometimes characterized by a possible phase separation, although the digestion of material in a single phase is by far the most common. Multi phase processes are designed to separate the liquid from the solid material at any time during the process and thus saving reactor volume. It might be interesting to hydrolyse the whole fraction (to get organic matter in solution), but then segregate the solids and only allow the liquid to go through the last steps in the anaerobic decomposition.

**4.1.7 Substrates**

Substrates occur mainly in anaerobic wastewater treatment. In the digestion of solids, sludge, waste, etc., substrates are typically not present.

**4.2 Techniques for Anaerobic Digestion to Produce Biogas from Seaweed**

The choice of anaerobic digestion technology for seaweed / algae is dependent upon many factors such as choice of treatment method, if digestion with other waste / sludge needs be done to get a better C / N ratio, etc.
Based on the experience in current situation (analysis of seaweed / algae in Trelleborg and experience from other studies of similar materials, etc.) below are a review of various process parameters for the digestion of seaweed / algae.
Further study and validation of technology should be done in laboratory experiments in the future of the project.
When making the choice of a dry or wet process it is particularly important to consider the dry solids content of seaweed and dry solids content of any other substrate. Data from various tests of seaweed / algae are collected in Table 6. The results suggest that a completely dry process is prohibitive because TS <20%. Possibly, the pre-treatment requires the addition of water (and then justify this is a wet process).

Table 6. Measured TS concentrations in seaweed. Data from literature and analysis performed within the project.

| Study | Type of Seaweed | TS Content | VS (% of TS) |
|---|---|---|---|
| Briand & Morand, 1997 | Raw Ulva sp. | 16% | 65-83% |
| Ascue & Nordberg, 1998 | Unground Green Algae | 16% | 75% |
| Linné & others. 2003 | Seaweed from beaches | 21% | Not Specified |
| Analysis of seaweed in Trelleborg 2006-07 | Seaweed from beach cleaning | 20% | 63,5% |
| Analysis of seaweed in Trelleborg 2007-06 | Beach specimens, various fractions (wet-dry) | 5-50% | 60-70% |
| Analysis of seaweed in Trelleborg 2007-06 | Samples from the water's edge | 9-17% | 60-70% |

Digestion of algae as the sole substrate at different temperatures (psychrophilic, mesophilic and thermophilic) was examined in a study by Briand & Morand, 1997. Best results are obtained during digestion at a mesophilic temperature of around 35ºC. This suggests that it is appropriate to choose a mesophilic digestion process. The choice of stirring depends on the choice of solids. As algal solid content makes a wet process appropriate, it will also be most appropriate to choose a total stirred technique. In a laboratory study by Ascue & Nordberg (1998) described and showed that the stirring technique does not affect methane recovery. In contrast, the stirring technique is to be of importance in full-scale because attempts to study it released a fungi quilt after propeller stirring.

Selection of the input frequency becomes dependent upon the availability of algae and the possibility to store the algae before treatment. In principle, the input can be both be at a fair and continuous rate. The studies described in the literature includes both batch and continuous studies.

The number of steps that is suitable for anaerobic degradation is dependent on the choice of purification method. A purification method based on getting the cadmium in solution by acidified material can also promote digestion by hydrolysis, i.e. solid organic material is dissolved and becomes more accessible for microorganisms. Since the plant material (such as algae) often contains some woody organic matter, which decomposes slowly in the digestion, it may be appropriate to carry out hydrolysis in a separate step. That way you can optimize ratios of hydrolyzable bacteria without harming the environment for methanogenesis, which has other demands on the pH and retention time.

As well as a step breakdown of the initial hydrolysis, into a separate step, it might be appropriate to separate a solid phase and a liquid phase. The liquid phase then contains the hydrolysates of organic material, which is used for digestion, while the solid fraction, whose organic content is persistently low, can be used in another way.

Substrates and filters can be used to keep the microorganisms in the digestion chamber. In this way, a longer residence time can be obtained in spite of a small volume. Substrates or filters can only be useful if the wet fraction is digested further for a possible hydrolysis step. If it is not possible to distinguish the wet and solid fractions substrates are not recommended because there is a high risk of clogging by solid materials.

### **4.2.1 Pre-Treatment**

A certain form of pre-treatment of the algae is necessary before digestion. The extent of pre-treatment depends on the purification method (to separate cadmium) and the digestion technology chosen. The pre-treatment may include removal of sand, decomposition of algae, removal of cadmium and some form of hydrolysis method to increase the decomposition of the algae.

**4.2.2 Gas Production and Gas Potential**

The studies of biogas production from seaweed and algae found in the literature are summarized in Table 7.

Table 7. Biogas production from anaerobic digestion of algae and seaweed in the studies found in literature.

| Study | Anaerobic Digestion Technique | Type of Seaweed | Gas Exchange | Methane Content |
|---|---|---|---|---|
| Briand & Moran, 1997 | Batch digestion 23 days (lab) | Raw Ulva | 110 L $CH_4$/kg VS | 59% |
| Briand & Moran, 1997 | Batch digestion 44 days (lab) | Rinsed Ulva | 94 L $CH_4$/kg VS | 55% |
| Briand & Moran, 1997 | Batch digestion 42 days (lab) | Raw Ulva | 145 L $CH_4$/kg VS | 49% |
| Briand & Moran, 1997 | Batch digestion 64 days (lab) | Ground Ulva | 177 L $CH_4$/kg VS | 52% |
| Ascue & Nordberg, 1998 | Continuous digestion, 25 days (lab) | Green algae (unground) (+50% household) | 200L $CH_4$/kg VS | -- |
| Ascue & Nordberg, 1998 | Continuous digestion, 25 days (lab) | Green algae & alda, NaOH and boiling (+50% Households) | 290 L $CH_4$/kg VS | -- |
| Morand, 2006 | Continuous digestion, fixed bed, 10 days (lab) | Ulva sp., hydrolysate. Pressed. | 290 L $CH_4$/kg COD | 81% |
| Linne 2003 | Batch digestion 28c (lab) | Seaweed from beaches | 160-250L $CH_4$/kg TS | |

VS, loss on ignition - measure of organic content
TS, dry
COD, chemical oxygen demand - measure of organic content
Lab - Anaerobic digestion experiments in laboratory scale

The results in the table show that it is possible to use seaweed and algae to produce biogas through anaerobic digestion, but these are relatively low biogas exchanges (94-290 liters of methane per kg injected organic matter (VS)). For comparison, the theoretical methane potential of carbohydrates is 415 liters of methane per kg VS and methane exchange in digestion of sewage sludge and food waste from households is around 300 liters / kg VS for sludge and around 400 liters / kg VS for food waste (Davidsson, 2007).

Reasons for the low gas exchange of algae can be due to:

- that much of the organic content is not easily degradable organically
- that any substance in algae hampers the digestion
- algae that contains too little of any substance or that e.g. carbon / nitrogen ratio is too low / high.

Assuming that the algae / seaweed can generate about 200 liters of methane per kg organic matter (VS-content is assumed to be 60-70% of TS in seaweed which is ~ 10%), the potential amount of seaweed in Trelleborg (less than 10 000 m3) is estimated to generate approximately 140 000 Nm3 $CH_4$/ year. The energy content of methane is 9.8 kWh/Nm3 $CH_4$. Roughly estimated, with a low methane production, seaweed in Trelleborg is able to provide a biogas equivalent of 1,3-1,4 GWh / year.

## 5 Authorities

During the design and planning of a biogas plant the municipality should include provincial government involvement in the discussion. The general requirements that exist today for biogas plants is a permit under the PBA, LBE and the Environmental Code as described below. When handling notifiable substances it is also required to be authorized under the law of serious chemical accidents. (KanEnergi, 2006)

• Permits under the LBE, Law of flammable and explosive goods.
Application is made by municipality housing, usually with the building permit.

• Permits under the PBA, the Planning and Building Act. Building permits for new construction or modification of existing biogas plant is applied for from the Building Committee. Building permits, examination of the location and exterior design, but not technical characteristics of buildings regulated by the Law on Technical characteristics of buildings.

• Permits under the Environmental Code. The use of land, buildings and plants through the discharge or otherwise detrimental to health or environment (known as environmentally hazardous activities). In order to be enforced an environmental hazard business license is required under the Environmental Code. Establishments handling> 50 tonnes of waste per year require a permit and it is the County Administrative Board that examines the issue of permits.

• Permits under the Act of serious chemical accidents. This authorization is required for the handling of substances that are notifiable under the SEVESO Act; management of more than 50 tonnes of liquefied gas (in stocks) or more than 10 tonnes of flammable gas (in stocks).

## 6 Conclusion of Stage 1 and Planning of Stage 2

The survey in Stage 1 of the project shows that the purification and digestion of seaweed / algae has good potential. There are various techniques for purification and digestion, which should be combined to achieve good results on this material. The results from other studies have shown that seaweed, algae and similar materials can be digested and gives an indication to the level of methane recovery. For the continued economic evaluation of the project it is necessary to determine the methane potential of seaweed / algae from Trelleborg with laboratory experiments, which will be made in Step 2.

Step 2 of the project is largely comprised of laboratory experiments, initially laboratory examination of different algae batches taken from Trelleborg's beaches. The aim of the experiment is to investigate the potential of biogas in material without any pretreatment. The algae will only need to go through a rough division to provide representative quantities of each fraction of the reactors. The experiment will show the biogas potential of algae and how it varies depending on how long the algae has been evident on the beach. The trial will also be important to evaluate the significance of the selected graft, i.e. retted material containing anaerobic microorganisms. We will try to use the graft from two existing digesters in the region. This choice of graft is very important for further experiments. The ability to separate cadmium after digestion can be investigated by testing methods of treatment for eradicated algae material. Pretreatment and treatment are combined and evaluated by a further algae sample batch. The goal is to initially clarify experimentally how different treatment methods affect digestion and the degree of purification obtained.
Further experiments are related to those described above. The design and the extent depends on what the previous experiments have shown.

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**Annex1**
Figure 1. The beach at Dalabadets, June 2007. (Photo: Asa Davidsson)

*Figur 1. Stranden vid Dalabadet, Juni 2007. (Foto: Åsa Davidsson)*

*Figur 2. Stranden vid Gislövs strandmark, juni 2007, (Foto: Åsa Davidsson)*
Figure 2. The beach at Gislövs shore, June 2007, (Photo: Asa Davidsson)

*Figur 3. Skårestranden, juni 2007. (Foto: Åsa Davidsson)*

*Figur 4. Stranden vid Äspö, Smygehuk, juni 2007. (Foto: Åsa Davidsson)*

Figure 3. Skärstrand, June 2007. (Photo: Asa Davidsson)
Figure 4. The beach at Äspö, Smygehuk, June 2007. (Photo: Asa Davidsson)

*Figur 5. Stranden vid Smyge (Fyren), juni 2007. (Foto: Åsa Davidsson)*

*Figur 6. Östra stranden, juni 2007. (Foto: Åsa Davidsson)*

Figure 5. The beach at Smyge (The Lighthouse), June 2007. (Photo: Asa Davidsson)

Figure 6. Eastern shore, June 2007. (Photo: Asa Davidsson)

**Biological Characterization**

The samples were dominated by the filamentous red algae Polysiphonia fucoides with a range of other filamentous as occurring. There was a part of some larger red algae Furcellaria lumbricalis, but never dominant.

Prov 1269 Dalabadet
Dominerande art Polysiphonia fucoides (fjäderslick)
Förekommande Enteromorpha sp. (tarmtång)
Ceramium tenuicorne (ullsläke)
Cladophora sp (grönslick)
Furcellaria lumbricalis (kräkel)

Prov 1269 Gislöv
Dominerande art Polysiphonia fucoides (fjäderslick)
Förekommande Enteromorpha sp. (tarmtång)
Ceramium tenuicorne (ullsläke)
Ceramium rubrum (stor havsmossa, grovsläke)
Cladophora rupestris (bergborsting)
Furcellaria lumbricalis (kräkel)

Prov 1269 Östra stranden
Dominerande art Polysiphonia fucoides (fjäderslick)
Förekommande Enteromorpha sp. (tarmtång)
Pilayella littoralis (trådslick)
Ceramium rubrum (stor havsmossa, grovsläke)
Cladophora rupestris (bergborsting)
Furcellaria lumbricalis (kräkel)

Prov 1269 Skåre strand
Dominerande art Polysiphonia fucoides (fjäderslick)
Vanlig Furcellaria lumbricalis (kräkel)
Förekommande Enteromorpha sp. (tarmtång)
Ceramium tenuicorne (ullsläke)
Ceramium rubrum (stor havsmossa, grovsläke)
Cladophora rupestris (bergborsting)
Pilayella littoralis (trådslick)

Prov 1269 Smyge
Dominerande art Polysiphonia fucoides (fjäderslick)
Ceramium rubrum (stor havsmossa, grovsläke)
Förekommande Enteromorpha sp. (tarmtång)
Ceramium tenuicorne (ullsläke)
Furcellaria lumbricalis (kräkel)

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