REPORT

Full-scale site solution of phosphorous retrieval from biowaste

PhosCad

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B2151
December 2013

The report approved:
2013-12-20

John Munthe
Vice president, research

<table>
<tr><td>Organization
IVL Swedish Environmental Research Institute Ltd.</td><td>Report Summary</td></tr>
<tr><td>Address
P.O. Box 21060
SE-100 31 Stockholm</td><td rowspan="2">Project title
Full-scale site solution of phosphorous retrieval from biowaste

Project sponsor
Nordic Investment Bank BSAP FUND and Foundation for IVL Swedish Environmental Research Institute, SIVL</td></tr>
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<tr><td colspan="2">Title and subtitle of the report
Full-scale site solution of phosphorous retrieval from biowaste
PhosCad</td></tr>
<tr><td colspan="2">Keywords
Algae, cadmium, phosphorous</td></tr>
<tr><td colspan="2">Bibliographic data
IVL Report B2151</td></tr>
<tr><td colspan="2">The report can be ordered via
Homepage: www.ivl.se, fax+46 (0)8-598 563 90, or via IVL, P.O. Box 21060, SE-100 31 Stockholm Sweden</td></tr>
</table>

Summary

The Baltic Sea suffers from eutrophication and one major effect is that seaweed and algae accumulate in large volumes on beaches along the sea. The seaweed and algae undergo partial decomposition which constitutes a major obstacle for usage of the beaches for bathing and other recreation.
The costs for removing the seaweed and algae in order to make the beaches available for tourism and recreation are substantial, but the benefits from tourism greatly exceed the cost for removing the algae. Additionally, the removal of the algae also brings about important environmental and social benefits since the phosphorous, cadmium and nitrogen in the algae are extracted from the Baltic Sea. The removal of algae also makes coastal areas available for spawning fish and other organisms by improving the availability of oxygen. When decaying, algae also contribute to high emissions of methane, which would be reduced if the algae are removed.

The initial idea of this project was to digest the sampled algae in a fermentation plant. The intention was to achieve recycling of the phosphorus while eliminating the cadmium content. During the project it was concluded that this is possible but not viable. This is carefully elaborated in the appendix "technical feasibility and ecological assessment".

The PhosCad project has investigated and examined the most cost-efficient solutions for removing the algae, recycling the phosphorous, reducing the level of cadmium and utilizing the residue for production of biogas and as fertilizer. The business plan framework is based on the results from the technical feasibility and ecological assessment report and presents the motives for removing the algae from a municipal business perspective. The municipality of Trelleborg functions as a case study since detailed information concerning beach related tourism and cost for removing algae is available for this city.

Drying, incineration and ash disposal, with partial drying and incineration for district heat and electricity, is considered to be the most viable way to handle the material. The project benefits, including municipal tax revenues from beach related tourism and environmental benefits substantially outweigh the project costs, i.e. costs for drying, transport, incineration and ash disposal. All costs and benefits are rough estimates and not all cost information is available, and needs to be further investigated in a fully elaborated business plan

The increase in algae blooms have resulted in empty beaches and reduced beach tourism all around the Baltic Sea. The suggested method, *Drying, incineration and ash disposal,* is most likely of interest to many other regional and local governments around the Baltic Sea, at least as interim measures until more far reaching measure are implemented to improve the marine environment in the Baltic Sea,

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PhosCad

2013-12-20

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Executive summary

The Baltic Sea suffers from eutrophication which leads to seaweed and algae accumulating in large volumes on beaches along the sea. The seaweed and algae undergo decomposition which constitutes a major obstacle for usage of the beaches for bathing and other recreation.

The costs for removing the seaweed and algae in order to make the beaches available for tourism and recreating are substantial. The benefits from tourism however greatly exceeds the cost for removing the algae. Additionally, the removal of the algae also brings about important environmental and social benefits since the phosphorous, cadmium and nitrogen in the algae are extracted from the Baltic Sea. The removal of algae also makes coastal areas available for spawning fish and other organisms by improving the availability of oxygen. When decaying, algae also contribute to high emissions of methane, which would be reduced if the algae are removed.

The PhosCad has investigated and examined the most viable solution for removing the algae, recycling the phosphorous, reducing the level of cadmium and utilizing the residue for production of biogas and as fertilizer. The business plan framework is based on the results from the technical feasibility and ecological assessment report and aim to present the motives for removing the algae from a municipal business perspective. The municipality of Trelleborg functions as a case study since detailed information concerning beach related tourism and cost for removing algae is available for this city.

Drying, incineration and ash disposal, with partial drying and incineration for district heat and electricity, is considered to be the most viable way to handle the material. The benefits, for *Drying, incineration and ash disposal* include municipal tax revenues from beach related tourism and environmental benefits substantially outweigh the costs, i.e. costs for drying, transport, incineration and ash disposal. All costs and benefits are rough estimates, not all cost information is available (e.g. area for drying and turning of material), and need to be further investigated in a full elaborated business plan

The increase in algae blooms have resulted in empty beaches and reduced beach tourism all around the Baltic Sea. The suggested method, *Drying, incineration and ash disposal,* is most likely of interest to many other regional and local governments around the Baltic Sea, at least as interim measures until more far reaching measure are implemented to improve the marine environment in the Baltic Sea,

The County Administrative Board of Skåne has admitted the municipality of Trelleborg dispensation to use the process to collect and reallocate the algae until 2014, but urges the municipality to use a more sustainable management of the problem, i.e. municipality will not receive dispensation forever. Taking this into consideration, and the fact that the benefits for removing and handling the algae, i.e. *Drying, incineration and ash disposal,* substantially outweigh the costs, the municipality should start planning for alternative solutions as soon as possible.

1. Introduction

The Baltic Sea suffers from eutrophication, due to pressures from human activities around the Baltic Sea, and show signs of oxygen depletion and excessive seaweed and algae production. In combination with the current wind and stream conditions along the coastal zones this lead to seaweed and algae accumulating in large volumes on beaches along the Baltic Sea. The seaweed and algae decompose and the malodorous gases, produced during decomposition, are so characteristic and dominating that it constitutes a major obstacle for usage of the beaches for bathing and recreation (WWF, 2013, Naturvårdsverket, 2009 and Filipkowska et al, 2005).

The costs for removing the seaweed and algae in order to make the beaches available for tourism and recreating are substantial, e.g. the costs for Trelleborg municipality amount to 4 million SEK annually. The benefits from tourism however greatly exceeds the cost for removing the algae, e.g. total municipal tax revenue from beach related tourism amount to 14,7 million SEK annually (Appendix 2). Additionally, the removal of the algae also brings about important environmental and social benefits since the phosphorous, cadmium and nitrogen in the algae are extracted from the Baltic Sea. Possibly some of this phosphorous and nitrogen could be retrieved and recycled.

There are several available techniques mainly for phosphorous retrieval from seaweed and biological waste. However, the techniques have been developed for wastewater sludge phosphorous retrieval and there have only been limited seaweed and algae applications in the Baltic Sea countries. This is due to the fact that the production processes are energy intensive, demand large amount of leaching chemicals, the amount of phosphorous which can be yielded varies substantially and also due to the fact that the degree to which contaminants can be removed varies considerably. The technical and ecological assessment report (Appendix 1 has investigated and examined the most cost-efficient solution regarding removing the algae, recycling of phosphorous, reducing the level of cadmium and utilizing the residue for production of biogas and as fertilizer (Ek et. al, 2013).

This business plan framework

draws on the results from the technical feasibility and ecological assessment report (Ek et. al, 2013). The business plan framework presents the motives for removing the algae, using the technique identified in the technical feasibility and ecological assessment report, from a municipal business perspective. The municipality of Trelleborg functions as a case study, i.e. project owner in the business plan framework, since detailed information on beach related tourism and costs for removing algae is available for Trelleborg. The business plan framework presents overall business related information on the project, i.e. removing and handling the algae using the identified technological solution, but does not constitute a fully developed business plan. More detailed information on project costs and revenues are needed in order to develop a more detailed financing plan, financial projections, disbursement plans and other important components of a fully developed business plan.

2. Project owner

The municipality of Trelleborg is situated in the southern part of Sweden, in Skåne in the Öresund region. The land area of the municipality is 342 square kilometers, including 35 km of beaches in the south, beech forest in the north and in-between farmland. The city of Trelleborg is located about 35 km from Sweden's third largest city Malmö, and 65 km from Copenhagen. The city has two airports within an hour drive, and five ferry connections with several daily tours to Poland and Germany. The city of Trelleborg has approximately 30, 000 inhabitants, while the municipality has 43, 000 inhabitants, i.e. the municipality is more populated than the average municipality in Sweden that has on average 33, 000 inhabitants on average (Trelleborg, 2013a).

The municipality of Trelleborg is the municipality in Sweden with the highest percentage of productive agricultural land. Mainly cultivation of cereals and sugar beet is of importance in Trelleborg. For instance, half of the grain used to produce the liquor Absolut Vodka grows in Trelleborg. The base of modern Trelleborg has mainly been created by a few large companies, particularly Trelleborg Industries and Port of Trelleborg. Trelleborg Industries is a global engineering group focused on polymer technology and the largest private employer with 375 employees. The port of Trelleborg is Sweden's second largest in terms of both goods and vehicular traffic and a key employer in the city. The municipality is the largest public employer with 3, 875 employees (Trelleborg, 2013a, Trelleborg, 2013b, Ekonomifakta, 2013). Businesses in the municipality are mostly characterized by manufacturing and there are plenty of mechanical workshops. However financial services as well as education and real estate services are constantly growing.

Tourism is an important business for the municipality of Trelleborg and the beaches are one of the main tourist attractions. Statistics show that in 2011 *overnight stay* amounted to 750 000, *over-day visits* to 275 000 and *transit travellers* amounted to approximately 250 000 (TEM, 2012). In addition, Trelleborg has a yearly festival known as Palmfestivalen, which is visited by more than 100 000 people (Svensson, 2013). In 2011 the total tourism turnover amounted to 370 million SEK, which is an increase of 8.5% compared to 2010.

The annual median income in Trelleborg, 228 096 SEK, is somewhat lower than the average, 241 622 SEK, in Sweden, while the unemployment rate in the municipality, 9.3%, is somewhat higher than the average, 8,4%, in Sweden. The tax rate, 30.75%, is lower than the average Swedish tax rate, 31.73%. The proportion of the population that runs their own business is slightly higher in the municipality, 7.1 %, than the average Swedish municipality, 6.8 % (Ekonomifakta, 2013). In 2012, the total tax revenue for the municipality was 34 548 SEK per inhabitant and the municipality had a total turnover of 2,4 billion SEK (Trelleborg, 2013a)

Annually, a citizen survey is conducted in Trelleborg municipality by Statistics Sweden. The citizen survey is an attitude survey in which the municipality residents give their view on how they perceive the municipality and its operations. The results for 2012 show that the municipality of Trelleborg is an attractive place to live in, seven out of ten survey respondents would recommend their friends and acquaintances to move to the municipality (Trelleborg kommun, 2013b)

3. Project information

3.1 Aim of the business plan framework

The business plan framework aims to identify the most suitable, including technical, environmental and economic perspectives, solution for removing seaweed and algae, which contain phosphorous, nitrogen and cadmium, from the beaches and harbours in Trelleborg. In order to enable usage of the beaches and harbours for tourism and recreational activities and improve the environmental status of the Baltic Sea.

The main idea for utilization of the algae was originally digestion into biogas, and using the residue as fertilizer. However, along the course of the project several difficult and severe factors have been identified concerning the original idea:

- The biogas potential in algae of this kind is relatively low due to the facts that the algae cell walls are relatively hard to digest, the organic content of the collected algae is low, and the content of sulphur is high.
- The content of phosphorous in the algae material is relatively low, which decreases the potential value as a fertilizer.
- The content of cadmium in the algae is high, especially in some species, due to an active uptake from sea water which limits the potential use as a fertilizer on farmland.

All in all these circumstances limits the possibilities to utilize algae for biogas fertilizer production (see Appendix 1 for more details).

3.2 Present situation

Currently, the Baltic Sea suffers from eutrophication, due to pressures from intensive human activities, and show signs of oxygen depletion and excessive seaweed and algae production. This in turn lead to, in combination with the current wind and stream conditions along the coastal zones, seaweed and algae accumulating in large volumes on the beaches e.g. in southern Sweden. The seaweed and algae decompose, partly under anoxic conditions due to the massive thickness of the algae piles, and the malodorous gases, produced under decomposition, are so characteristic and dominating that it constitutes an obstacle to the use of the beaches for bathing and recreation (Naturvårdsverket, 2009). In Trelleborg the municipality currently collect approximately 2 000 m^3 (app. 100 tons dry matter) of algae from the beach bathing areas and harbours for pleasure boats each year. The seaweed and algae are reallocated to beach areas which are not used during the bathing seasons and then during the autumn, after the bathing season, the algae are discharged in the sea. The costs for Trelleborg municipality amount to 4 million SEK annually. The removal of algae is, however, deemed absolutely necessary during the tourism season and the benefits from tourism greatly exceeds the cost of removing the algae, e.g. total municipal tax revenue from beach related tourism amount to 14,7 million SEK annually (Appendix 2).

3.3 Description of technical solutions/measures

In theory there are several available technical solutions/measures for removing algae from beaches and harbours (See Appendix 1 for more detailed information).

Possible technical solutions/measures include:

- *Collect and reallocate the algae (Business-As-Usual, BAU):* Currently the municipality of Trelleborg collect approximately 2 000 m^3 (app. 100 tons) of algae from the beach bathing areas and harbours for pleasure boats and reallocate it to beach areas which are not used during the bathing seasons. During the autumn, after the bathing season, the algae are discharged in the sea.

- *Disintegration in water, conventional one stage digestion, biogas utilization, disposal of digester residue:* This method entails collecting algae from the beach bathing areas and harbours for pleasure boats and transporting it to a reactor installation (new investment in reactor and burner is needed). At the reactor installation the algae is disintegrated in water and then undergo conventional one stage digestion, in order to produce biogas. The process water will be contaminated and will need to be treated. The digester residues will contain low levels of phosphorous and high ratio Cd/P, which mean disposal on non-farmland or possibly land for energy crops are most likely the only options.

- *Disintegration in water, co-digestion with low cadmium material, biogas utilization, digester residue as fertilizer:* This method entails collecting algae from the beach bathing areas and harbours for pleasure boats and transporting it to a biogas plant (new investment is not needed – the biogas will be produced in an existing plant). At the biogas plant the algae is disintegrated in water and then undergo co-digestion with a great amount of low cadmium material (e.g. farmland residues). The digester residues can be recirculated to farmland, however the residue still contain all algal cadmium and little phosphorous, which mean new cadmium will be introduced to the food chain without much input of phosphor. This method remains a theoretical alternative but not a real option. Since good digester residue from other sources will be contaminated with cadmium when co-digested with the algae, it will be very difficult to find an installation/plant which will accept the algae material.

- *Leaching to remove cadmium, conventional one stage digestion in existing digester, biogas utilization, digester residue as fertilizer, leaching water treatment, and disposal of cadmium rich waste:* This method entails collecting algae from the beach bathing areas and harbours for pleasure boats and transporting it to a reactor for leaching of cadmium (new investment in reactor installation is needed). In a separate reactor acid and base is used for leaching and precipitation of cadmium and the algae (about 5 000 m^3) then undergo conventional one stage digestion in an existing plant. The leachate will be neutralized and the cadmium precipitate will need to be taken care of. The digester residue, which contains phosphorous and low levels of cadmium, will be able to be used as fertilizer.

- *Dry digestion in two stages, biogas utilization, and disposal of digester residue:* This method entails collecting algae from the beach bathing areas and harbours for pleasure boats and transporting it to a plant for dry digestion (new investment is needed in construction of plant for dry digestion). The algae will undergo dry digestion in two stages. The cadmium will not be removed, but some biogas is formed. The digester residues will contain low levels of phosphorous and high ratio Cd/P, which mean disposal on non-farmland or possibly land for energy crops are most likely the only options.

- *Composting and disposal of the compost:* This method entails collecting algae from the beach bathing areas and harbours for pleasure boats and transporting it to an area for composting (new investment is needed in approximately 2 000 and 10 000 m^2 composting area respectively). The algae will be mixed with structure material (e.g. straw or bark) and put in piles, which need to be turned sometimes, in order to get even composting. The residues will contain low levels of phosphorous and high ratio Cd/P, which mean disposal on non-farmland or possibly land for energy crops is most likely the only options. This method remains a theoretical alternative but not a real option, i.e. earlier tests with composting have failed, the material is difficult to compost, and the residue is not possible to sell. SYSAV are not willing to accept the material for composting.

- *Drying, incineration and ash disposal:* This method entails collecting algae from the beach bathing areas and harbours for pleasure boats and transport it to an area for drying (new investment is needed in a large drying area, up to 50 000 m^2, or in a more compact drying drum). The algae will need to be turned 2-3 times per season, while drying. The dried material will be transported to an incineration plant (new investment is not needed – the incineration will take place in an existing plant). The ashes from the incineration will be needed to be taken care of.

3.4 Viability of technical solution/measures

The following criteria were used for assessing the viability of the technical solutions and measures:

- Current and forthcoming laws and regulations
- Cadmium and nutrients should be extracted from the sea
- Cadmium should be removed from circulation
- The energy content should be used
- Nutrients in the algae should be used
- Reasonable costs and usage of resources

Having taken these criteria into consideration, *Drying, incineration and ash disposal*, with partial drying and incineration for district heat and electricity, is considered to be the most viable way to handle the material (See Appendix 1 and 2 for more details on assessment of viability of the technical solutions). The incineration process is straightforward and should not cause any problems, however there are restrictions. The dry content has to be at least 50%, the amount of sand has to be minimized, and the odour in vicinity to the incineration has to be acceptable. The amount of sand in the material is very dependent on the harvesting method, and also the drying procedure. Algae and seaweed dry very fast in open air and a simple drying procedure in a drum or on a hard surface during summer should be sufficient.

The second most interesting option would be *Leaching to remove cadmium, conventional one stage digestion in existing digester, biogas utilization, digester residue as fertilizer, leaching water treatment, and disposal of cadmium rich waste.* However, both leaching and collection of the separated cadmium in a small fraction seem to be difficult. Large resources in the form of chemicals will be needed in a relatively complicated process. The economical estimations in Appendix 2 are rough, but they imply an expensive process.

The current practice to *Collect and reallocate the algae (Business-As-Usual, BAU)* does not meet the first criteria, Current and forthcoming laws and regulations, and will not be feasible even in the near future. The County Administrative Board has given the municipality dispensation to use the process to collect and reallocate the algae until 2014, but would like the municipality to use a more sustainable management of the problem (See appendix 3).

3.5 Costs and benefits - Drying, incineration and ash disposal

The suggested method *Drying, incineration and ash disposal* entail both costs and benefits. Project costs include: costs for collecting and reallocating the algae, operational costs (i.e. costs for transportation and fee for incineration). Project benefits include municipal tax revenue (i.e. beach related tourism) and environmental benefits (i.e. reduced Cd, P and N in the sea). Table 1 presents costs and benefits for *Drying, incineration and ash disposal* of 2 000 m^3 of algae, while table 2 presents costs and benefits for drying, incineration and ash disposal of 10 000 m^3 of algae.

See Appendix 2 for more detailed information on costs and benefits.

Table 1. Amount of algae – 2 000 m^3 (app. 100 tons)

Costs		**Benefit**	
Collect algae	4 million SEK/year[1]	Total municipal tax revenue (beach related tourism)	14,7 million SEK/year[2]
Area for drying (50 000 m[2])	TBC SEK/year[3]	Reduced P in the sea	125 000 - 510 000 SEK/year[4]
Turning of material	TBC SEK/year[5]	Reduced N in the sea	320 000 - 1 690 000 SEK/year[6]
Fee for incineration and disposal of ashes	150 000 SEK/year[7]	Reduced Cd in the sea	-
Transport	72 000 - 121 000[8]		
Total SEK	**4 222 000 -** **4 271 000**	**Total SEK**	**15 145 000 -** **16 900 000**

1) Current costs for the municipality for collecting 2 000 m^3 is 4 million SEK/year (Trelleborg, 2012).
2) Total tourism related tax revenue 35 million SEK per year (Resurs AB, 2012). According to estimates 42% of the tourism is beach related (Sweco, 2012). 35 million SEK x 0,42 = 14,7 million SEK per year. Break even for implementing the project = an impact on tourism of approximately 29 %> (4, 271 MSEK / 14,7 MSEK=29%), i.e. if the municipality expect that not removing will decrease tourism revenues with more than30% it is reasonable to implement the project.
3) TBC. Information not available currently.
4) Calculated marginal benefit for phosphorus reduction – source sewage plant (Gren et al, 2008)
5) TBC. Information not available currently.
6) Calculated marginal benefit for nitrogen reduction – source sewage plant (Gren et al, 2008)
7) 750 SEK/ton wet material, 50% DS (SYSAV 2013b)
8) Appendix 4

Table 2. Amount of algae - 10 000 m^3 (app. 500 tons)

Costs		**Benefit**	
Collect algae	20 million SEK/year[1]	Total municipal tax revenue (beach related tourism)	14,7 million SEK/year[2]
Area for drying (50 000 m[2])	TBC SEK/year[3]	Reduced P in the sea[4]	622 000 - 2 552 000 SEK/year
Turning of material	TBC SEK/year[5]	Reduced N in the sea[6]	1,6 - 8,4 million SEK/year
Fee for incineration and disposal of ashes	750 000 SEK/year[7]	Reduced Cd in the sea	-
Transport	360 000 - 601 000[8]		
Total SEK	**21 110 000 – 21 351 000**	**Total SEK**	**16 922 000 - 25 652 000**

1) Current costs for the municipality for collecting 2 000 m^3 is 4 million SEK/year (Trelleborg, 2012). 4million SEK x 5 = 20 million SEK/year
2) Total tourism related tax revenue 35 million SEK per year (Resurs AB, 2012). According to estimates 42% of the tourism is beach related (Sweco, 2012). 35 million SEK x 0,42 = 14,7 million SEK per year. An increase of the amount of algae collected (from 2 000 m^3 to 10 000 m^3) will not lead to increased tourism (beach related), since the additional amount of algae will be collected from beach areas which are not frequented by tourists. Break even for implementing the project = an impact on tourism of approximately 83-126%> (21, 351 MSEK / 16, 922 MSEK=126% and 21, 351 MSEK/25,652 MSEK = 83%), i.e. if the municipality expect that not removing will decrease tourism revenues with more than 83-126% it is reasonable to implement the project.
3) TBC. Information not available currently.
4) Calculated marginal cost for phosphorus reduction – source sewage plant (Gren et al, 2008)
5) TBC. Information not available currently
6) Calculated marginal cost for nitrogen reduction – source sewage plant (Gren et al, 2008)
7) 750 SEK/ton wet material, 50% DS (SYSAV 2013b)
8) Appendix 4

In conclusion, the cost benefit analysis shows that the benefits of removing and handling the algae, using drying, incineration and ash disposal, outweigh the cost. This conclusion however is based on a number of assumptions and conditions:

i) from a business perspective it is not reasonable to collect more than 2 000 m^3 algae. Increases of the amount of algae collected will not necessary lead to increased tourism, since the additional amount of algae will be collected from beach areas which are not frequented by tourists. Marginal benefits from collecting more algae include additional environmental benefits, i.e. more phosphorous, nitrogen and cadmium removed from the environment, but these benefits are small compared to the additional cost

ii) the municipality of Trelleborg assume that the beaches could not be used for recreational activities or tourism if the algae is not removed, i.e. the tax revenue from beach related tourism would almost or completely disappear. Quite possibly, however, beach related tourism would not completely disappear, i.e. some tourists would still frequent the beaches, and non-beach related tourism could possibly gain from less beach related tourism, e.g. tourists would visit other attractions instead. This means that the benefit, in the form of beach related municipal tax revenues, most likely is overestimated.

iii) All costs and benefits are rough estimates, not all costs are available (e.g. area for the drying and rotation of material), and need to be further investigated in a fully developed business plan

4. Environmental and social benefits

Removal of the algae is not only important for the tourism industry but also brings about important environmental and social benefits, since the phosphorous, cadmium and nitrogen in the algae are extracted from the Baltic Sea. Currently the municipality of Trelleborg annually collects 2 000 m^3 of seaweed and algae from the beaches and harbours. However, it is estimated that about 10 000 $m^3$of algae can be removed from the coastline (Davidsson, 2007). Removing additionally 8 000 m^3/year from the beaches and sea would not necessary lead to increased tourism, but for sure lead to that more phosphorous, cadmium and nitrogen would be extracted from the Baltic Sea. Table 3 shows the amount of cadmium, phosphorous and nitrogen which would be extracted from the sea if 2 000m^3 respectively 10 000m^3 of algae was collected from the beaches and sea (See Appendix 1 for more details).

Table 3: Removal of Cd, P and N (2 000m^3 and 10 000m^3 of algae)

Removal compounds	Cd (kg/year)	P (kg/year)	N (kg/year)
Removal 2 000 m3/year	-0.12	-220	-2300
Removal 10 000 m3/year	-0,6	-1 100	-11500

The marginal benefits of reducing nitrogen and phosphorus to the Baltic Sea can be calculated (See Appendix 3 for more details). The social economic benefits for removing 2 000m^3 algae is between 320 000 - 1 690 000 SEK/year and between 1,600,000 - 8,430,000 SEK/year for removing 10 000m^3 algae. The corresponding socio economic benefit or removing 2 000m^3 algae are between 125 000 - 510 000 SEK/year and between 622 000 - 2 552 000 SEK/year for removing 10 000m^3 algae. Table 4 shows the socio economic benefits from removing 2 000m^3 and 10 000m^3 algae.

Table 4: Marginal costs for nitrogen and phosphorus reductions to the Baltic Sea from measures affecting sewage treatment.

Measures	Marginal costs* (€$_{2005}$/kg)	Marginal costs (SEK$_{2005}$/kg)	Benefits from removing 2000m^3 (kSEK/year)	Benefits from removing 10000m^3 (kSEK/year)
Sewage treatment (N)	15-79	139-733	320-1690	1600-8430
Sewage treatment (P)	61-250	566-2320	125-510	622-2552

Although no similar cost estimates are available for cadmium, it is definite that removing cadmium from the environment brings about positive health effects (Swedish Chemicals Agency, 2012). The removal of algae makes coastal areas available for spawning fish and other organisms by improving the availability of oxygen. The decaying algae also contribute to high emissions of methane, which would be reduced if the algae are removed.

5. Market

WWF (2013) argue that there will be continued or increased algae bloom in the Baltic Sea due to insufficient efforts to reduce leaching from agriculture around the Baltic Sea. A study conducted by Boston Consulting Group (2013) showed that restoring the marine environment in the Baltic Sea by 2030 would create 550,000 jobs and provide about 280 billion SEK in annual value to the region. The same study estimated that tourism generated €42 billion in the countries around the Baltic Sea in 2012. Beach tourism, recreational boating, cruise tourism and recreational fishing are the main drivers of the tourism revenue. Further, the study revealed that the continued degradation of the marine environment in the Baltic Sea has led to difficulties in maintaining the high growth rates from tourism, as of now the tourism is only increasing nominally at the rate of the inflation (2 % annually). An interview study, conducted by Hasselström (2008), shows that there are strong indications in Sweden, Denmark and Finland that the increased presence of algae can cause serious harm to the beach tourism. Although the indications are not as strong in Estonia, Latvia, Lithuania, Poland and Russia, the tourism industries in these countries are also negatively affected by algae. For instance in Sopot beach, Poland, the beach is closed during the middle of tourist season due to algae on the beaches (Filipkowska et al, 2005). The increase in algal blooms have led to empty beaches and reduced beach tourism (Filipkowska et al, 2005, WWF, 2013).

According to the study of WWF (2013) almost half of the Swedes think that algae blooms have become worse over the last ten years. In addition, 15 % stated that they had travelled abroad on beach holiday instead of spending beach holidays in the Baltic Sea or Swedish lakes due to algae blooms. Along the coastline of Trelleborg and many other municipalities in Sweden, e.g. Malmö, Öland, Gotland and Kalmar, the large amounts of filamentous algae are accumulated. When these algae die or become washed up on the beaches they rot and smell bad. These odours affect residents and tourists negatively and make them reluctant to visit the beaches. For instance, in 2005 the increase in algae blooms in Öland led to losses of about 24%[1] of total tourism and fishing sector turnover (Naturvårdsverket, 2009).

In summary, several regions around the Baltic Sea report problems with algae on the beaches and are in the need of efficient and sustainable solutions. The suggested method, *Drying, incineration and ash disposal,* is most likely of interest to many other regional and local governments around the Baltic Sea, at least as interim measures until more far reaching measures are implemented to improve the marine environment in the Baltic Sea.

[1] In 2005 the increase in algae blooms in Öland led to losses of about 27 million EUR_{2005} in the tourism and fishing sector (Naturvårdsverket, 2006). 27 million EUR_{2005} gives 254.9 million SEK_{2005} (oanda.com). Total tourism turnover for 2008 was 1.07 billion SEK (Resurs AB, 2012). Based on the assumption, since no data is available for 2005, that tourist turnover was 1.07 billion SEK in 2005 as well, since tourism turnover was relatively stable 2005-2008, this gives a 24 % decrease in tourism turnover in Öland.

6. Project implementation and financing

Currently the municipality of Trelleborg collect algae from the beach bathing areas and harbours for pleasure boats and reallocate it to beach areas which are not used during the bathing seasons. During the autumn, after the bathing season, the algae are discharged in the sea. The County Administrative Board of Skåne has given the municipality dispensation to use the process to collect and reallocate the algae until 2014, but would like the municipality to use a more sustainable management of the problem, i.e. municipality will not receive dispensation forever.

Taking this into consideration, and the fact that the benefits benefits of removing and handling the algae, using drying, incineration and ash disposal, substantially outweigh the project costs, the municipality should start planning for alternative solutions, e.g. *Drying, incineration and ash disposal* as soon as possible. The project should be managed by the municipality, but should have an expert reference group (i.e. environmental and technical experts) linked to it, that can provide valuable ideas and experiences from the industry.

The first step of the project team would be to sign a long-term contract with landowners to ensure an area for the drying of algae. Personnel will need to be hired in order to turn the algae during the dehydrating period. Long-term contracts should also be signed with a transport company and Sysav, i.e. the company which will incinerate algae. The project should be evaluated on an annual basis and alternative solutions should be assessed regularly in order to investigate new and potentially better methods to handle the algae.

The project costs are not substantial, from a municipal point of view, taking into consideration that the annual turnover for Trelleborg is 2,4 billion SEK, and the project will probably not need third party financing.

In case third party financing would be needed Trelleborg is a member of Kommuninvest (www.kommuninvest.se), the Swedish local government debt office. Kommuninvest support Swedish municipalities and county councils in their financial operations, through financing, financing advice, skills development and cooperation.

7. References

Bergström, K. 2012. Impact of Using Macroalgae from the Baltic Sea in Biogas Production: A Review with Special Emphasis on Heavy Metals. Master degree thesis, LNU.

Boston Consulting Group, 2013. *Turning adversity into opportunity – A Business plan for the Baltic Sea.*

Bäckström, S, 2013. Personal Communication with Sebastian Bäckström, IVL Swedish Environmental Research Institute

Davidson, Å, 2007. Tång och alger som en naturresurs och förnyelsebar energikälla. Detox AB: Rapport Steg 1 till Trelleborgs kommun.

Davidsson, Å & Ulfsdotter Turesson, E, 2008. Tång och alger som en naturresurs och förnyelsebar energikälla. Detox AB: Rapport Steg 2 till Trelleborgs kommun.

European Commission, 2002. Eutrophication and health.

Filipkowska A., Lubecki L., Szymczak-Żyła M.,Lotocka,M., Kowalewska G., 2005.*Factors affecting the occurrence of algae on the Sopot beach (Baltic Sea). Marine Chemistry and Biochemistry Department, Institute of Oceanology, Polish Academy of Sciences. Report.*

Gren, I-M., Jonzon, Y., Lindqvist, M., 2008. Cost of nutrient reductions to the Baltic Sea – technical report, Swedish University of Agricultural Sciences, Working Paper Series 2008:1

Hasselström, L, 2008. Tourism and recreation industries in the Baltic Sea are - How are they affected by the state of the marine environment? - An interview study.

Jorhem, L. & Slanina, P, 2000. Does organic farming reduce the content of Cd and certain other trace metals in plant foods? A pilot study. Journal of the science of food and agriculture 80, 43-48.

Kemikalieinspektionen, 2012. Samhällsekonomisk kostnad för frakturer orsakade av kadmiumintag via maten. Report.

Kemikalieinspektionen, 2011. Kadmiumhalten måste minska – för folkhälsans skull. En riskbedömning av kadmium med mineralgödsel i fokus Rapport från ett regeringsuppdrag.

Larsson, B, 2013. Personal communication with Bengt Larsson Tekniska förvaltningen.

Naturvårdsverket, 2009. *What's in the sea for me? Ecosystem Services Provided bythe Baltic Sea and Skagerrak. Report 5872.*

Resurs AB, 2012. TEM rapport Ekonomiska och sysselsättningsmässiga effekter av turismen i Trelleborgs kommun inklusive åren 2008-2011.

Resurs AB, 2012. TEM rapport Ekonomiska och sysselsättningsmässiga effekter av turismen på Öland inklusive åren 2008-2011

SAKAB, 2013. Personal communication Marina Andersson, SAKAB.

Sweco, 2012. Stranderosion i Trelleborgs kommun. Inventering av nuvarande förhållanden och förslag till åtgärder. Report.

SYSAV, 2013a. Personal communication Anders Persson and Ann Thorén, SYSAV.SYSAV, 2013b. Personal communication Ann-Christine Hallberg, SYSAV.

Svensson, O 2013. Personal communication with Ola Svensson, Chairman of Palmfestivalen.

Trelleborgs kommun, 2011. Uppförande av biogasanläggning för insamling, hantering, rötning och om händertagande av alger vid Smyge reningsverk.

Trelleborg STP 2013. Connection fees 2013.

Internet sources

Biogas Syd: Gårdsbaserad biogasproduktion – Lönsamhetsberäkningar (Farm based biogas production – Calculations of profitability), June 2010. www.biogassyd.se

Ekonomifakta, 2013 http://www.ekonomifakta.se/sv/Fakta/Regional-statistik/Din-kommun-i-siffror/Oversikt-for-region/?region=1287 2013-11-28

Kommuninest, 2013. www.kommuninvest.se 2013-12-15

Oanda, 2013 http://www.oanda.com/lang/sv/currency/historical-rates/ 2013-11-19

Trelleborgs hamn, 2013. http://www.trelleborgshamn.se/?id=3814Z 2013-11-26

Trelleborg, 2013a
http://www.trelleborg.se/files/Kommunledningsforvaltningen/Ekonomi/Filer/Budget/Budgetdokument/Budget2014.pdf 2013-11-28

Trelleborg, 2013b http://www.trelleborg.se/sv/naringsliv-arbete/om-naringslivet 2013-11-28

U.S. Geological Survey, 2013
http://minerals.usgs.gov/minerals/pubs/mcs/2013/mcs2013.pdf 2013-12-06.

WWF, 2013 http://www.wwf.se/press/pressrum/debattartiklar/1540909-algblomningen-r-igng-8211-utslppen-mste-minska>2013-12-03

Technical feasibility and ecological assessment

PhosCad

Appendix 1:

Contents

Report summary

This report describes different scenarios for the removal and management of beach algae in southern Sweden. The report broadly summarizes available methods for algae removal, potential use and solution thereof. A cost-benefit analysis of proposed methods is included.

- The biogas potential in algae of this kind is relatively low. The content of cadmium (Cd) in the algae is high. The content of phosphorous (P) in the algae mass is relatively low

- There are many problems in digestion of this mixture of algae and seaweed. The methane yield is low, a lot of hydrogen sulphide is formed and it is difficult to get a product with low cadmium content. The available substrate volume in Trelleborg is also much less than what is normally necessary for economic break even in digestion

- Separation of cadmium from the algae before or after digestion involves high costs in resources and money, and will create a cadmium rich phase that has to be treated as hazardous waste. This phase has to be as concentrated as possible

- It is very unlikely that someone will pay for the digestion residue, due to the low content of phosphorous and high ratio Cd/P. Disposal on non-farmland or possibly energy crops is most likely

- The specific cadmium removal method tested in this project, based on positive results from literature, is not a solution to the problem with cadmium in beach algae when using realistic values on leaching pH and natural cadmium concentrations in beach algae. The efficacy is too low and the costs are too high

Background

Deposition of filamentous algae and seaweed on shores is a problem in southern Sweden. Along the shore line of Trelleborg municipality it is estimated that about 10 000 m^3 of algae can be removed on land (1). Another estimation is that there were about 10 500 tons, or about 30 000 m^3, on the shores in August 2009 (12). With collection also in shallow water up to 200 000 m^3 can be harvested every year (2), but there is no full scale technique for this yet. Today only algae from bathing areas are collected, and this amounts to about 2 000 m^3/year.
The collection from shores is necessary during the tourist season, and today the algal mass is allowed to be washed back to the sea in autumn. However, the municipality of Trelleborg, and other shore municipalities in southern Sweden, wants to make use of the

collected biomass. The main idea is to anaerobically digest the algal mass for biogas production and use the residue as a fertilizer on farmland.
For the above mentioned 2 000 m^3/year the positive effects would be clean and nice shores for recreation (as today), renewable biogas, a fertilizer and removal of some cadmium and nutrients from the water body. For the remaining 8 000 m^3/year the tourist factor would be less important, but still production of biogas, fertilizer and removal from the water would be positive. It might also be more difficult and expensive to collect these 8 000 m^3 (17).
Based upon the idea of utilizing the algae, Trelleborg municipality has during the last years investigated the practical possibilities (6). Starting in 2012 IVL Swedish Environmental Research Institute (IVL) has with financial support from Nordic Investment Bank (NIB) assisted Trelleborg in this, and will suggest at least two different methods to handle the algae problem.

Several difficult factors have been identified concerning the original idea.

1. The biogas potential in algae of this kind is relatively low (2, 4). It has several reasons. The algal cell walls are relatively hard to digest, the organic content of the collected algae is low, and the content of sulphur is high.
2. The content of cadmium (Cd) in the algae is high, especially in some species, due to an active uptake from sea water. Average concentrations (1, 2) are about 1.2 mg Cd/kg DS (Dry Substance). With a limit for distribution on farmland of 2 mg Cd/kg DS many batches of digested algae would be impossible to spread, since the concentration increases during normal anaerobic digestion. Furthermore, the Swedish Environmental Protection Agency suggests that the limit should be 1 mg Cd/kg DS from 2015 (7).
3. The content of phosphorous (P) in the algal mass is relatively low (1, 2). This decreases the value as a fertilizer (15). It also contributes to a high ratio P/Cd, about 600 mg Cd/kg P. This can be compared to the limit 100 mg Cd/kg P in imported phosphorus fertilizers, and to the average value for digested municipal sludge spread on farmland in Sweden, 25 mg Cd/kg P.

The chemical composition of a number of algae samples collected in the Trelleborg area is compiled in Table 1.
All the above mentioned difficulties have to be considered when deciding what to do with the algae on shores. In the following sections different ideas and tests performed by IVL and others to overcome some of the problems are given.

Table 1. Average composition of 12 different algae samples from the area.

		Average 6 samples Ref. 1	Average 5 samples Ref. 2	IVL 1 sample	Average	Maximum conc. to farmland	Suggested new limit 2015
DS	%	12	20	20	16		
Ash	% av DS		36	37	36		
C	g/kg DS	260	270	300	270		
H	g/kg DS	36	36	36	36		
N	g/kg DS	22	25	19	23		
Ca	g/kg DS	18	24		21		
Cl	g/kg DS	20	15	18	18		
Fe	g/kg DS	2,2	1.0		1.7		
K	g/kg DS	13	10		12		
Mg	g/kg DS	5,7	8.0		6.7		
Na	g/kg DS	21	21		21		
P	g/kg DS	2.5	1.9		2.2		
S	g/kg DS		22	18	21		
Al	mg/kg DS	950	360		680		
As	mg/kg DS	3.9	3.4	4.6	3.8		
Cd	mg/kg DS	1.1	1.4	1.1	1.2	2	1
Co	mg/kg DS	0.82	0.97	1.3	0.92		
Cr	mg/kg DS	2.0	0.87	2.9	1.6	100	60
Cu	mg/kg DS	8.0	7.5	13	8.2	600	600
Hg	mg/kg DS	0.036	0.050	0.017	0.040	2.5	1
Mn	mg/kg DS	47	180	54	100		
Ni	mg/kg DS	6.4	5.9	7.7	6.3	50	40
Pb	mg/kg DS	3.8	2.2	4.0	3.2	100	35
Zn	mg/kg DS	74	87	91	81	800	800
Cd/P	mg/kg	440	740		580		

In Denmark there are similar plans to produce biogas from collected algae and seaweed (18). At Solrød in eastern Sjælland a plant is projected that from 2015 will digest 22 000 ton algae, 74 000 ton by-product from kelp processing and 53 000 ton manure per year. However, they see the problem with cadmium content over 0.8 mg/kg DS in winter time. This cannot be used for digestion according to Danish regulations (18). Nothing is mentioned about how algae batches with too high cadmium content will be handled.
In Trelleborg an anaerobic digester of shore-algae is to be built on commission of Trelleborg municipality by the manufacturer Norup Bioraff AB. They plan to deal with the cadmium levels by harvesting the algae at certain period (pers. com Sven Norup).

Sources/abundance of shore algae

The biomass of algae on vicinity of Simrishamn is presented in *Table* . The potential biogas production is also included and ranges from 130 – 250 Nm^3/ton VS (volatile solids) with a mean of 200 Nm^3/ton VS (seven studies and references in 27). A case which extrapolates the beach algae to a larger area is also included but has a small significance for this project (29).

Table 2. Literature data on available algae biomass in Simrishamn area. All calculations are based on Dry substance (DS) =12 % of wet weight, Volatile solids (VS)= 63 % of DS and methane production is 200 Nm^3 CH_4/ton VS. The values are averages of reported values in literature.

	Yearly biomass production				
Beach algae yield	Wet weight (ton)	Dry weight (ton)	Volatile solids, VS (ton)	Potential CH_4 prod (Nm^3)	Ref.
Data from Simrishamn 2001-2004	620	75	48	9.672	27
Potential harvest from 30 km	3.500	420	273	54.600	27
Potential harvest from 30 km [maximum harvest]	10.500	1260	819	163.800	27
Potential harvest from water	1.200	144	94	18.720	27
Potential harvest from Simrishamn area	70.000	8.400	5.460	1.092.000	28
Harvest from Malmö - Simrishamn	358.900	43.068	27.994	5.598.840	29

The biogas potential from beach algae has been studied by several authors and we refer to (19; 38; 2) that have studied anaerobic digestion on local beach algae.

Positive effects of removing algae from the shore

Today about 2 000 m^3 of algae is collected from bathing areas every year. With about 0.35 ton wet weight/m^3 (5) and about 14 % DS (dry substance) of wet weight (1) this corresponds to about 100 tons DS. The total amount along the Trelleborg shore line is estimated to about 10 000 m^3 (1), or 500 tons DS/year. If this material is not discharged back to the sea in autumn the amounts given in table 2 would be extracted from the water body. Some sources of cadmium and nutrients to the water body outside the shore are also listed.

Data for STP (Sewage Treatment Plant) are for 2012 (10). Tullstorp river is included as a main river with outflow within the Trelleborg shore line. The water quality has also been studied in a special project (11). The figures in table 2 are from 2009/2010.

Table 3. Possible removal of some compounds with algae, and comparisons with some sources along the Trelleborg shore line.

	Cadmium, g/year	Phosphorous, kg/year	Nitrogen, ton/year
Algae removal 2 000 m^3/year	**-120**	**-220**	**-2.3**
Algae removal 10 000 m^3/year	**-600**	**-1 100**	**-11.5**
From Trelleborg STP	**+110**	**+610**	**+38**
From Smygehamn STP	**+23***	**+140**	**+7.9**
Via Tullstorp river	**+?**	**+2 500**	**+90**
Via air transport	**+?**	**+?**	**+?**
Via diffuse water sources	+?	+?	+?

*Estimated provided the same concentration as from Trelleborg STP

According to the figures in the table removal of algae from the shores could have a significant influence for cadmium, some influence on phosphorous, but small influence on nitrogen balance.

Beach cleaning – ecosystem services

Ecological and physical parameters from beach cleaning have been measured by Malm 2004 (39). Their findings are summarized in table 4. They also find a qualitative improvement of the beaches: "*The organic content of the sand was reduced by beach cleaning at northern Öland, giving a brighter appearance to the shore and increased stability for visitors walking along the beaches.*"

Table 4. Summary of effects on cleaned and not cleaned beaches. Data compiled from Malm et al 2004.

	Cleaned beaches	Not cleaned beaches
Oxygen and pH	No difference	
Total nitrogen	No difference	
Ammonia	Lower conc. of ammonia in water	
Organic content in sediment	Lower carbon content in outside sediment	
Water visibility (secchi depth)	Improved outside water visibility [a]	
Bacterial abundance	Lower bacterial abundance (3 times) in water	
Protist abundance		Higher abundance of bacterivore ciliates
Species abundance	No difference, except for mysid shrimps in higher abundances outside uncleaned beaches.	

[a] Significant difference for intensively cleaned and uncleaned. No effect for moderate cleaned beaches.

Long-time harvest of shore macroalgae was studied in Australia (40). The results showed that harvested beaches suffered in the short time-scale (days-weeks) from the harvest but the beach thereafter was more similar to a "natural" shore with small amounts of macroalgae. They conclude that beach-cleaning is a possible management tool for eutrophicated areas.

Other ecosystem services/costs are discussed in (41, 42; 43).

Best time to harvest beach cast algae is before and after the summer period (May and September) according to (29) and references therein.

Management of beach-cleaning is discussed by (44), the author states that it is important to avoid extra damage by the harvesting machines such as diesel/oil slips and plan harvest time with animal protection in mind.

Different systems for anaerobic digestion

Digestion of this kind of mixture of algae and seaweed has been reported by many authors (2, 4, 8 and more). They all found methane yields well below the theoretical, and report different problems beside that with cadmium. Fresh material gives higher yield than material that has been partly dried on the shores. Some kind of disintegration or chemical pre-treatment will increase yield and degradation speed. Enzymatic pre-treatment gave some effect, but still low yield.

The cell walls of these algae and seaweed are obviously difficult to digest, but there are also other problems. The high content of sulphur (21 g/kg DS) will during digestion create a lot of hydrogen sulphide. Some of the sulphide will be bound to different metals, but the content of the corrosive and toxic hydrogen sulphide in the biogas is a problem. Sulphur in the form of sulphate will during digestion consume a significant part of the organic material that could otherwise have formed methane gas.

Most anaerobic digestion to form biogas is performed in suspension in completely mixed reactors in one step. It is also possible to have two reactors in series, with first acidification and then methane formation. The suspended systems with long retention time give the highest yield. However, the high content of sand and small mussels in the material collected from shores might give corrosion problems in pumping and mixing. Norup Bioraff AB therefore tested so called dry digestion within the Wetland Algae Biogas (WAB) project (4). "Dry digestion" means that the material to be digested is soaked or sprayed with water, but not suspended, in a first step. Organic material is here to some extent transformed to short organic acids, mainly acetic acid. The acidic water but no solid material is pumped into the biogas reactor where methane gas is formed.

At Smygehamn (4) collected algae and seaweed was mixed with straw (to give a more permeable structure). The mix was distributed in beds between water tight membranes, and water could be circulated over the bed via a normal anaerobic reactor. The reactor contained plastic carrier material to give a high sludge concentration and retention time, in spite of the low organic content in the water. The idea was to have a low pH in the bed, and in this way mobilize cadmium that would then be trapped in the biomass in the reactor. This would give lower concentrations of cadmium in the algae residue, so it could be used as a fertilizer.

In the first reported period (4) from September 2011 to 20 January 2012 air dried algae from the shore were used. pH in the bed fell to just below 6 due to spontaneous acid formation, and methane formation started. However, within a month pH in the bed increased to over 8, due to the recirculation of water with methanogenic organisms. At the end of the period about 38 m^3 methane had been collected. With the estimated amount of organic material in the bed from start this is about 9 m^3 methane/ton organic material. This can be compared to the estimated possible yield 200 m^3/ton for this material in a conventional mixed reactor. The theoretical yield from carbohydrate is about 415 m^3 methane/ton digested. This shows that a very small part of the algal mass was converted to methane.

Norup Bioraff (4) reported that 50 % of the cadmium in the algae mass was removed in the process. This is surprising and unlikely as pH was never below 5.8 and a very small part of the material was digested. It was also suggested that the high apparent reduction was due to difficulties in determination of cadmium in the inhomogeneous solid phase. They determined the ratio Cd/P to 1 240 mg Cd/kg P at the start, to compare with the mean value 580 mg Cd/kg P according to table 1.

In the second reported period, from 20 January 2012 to 30 May 2012, a similar bed was used (4). It was constructed at the same time as the first one, but left without water circulation until now. The pH had now fallen to about 5.3, but increased fast when recirculation started. During some period's whey or acetic acid were added to lower pH again, with the aim to reach pH 3.8-4.2 in the bed. The gas production in this case was higher than during the first period, but the difference could be completely attributed to the added substrate in form of whey and acetic acid.

Any leaching of cadmium from the algae mass is not reported (4). The pH interval 3.8 to 4.2 is cited from (2), but this figures is probably for solution of cadmium sulphide under oxidizing conditions, not for organically bound cadmium. Another way to increase the yield of methane from algae, besides disintegration, biological, thermal or chemical pre-treatment, is by co-digestion with other organic material (2). This can increase the yield somewhat, probably due to addition of limiting trace elements or dilution of inhibiting compounds, or both. However to gain a little more biogas and get a digestion residue with low cadmium content, you have to "sacrifice" a lot of good, low cadmium material.

Methane production

In a normal one stage digestion the expected yield of methane is about 200 Nm^3/ton organic material (1, 31 and references in Table 5). This would for the two cases 2 000 and 10 000 m^3 algae/year mean 13 000 and 65 000 m^3 of methane respectively. This corresponds to about 127 and 630 MWh thermal energy respectively. However, no biogas plant in Skåne will be able to handle the material without removal of most of the cadmium, due to restrictions on substrate (16).

The so called dry digestion reported by Norup (4) yielded about 9 Nm^3/ton organic material. With the two cases 2 000 and 10 000 m^3 algae/year this means 580 and 2 900 m^3 of methane respectively, or 5.6 and 28 MWh thermal energy respectively. A commercial biogas plant based upon organic waste material is estimated to need a production of at least 2 000 000 m^3 methane/year to be profitable, and even more if there is a cost for substrate or handling of the digested residue.

It is clearly shown that different algae and algae mixtures have different biogas potential and that harvest period, pre-treatment and co-digestion with other substrates affects the biogas potential. Fresh and wet algae have higher biogas potential than old and dried algae as example.

Table 5. Summary of biogas potential from beach cast algae and similar substrates.

	Nm^3 CH4 /ton VS	period (days)	Note	Reference
50:50 municipal organic waste : algae	200	32	Green algae Cladophora	31 Melin 2001
50:50 municipal organic waste : algae	290	125	Cladophora (boiled in NaOH and mixed)	31
100 % municipal organic waste	450			31
100 % beach cast algae	170		Ulva	Cited in 31
100 % beach cast algae	100		Ulva	Cited in 31
100 % beach cast algae	90-330		Ulva, Cladophora	32
100 % blue mussels (Mytilus edulis)	330	40	UASB rector (dry)	33
100 % reed (Phragmites)	212	107		33
100 % "raw seaweed"	120			19
100 % leachate from "raw seaweed"	200-240			19
Sea Lettuce	80-110			34
Sea Lettuce	170			Cited in 27
Mixed samples from beach	130-220			Cited in 27
Mixed sample	160-250			Cited in 27
Mixed sample	190-220			1

Utilization of the gas

The biogas can be expected to contain 50-60 % methane. It can be used locally either direct for heating, or in a gas engine. A gas engine can give about 30 % of the energy in the gas as electricity, and the rest as heat. Some of the energy is normally used to warm the biogas reactor.

However, before the gas can be used either in a boiler or in a gas engine the high concentration of hydrogen sulphide has to be removed in order to avoid severe corrosion. It can for example be removed in a scrubber or trapped on metal pellets.

At larger biogas production sites the gas is today often upgraded to vehicle fuel. This means at least 98 % methane and very low levels of water, sulphur, nitrogen and particles. The most common methods for upgrading are Water Scrubber, Pressure Swing Adsorption and Chemical Adsorption (13). They are all relatively complicated and thus expensive in smaller scale.

A reasonable economic limit in size is about 100 m^3 raw gas/h, or about 900 000 m^3/year. The cost for upgrading is here about 0.35 SEK/kWh gas energy. The energy used for upgrading is about 6-7 % of the original gas energy.

Value of the gas

Dependent on the use of the gas the value of the raw gas will be from 0.15 to 0.50 SEK/kWh (14), the highest value if it is directly used for heating. As a conclusion, there are many problems in digestion of this mixture of algae and seaweed. The methane yield is low, a lot of hydrogen sulphide is formed and it is difficult to get a product with low cadmium content. The available substrate in Trelleborg is also much less than what is normally necessary for economic break even in digestion.

Removal methods of cadmium

Leaching conditions

Cadmium can be removed from the algal mass either before or after digestion (2) (and possibly during digestion according to (4)). Davidsson and Turesson (2) reports that acidic leaching during 24 hours removed 75 % of the cadmium in the material. pH during leaching is not given. Experiments at IVL (9) showed that leaching over night with sulphuric acid at pH 2.5 solubilized about 40 % of cadmium, and at pH 1.8 about 60 %. The experiments were performed with mechanically disintegrated algae, and already leaching at the natural pH 6.1 gave dissolution of 15 % of cadmium, 45 % of phosphorous and 8 % of organic material. Acidic leaching of cadmium at slightly decreased pH, that could be the case in systems that used natural acidic substances such as whey, was tested in this project as a part of a cadmium removal system using shrimp-shell chitosan. The cadmium removal at pH 4.8 was only 10 %, see below for further details.

Already to reach pH 1.8, about 105 kg concentrated sulphuric acid was needed per ton DS. Leaching at both tested pH also removed about 50 % of phosphorous and 10 % of organic material. The 10 % loss of organic material for methane production might well be outbalanced by increased yield from the chemically pre-treated residual material. Since about 50 % of both cadmium and phosphorous was removed in leaching, the ratio between Cd and P would still be high in the digested residue. Before digestion of the leached algae pH has to be raised to about 7, with a substantial need of alkali. Also, sulphuric acid should not be used before digestion, because the negative effect of sulphate during digestion. The more expensive, and less pleasant to work with, hydrochloric acid will have to be used in practice.

In a new test at IVL hydrochloric acid was used for leaching. Two batches of 100 g of wet algae mass were cut in about 1 cm pieces, and 300 mL of water was added to each batch. HCl (2 M) was then added to pH 1.69 and 1.50 respectively. After one day (with manual mixing 5 times), the algal mass was filtered and washed with 100 mL of water. The composition of both samples of algal mass and leachate with washing water was analysed. 100 mL of the leachates were then titrated to pH 11.1. Appendix 1 shows why this pH was chosen. Cadmium should be precipitated as $Cd(OH)_2$, while calcium is still mainly in solution as Ca^{2+}. The precipitate was allowed to settle for 30 min, and about 65 mL supernatant could be decanted. The residual with precipitate was filtered and washed on glass fiber filter. The filtrate was analysed. To reach pH 1.69 and 1.50 hydrochloric acid corresponding to 220 and 310 kg 34% HCl/ton DS respectively was needed. To increase pH to 11.1 to precipitate cadmium 265 and 380 kg 25% NaOH/ton DS respectively had to be used.

About 70% of cadmium in the algae was extracted, but also more than 10% of the organic material and 50% of the phosphorous was lost. At pH 11.1 90% of cadmium and other heavy metals were precipitated, but still not more than 20% of calcium. The residual concentration of cadmium was still about 3 mg/l, and this makes it difficult to treat in a normal STP with sludge utilization. pH should probably be closer to 11.5. Leaching after digestion of algae has been suggested by Nkemka (19) who measured ~17 % lower methane production if metal leaching was done prior to anaerobic digestion. You can expect a little less acid demand with such a procedure, since some of the organic material is gone, and some cadmium is in the form of sulphide instead of organically bound. However, leaching after digestion will only be an option if only algae have been digested. The amount of digestion residue to be extracted would otherwise be too large. If the algae are to be co-digested with other organic material, only extraction before digestion can thus be of interest.

Separation of cadmium from leachate

The leachate has to be taken care of. In the experiment at IVL (9) the amount leachate was about 25 m^3/ton DS. Even if this probably be decreased a bit, it has to be neutralized and most of the cadmium removed before it can be accepted by a municipal waste water treatment plant.

Chemical precipitation

Removal to a certain degree is achieved by increasing the pH, cadmium hydroxide will precipitate. The precipitation has not been tested, but it is possible that a specific precipitation as cadmium sulphide has to be used in order to reach the limit values for acceptable water to the treatment plant. The precipitate will have to be separated and treated as hazardous waste.
About 50 % of the original amount of phosphorous will be in the acidic leachate. The concentration would be about 40 mg P/l, mainly as phosphate. Most of this will precipitate directly at pH increase, as metal phosphates. This will be difficult to separate from the cadmium precipitate without further separation steps.

Ion exchange

Cadmium in solution (in ion form) can be trapped in different kinds of ion exchange resins. It is possible to reach low concentrations in the treated water. There are resins with some selectivity, but in general the affinity of metal ions to a cation exchanger is dependent on the charge and the concentration. Since the concentration ratio between calcium (Ca^{2+}) and cadmium (Cd^{2+}) in the leachate is about 30 000 (9) mainly calcium will occupy the sites in the ion exchanger. Also metals like magnesium, iron and aluminium will compete successfully with cadmium. Due to the high concentration of calcium, regeneration of the resin with a strong sodium chloride solution will give a great amount of eluate, not much less than the leachate itself.

Adsorption

While ion exchange is based upon electrostatic binding, there might be other material with different binding mechanisms. It can be chemical or other physical binding. These materials can have a much higher selectivity than ion exchangers. One suggested material is chitosan that is a chemically modified form of chitin that is an important constituent in crustaceans and insects shells. A common method is to use shrimp or crab shell as raw material since this is a high volume waste product from seafood industry.

Methods using organic waste

There is a growing literature on the use of organic waste as adsorbents and ion-exchange material and their role in removal of heavy metals in contaminated matrixes. Some adsorbent have very high capacity to adsorb cadmium, in the literature report to NIB as part of this project (35) data are compiled from a large review of organic adsorbents with cellulosic origin, and e.g. Eucalyptus, brown algae, saw dust and some carbons have capacities to remove up to 200 mg Cd/g adsorbent. A more conservative removal capacity is estimated to 20 mg Cd/g adsorbent.
In the case of removing all cadmium from a treatment plant in Smygehamn, the amount of organic adsorbent that would be needed to remove 0,6 kg Cd (based on data in table 3) could be estimated to be less than 10 tons (assuming a adsorption capacity of 20 mg/g DW and a process efficacy of 10 %.
Research has been conducted by Yulia Kalmykova at Chalmers that reported a high Cd removal with shrimp shells rich in the substance chitosan (36 and 37). The adsorption potential of different organic materials (all were waste material) showed that chitosan was the most promising agent with an adsorption of 25 % Cd per weight chitosan. Kalmykova et al. (37) also investigated the effect of salinity, low temperature and drying on the adsorbent, the results shows low interference on the adsorption from those factors. In the case of salinity-addition the adsorption decreased during a period but adjusted to the new environment after a short time. Nkemka and Murto (19) reported a cadmium removal of 75% by using a cryogenic gel. This is the same percentage removal reported by Davidsson and Ulfsdotter Turesson (1). The total removal is calculated as both the extraction and adsorption of cadmium.

In this project IVL also conducted tests with untreated shrimp shells to study their potential Cd adsorption capacity, see Fig 1 and next section, but the concentration of cadmium was naturally so high in the shrimp shells that the algae leachate instead increased its Cd concentration during the adsorption experiment. Measured Cd concentration in natural shrimp shell was 0.36 mg/kg DW but this decreased after leaching to 0.14 mg/kg DW after three days incubation. In the leachate the Cd concentration increased from 0.64 μg/lit to 11.78 μg/lit during the same period.

Figure 1 Preparation of dried shrimp shells for use as cadmium adsorbent in leachate. a) Drying of fresh shrimp shells from sea-food industry b) Dry shrimp-shell c) Grinded shrimp-shell (diam. ~0,1-3 mm) d) The grinding process using a large kitchen macerator.

After adsorption of cadmium, the material either has to be regenerated or discharged. In both cases it is important to have the cadmium phase in as small volume as possible, since it will probably have to be treated as hazardous waste.

In a holistic perspective it is very important that we don't cause a cadmium problem at the location where cadmium free chitosan is produced (which most often is China), just to be able to remove our own heavy metals. The excess cadmium atoms, that mostly comes from anthropogenic sources, must be taken care of somewhere during the whole process. As a conclusion separation of cadmium from the algae before or after digestion involves high costs in resources and money, and will create a cadmium rich phase that has to be treated as hazardous waste. This phase has to be as concentrated as possible.

Experimental test of possible method (acid leaching and cadmium adsorption)

Experimental background

The possibility of using natural waste products as cadmium adsorbent was tested in laboratory scale. The purpose was to verify literature results which had reported high degree of removal of cadmium (see above for references). If the results from lab-scale were positive, a pilot-scale treatment system should be developed.

Experimental setup (methods)

The tested system is based on 1) acid leaching of cadmium from algae 2) neutralization of the leachate 3) adsorption of cadmium onto chitosan with low cadmium concentration 4) disposal of cadmium rich chitosan as harmful waste, see Fig 2.

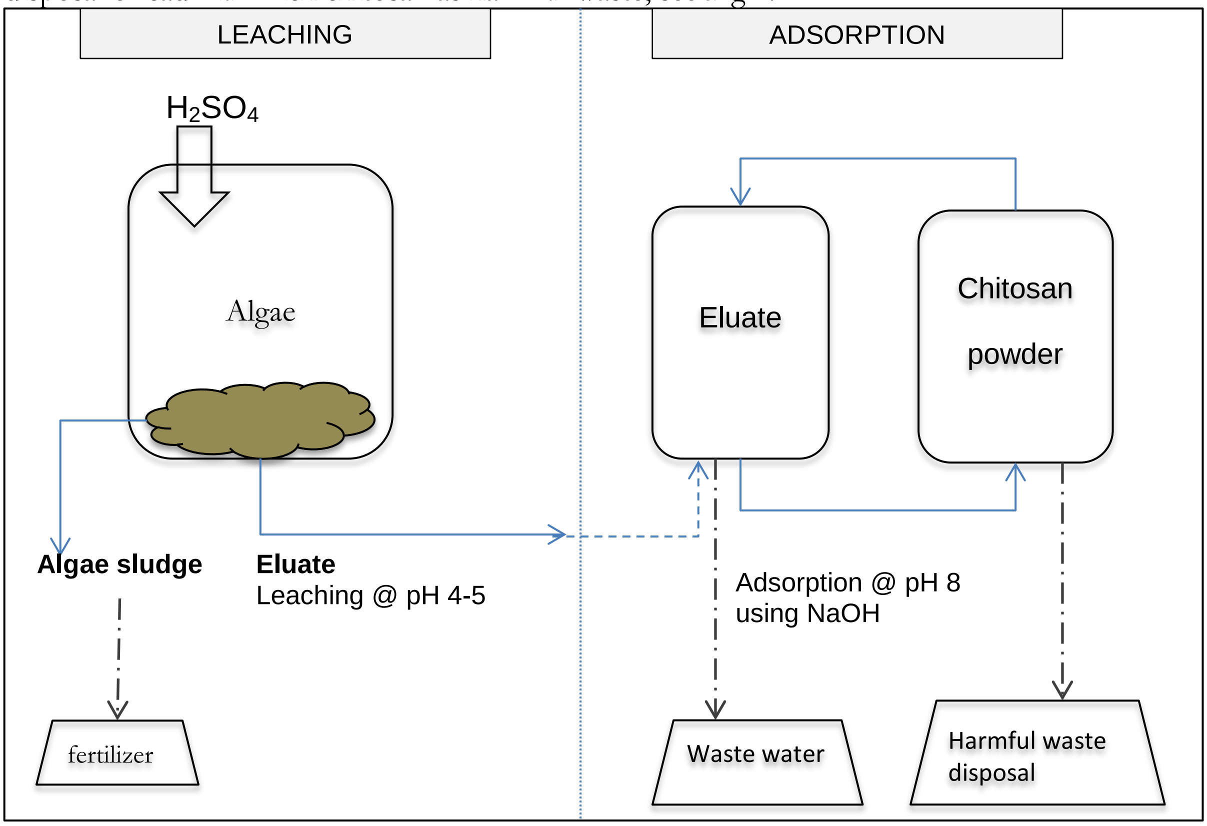


Figure 2 Schematic presentation of tested cadmium removal system in digestion of beach algae.

Algae were taken from a sandy beach of Smygehuk (Municipality of Trelleborg) 2013-05-31 and were stored in 10 liter PE buckets with lid to simulate an anaerobic digestion process until 2013-09-01. The experimental procedure was hereafter performed with three independent replicates, each algae sample taken from a separate bucket of algae. The weight of algae was measured to 300 gram (+/- 1 g) and tap-water was added to a total volume of 1,0 l. The algae were acidified using 1 M H_2SO_4 where the approximate volume had been estimated in forehand on similar mass of algae needed to reach pH 4. The choice of pH 4 as leaching pH was based on the assumption that this would be a pH that could be reached in large scale systems using cheap acids or addition of acidic substrates such as whey. If lower pH would be used, the system would be more expensive, both from acid cost and from the cost of base for neutralization. The algae were leached for 24 hours. Algae and leachate was separated with a 0.5 mm nylon mesh using hand-pressure. The pH of the leachate was raised to pH 8.0 using 1 M NaOH. Total volume of leachate was 0.53 – 0.6 litre. 6.0 gram chitosan (Sigma Aldrich # C3646-25G) was added to the leachate and the solution was stirred gently 14 hours using a magnetic stirrer. The leachate was separated from the chitosan using a glassfiber filter (GF/F) and vacuum. Samples were taken from all steps of the procedure (both liquid and solid phase) and sent to accredited laboratory for analysis of cadmium, nitrogen, phosphorus, dry weight and ash-content.

Figure 3 Experimental set-up of acid leaching of algae

Experimental results and discussion

The algae used had high concentrations of cadmium (3.6 mg/kg DS) compared to the mean value of reported cadmium concentration in beach algae (1.2 mg/kg DS), see table 6. This could partly be explained by the long period of bacterial digestion during the summer since the ash content was higher (56 %) compared to the average value (36 %) in table 1. This fact can also partly explain the high degree of dissolved ammonium in the algae at start (8.6 g/kg DS) and the loss during filtering in the leaching step.

Table 6. Summary of analysis results in the cadmium removal system (lab-scale). All concentrations for solids are per dry weight. Ptot is total conc. of phosphorus, Ntot is total conc. of nitrogen and NH4-N is conc. of ammonium nitrogen. DS is dry substance, VS is volatile substance

	Cadmium		DS		VS	pH		Ptot	Ntot	NH4-N
	Mean	SD	Mean (%)	SD	(% of DS)	Mean	SD	g/kg	g/kg	
Algae before anaerobic digestion	3.63 mg/kg	0.25	13.10	0.73	44.7			4.3	38	8.6
Algae after anaerobic digestion	3.28 mg/kg	0.87	16.90	4.13	46.8	4.85	0.1	1.6	32	3.8
Leachate before chitosan adsorption	30.17 µg/l	8.04	2.43	0.12		7.33	0.26			
Leachate after chitosan adsorption	3.34 µg/l	1.33	0.83	0.12		7.03	0.25			
Chitosan before adsorption	<0.005 mg/kg		89.10	n/a						
Chitosan after adsorption	1.36 mg/kg	0.73	15.23	1.46						
Key figures										
Removal of Cd in algae with acid	10%									
Removal of Cd in eluate with chitosan	83%									

The system did not adsorb cadmium in such a degree that the system could be used for practical treatment of cadmium contaminated algae. The concentration of cadmium in the algae was still above the limit for use in farming (2 mg/kg DS). The actual capacity of the chitosan was probably not reached due to the low concentration of cadmium in the leachate, but on the other hand the residual concentration in the leachate was so high that it could be a problem to connect it to a STP. The costs of chitosan with low cadmium concentrations (~30 €/kg) are also very high compared to the low cadmium removal since it would require ~441 ton of chitosan to remove 600 gram of cadmium (from table 2), with the capacity found here. There will also be a disposal cost of this waste as well as for the treated algae and leachate. The chosen pH for leaching in this experiment could be decreased since the solubility of cadmium is pH dependent, especially when it is bound in organic tissue. However, the amount of acid and base for leaching and neutralization and the equipment for this is a big problem.

Our conclusion, using realistic values on leaching pH and the natural cadmium concentrations in beach algae, is that this method is not a solution to the problem with cadmium in beach algae. The efficacy is too low and the costs are too high. The reason that several other authors report high degree of cadmium removal using chitosan is primarily that they use much higher concentration (0.1-0.5 g Cd/liter) in their experiments then found in nature (30 µg Cd/liter in this experiment). The secondary reason is that the reported parameter, in tests with natural concentrations, is percent removed Cd in leachate which often is high - but the absolute uptake is still small since the concentration is low.

Fate of the algae mass in different systems

Directly collected algae

The algal mass after collection can now be recirculated to the sea. It is not possible to landfill the algae, due to the organic content. It can be incinerated with heat recovery, but the mass has to be dried before it can give net energy during combustion.

The algae can, at least after some time of composting, be spread on farmland. This was common in older days, but is not normal today. The content of Cd is in some batches over the limits of today, and in most batches over the expected limits for use on farmland. The content of phosphorous is low, and phosphorous is probably slowly released. The high ratio Cd/P means that the interest of the material as a fertilizer is probably very low. The content of salt as such can also restrict the kinds of crop that can be cultivated in algae fertilized soil (2).

It is possible to spread the algae directly as a fertilizer in willow plantations. Willow is effective in accumulating cadmium, and most of the added cadmium will end up in the ashes after combustion of the willow. The expected slow release of nutrients from the untreated algae will probably be a problem.

Algae after processing

Algae after processing (anaerobic digestion or composting) cannot any more be dumped at sea, and still not be landfilled. It is possible to incinerate it, but it contains less organic material than the original algae. It has to be dried even longer to give net energy during combustion.

If there is no special step to reduce the content of cadmium, the residue will contain higher levels of cadmium than before treatment. This is because organic material but not cadmium is removed in the processing. Cadmium content would stop spreading on farmland.

With leaching of cadmium before or after digestion the cadmium content can be reduced by at least 75 % (2). This would give some margin to the expected limit 1 mg Cd/kg DS. However, at least acidic extraction will also reduce the content of phosphorous (9), and the ratio Cd/P would still be much higher than the limit for imported fertilizers.

The possibility to use digested algae, without cadmium removal, as a fertilizer in willow plantations (energy crop) has been discussed (5). It was estimated that an area of about 20 000 ha would be needed to make use of all the algae in the Trelleborg area. During combustion of the willow there will be some separation of phosphorous and cadmium in different fractions of ashes, dependent on type of incineration. The low cadmium fraction might be used as fertilizer in forests.

As a conclusion it is very unlikely that someone will pay for the digestion residue, due to the low content of phosphorous and high ratio Cd/P. Disposal on non-farmland or possibly energy crops is most likely.

Possible methods for treatment

The main idea for utilization of the algae was from start of the project to digest it to biogas, and use the residue as fertilizer. However, this doesn't seem to be the best way, and certainly not an economic possibility compared to the value of biogas and fertilizer. Some different treatment solutions are discussed here. They all start with the harvested algae close to the shore.

1. As today, return the algae to the sea.
2. Disintegration in water, conventional one stage digestion, biogas utilization, disposal of digester residue.
3. Disintegration in water, co-digestion with low cadmium material, biogas utilization, digester residue as fertilizer.
4. Leaching to remove cadmium, conventional one stage digestion, biogas utilization, digester residue as fertilizer, leaching water treatment, disposal of cadmium rich waste.
5. Dry digestion in two stages, biogas utilization, disposal of digester residue.
6. Composting, disposal of the compost.
7. Drying, incineration, ash disposal.

All methods have advantages and disadvantages. Some figures and costs are given in Appendix 2.

Comments to the different methods

Method 1. Collection and return to sea

This is the simplest method, but it is **dependent on prolonged permission** to discard the biomass to sea. Collecting more algae than today will not improve the touristic value much, but increase the cost for collection.

Method 2. Collection and one stage digestion

Digestion of this material separately will be expensive due to the small scale and low yield. It will be difficult to get rid of the digestion residue, with higher cadmium content than the original material.

Method 3. Collection and co-digestion

This is the normal method for a relatively small amount of substrate, but regulations about metal content in substrate makes it impossible in a plant that spread the residue on farmland. Theoretically this would have been the most economic method, **but it is not legal**. It would also have meant that cadmium from the sea was transferred to the food chain on land.

Method 4. Collection, leaching of cadmium and co-digestion

Removal of cadmium from the algal mass can be achieved at low pH. After separation of the acid, cadmium can be precipitated or removed from the water phase in different ways. The washed algal mass can then be co-digested in a larger biogas production unit without problems with cadmium. Severe problems are the **great demands for acid and alkali, and handling of the cadmium rich residue**. With the methods tested so far, the leaching of cadmium is very expensive.

Method 5. Collection and two stage digestion

The collected algae are mixed with straw as structure material. The material is spread in large covered basins and water is percolated through the bed to a biogas reactor where methane is formed. The system is simple and not sensitive to sand in the material. Biogas yield is however very low and the residue will still contain too much cadmium to be used on farmland. The question is if the small amount of biogas can pay for the investment, compared to other ways to get rid of the material.
This method will be tested by Norup Bioraff AB in a project with Trelleborg municipality (Gradin 2013). The treatment will depend on cadmium concentration in each batch.

Method 6. Collection and composting

The collected algae are mixed with straw as structure material, and probably horse manure for inoculation of bacteria. It is composted in strings, and turned once or twice during the season. This will stabilize the algal material to some extent, but the ready compost will still have a high concentration of cadmium. There will be no biogas and a great risk of odour during treatment.
Composting has been tested several times (Thorén 2013), and shown to be difficult. It is difficult to get air into the compost in spite of mixing with other material. There is also no market.
The waste management plant SYSAV will not take the material for composting.

Method 7. Collection, drying and incineration

The collected algae are spread over a hard surface in a thin layer to air-dry. After at least 50 % DS is reached the material with as little sand as possible is transported to incineration for district heating in Malmö. The ashes with cadmium will be handled with the other incineration ashes, and removed from circulation.

Suggested methods for treatment

Important criteria for interesting methods are:

1. According to laws and regulations now and in some years to come
2. Cadmium and nutrients should be extracted from the sea
3. Cadmium should be removed from circulation
4. The energy content should be used
5. Nutrients in the algae should be used
6. The cost in money and other resources has to be reasonable

Criterion 1 stops methods 1 and 3.
All other methods comply with criterion 2.
Criterion 3 is best fulfilled with method 7, where all cadmium will be trapped in fly ash that will be safely stored. Also in method 4 most of the cadmium will be safely stored, out of circulation. For methods 2, 5 and 6 the removal depends upon where the treated residue will end up. A problem here is to get reliable concentration figures in the inhomogeneous material. If it is used as soil replacement in non-farmland, there is a risk of spreading to soil and water. If it is used in Salix plantations most of it can be trapped in the combustion ashes, but this is another treatment step and adds very little phosphorous to the plantation.
Criterion 4 is best met by methods 2 and 4, but to a high cost. Method 5 gives some biogas, but this is a small part of the total energy content. Method 6 gives no useful energy at all. Method 7 gives some heat and electric energy, dependent on the moisture content at incineration.
Criterion 5 is best met by method 4, but to a high cost and with reduced amounts of phosphorous. For methods 2, 5 and 6 some utilization is possible.
Criterion 6, including cost, is difficult to discuss with the often very rough cost estimates in Appendix 2. However, with the methods discussed here it is obvious that not more algae than today should be harvested from the shore. Harvesting cost for more material is much higher than the venue in form of touristic value. This is true even with the highest value set on removal of nutrients from the sea. The cost for treatment in the different methods is relatively small compared to these figures.
The simplest methods (except for 1) are number 5 and 7. The low yield of biogas and expected problems to use the residue in method 5 (dry digestion) is a problem. However, the method will be tested in large scale. Composting in method 6 seem to be very difficult in practice, has the same residue problem and no energy extracted. It is in practice not realistic to use land for this treatment.
Method 7, with partial drying and incineration for district heat and electricity, seem to be the most interesting way to handle the material. The incineration is no problem (26), but there are restrictions. The dry content has to be at least 50%, the amount of sand has to be minimized, and the odour in connection to the incineration has to be low. The amount of sand in the material is very dependent on the harvesting method, and also the drying procedure. Larger pieces of algae or seaweed dry very fast in air, even in several centimeter thick layers. Under indoor conditions during 5 days and one turning of the material the dry content went from 16 to over 90% dry matter. A simple drying procedure in a drum or on a hard surface during summer seems to be enough. Possible problems can be drying of material with less structure, and the separation of dried algae and sand.
The second interesting option would be method 4 with separation of cadmium and then co-digestion with other material. However, both leaching and collection of the separated cadmium in a small fraction seem to be difficult. Large resources in the form of chemicals will be needed in a relatively complicated process. The economical estimations in Appendix 2 are rough, but they point to an expensive process.

Acknowledgments

Thanks to *Trelleborg kommun* and *Norup Bioraff AB* for a study visit at their algae digestion plant in Smygehuk. Thanks to *Räkor och laxgrossisten AB* for supplying shrimp-shells.

References

1. Åsa Davidson, Detox AB: Tång och alger som en naturresurs och förnyelsebar energikälla. (Seaweed and algae as a natural resource and renewable energy source) Report Step 1 to Trelleborgs municipality 2007.

2. Åsa Davidsson och Eva Ulfsdotter Turesson, Detox AB: Tång och alger som en naturresurs och förnyelsebar energikälla. (Seaweed and algae as a natural resource and renewable energy source) Report Step 2 to Trelleborgs municipality 2008.

3. Anders Dahl, Bertil Siversson och Emelie Persson, BioMil AB: Utredning avseende uppstart av befintlig biogasanläggning på Smygehamns avloppsreningsverk för rötning av tång och alger. (Investigation of potential to modify the present digester at Smygehamn STP for degradation of seaweed and algae) 2009.

4. Norup Bioraff AB: Algae fermentation in Pilot biogas plant – final report. 2013.

5. Kristoffer Bergström: Impact of Using Macroalgae from the Baltic Sea in Biogas Production: A review with Special Emphasis on Heavy Metals. Mastersarbete at Linnéuniversitetet nr 2012:Bi4, 2012.

6. Final report from Wetlands Algae Biogas (WAB), A Baltic Sea Eutrophication Counterpart Project, 2012.

7. Naturvårdsverket: Hållbar återföring av fosfor. (Sustainable recirculation of phosphorous) Rapport 6580 September 2013.

8. Haghighatafshar, S., Kjerstadius, H., La Cour Jansen, J. and Davidsson, Å. :"Mangement of hydrogen sulphide in anaerobic digestion of enzyme pretreated marine macro-algae", Vatten 68:4 (2012) p. 265-273.

9. Mats Ek: Hur kan man skilja kadmium från fosfor i makroalger och tång? (How to separate cadmium from phosphorous in algae and seaweed?) Internal report 2013.

10. SMP, Svenska Miljörapporteringsportalen. www.naturvardsverket.se.

11. Tullstorpsprojektet. www.tullstorpsan.se.

12. www.balticsearevival.se.

13. IEA Bioenergy, Task 37: Energy from biogas and landfill gas. October 2009.

14. Biogas Syd: Gårdsbaserad biogasproduktion – Lönsamhetsberäkningar (Farm based biogas production – Calculations of profitability), June 2010. www.biogassyd.se

15. Jogbratt, A.: Kadmium som begränsande faktor för användande av tång som biogassubstrat – en laborativ undersökning. (Cadmium as a limiting factor for the

use of seaweed as substrate for biogasproduction – experimental study), bachelor's thesis at Högskolan i Halmstad 2011.

16. Anna Hansson, Biogas Syd, personal communication 2013.

17. Bertil Siversson, operator of the Norup plant in Smygehamn, personal communication November 2013.

18. Planned biogas production, www.solrodbiogas.dk

19. Nkemka, Valentine Nkongndem, and Marika Murto. 2010. "Evaluation of Biogas Production from Seaweed in Batch Tests and in UASB Reactors Combined with the Removal of Heavy Metals." Journal of Environmental Management 91 (7) (July): 1573–1579. doi:10.1016/j.jenvman.2010.03.004.

20. Babel, Sandhya, and Tonni Agustiono Kurniawan. 2003. "Low-Cost Adsorbents for Heavy Metals Uptake from Contaminated Water: A Review." Journal of Hazardous Materials 97 (1): 219–243.

21. Bailey, Susan E., Trudy J. Olin, R.Mark Bricka, and D.Dean Adrian. 1999. "A Review of Potentially Low-Cost Sorbents for Heavy Metals." Water Research 33 (11) (August): 2469–2479. doi:10.1016/S0043-1354(98)00475-8.

22. Demirbas, Ayhan. 2008. "Heavy Metal Adsorption onto Agro-Based Waste Materials: A Review." Journal of Hazardous Materials 157 (2): 220–229.

23. Bailey, Susan, Trudy J. Olin, and R. Mark Bricka. 1997. "Low-Cost Sorbents: A Literature Summary." DTIC Document. http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA326511.

24. Benguella, B., and H. Benaissa. 2002. "Cadmium Removal from Aqueous Solutions by Chitin: Kinetic and Equilibrium Studies." Water Research 36 (10): 2463–2474.

25. Gradin 2013. Contract between Trelleborg municipality and Norup BioRaff AB according to Matilda Gradin, Trelleborgs municipality 2013.

26. Thorén 2013. Personal communication with Ann Thorén, SYSAV 2013.

27. Bergström, K. 2012. "Impact of Using Macroalgae from the Baltic Sea in Biogas Production: A Review with Special Emphasis on Heavy Metals". Master degree, LNU. http://lnu.diva-portal.org/smash/record.jsf?pid=diva2:541578

28. Gradin, Matilda, and Ellinor Tjernström. 2012. "Techniques for Collecting Algae in Sopot and Trelleborg". Powerpoint presented at the Wetlands-Algae-Biogas. http://wabproject.pl/files/file/pdfwab/Municipality%20of%20Trelleborg.pdf .

29. Karlsson, Sara. 2009. "Sustainable Use of Baltic Sea Natural Resources Based on Ecological Engineering and Biogas Production : System Analysis and Case Study Trelleborg". Student report, Stockholm: KTH Royal Institute of Technology. http://www.diva-portal.org/smash/record.jsf?pid=diva2:555405

30. Kelly, MS, and S Dworjanyn. 2008. "The Potential of Marine Biomass for Anaerobic Biogas Production: a Feasibility Study with Recommendations for Further Research." Scotland: Scottish Association for Marine Science.

31. Melin, Ylva. 2001. "Alternativ Användning Av Marina Fintrådiga Alger". 2001:41. Länstyrelsens Rapportserie. Göteborg: Länsstyrelsen Västra Götaland.

32. Hansson, G. 1983. "Methane Production from Marine, Green Macro-Algae." *Resources and Conservation* 8 (3): 185–194.

33. Nkemka, Valentine, and Marika Murto. 2011. *Torrötning Av Musslor Och Vass i Två-stegsprocess*. Slutrapport. Lunds Universitet, Dept. of Biotechnology.

34. Briand, Xavier, and Philippe Morand. 1997. "Anaerobic Digestion of Ulva Sp. 1. Relationship between Ulva Composition and Methanisation." *Journal of Applied Phycology* 9 (6): 511–524.

35. Norén, Fredrik, Kåre Tjus, and Uwe Fortkamp. 2013. "Full-Scale Site Solution of Phosphorous Retrieval from Biowaste - Make Way for Recycling of Cadmium Contaminated Biowaste as Phosphorous Fertilisation - Short Literature Summary". U4184. Stiftelsen IVL Report Series. Stockholm: SIVL. http://sivl.ivl.se/download/18.372c2b801403903d2751d16/1378129494673/U4184+PhosCAd+short+litteratury+summary.docx

36. Kalmykova, Yuliya. 2009. *Alternative sorption materials for contaminated water treatment.* Göteborg: Chalmers Univ. of Technology.

37. Kalmykova, Yuliya, Ann-Margret Strömwall, and Britt-Marie Steenari. 2008. "Alternative Materials for Adsorption of Heavy Metals and Petroleum Hydrocarbons from Contaminated Leachates." *Environmental Technology* 29 (1): 111–122.

38. Nkemka, Valentine Nkongndem. 2012. "Two-Stage Conversion of Land and Marine Biomass for Biogas and Biohydrogen Production". PhD dissertation, Lund: Lund University.

39. Malm, Torleif, Sonja Råberg, Sabine Fell, and Per Carlsson. 2004. "Effects of Beach Cast Cleaning on Beach Quality, Microbial Food Web, and Littoral Macrofaunal Biodiversity." Estuarine, Coastal and Shelf Science 60 (2) (June): 339–347. doi:10.1016/j.ecss.2004.01.008.

40. Lavery, P., S. Bootle, and M. Vanderklift. 1999. "Ecological Effects of Macroalgal Harvesting on Beaches in the Peel-Harvey Estuary, Western Australia." Estuarine, Coastal and Shelf Science 49 (2): 295–309

41. Weslawski, Jan Marcin, Barbara Urban-Malinga, Lech Kotwicki, Krzysztof Opalinski, Maria Szymelfenig, and Marek Dutkowski. 2000. "Sandy Coastlines-are There Conflicts Between Recreation and Natural Values?" *Oceanological Studies* 29 (2): 5

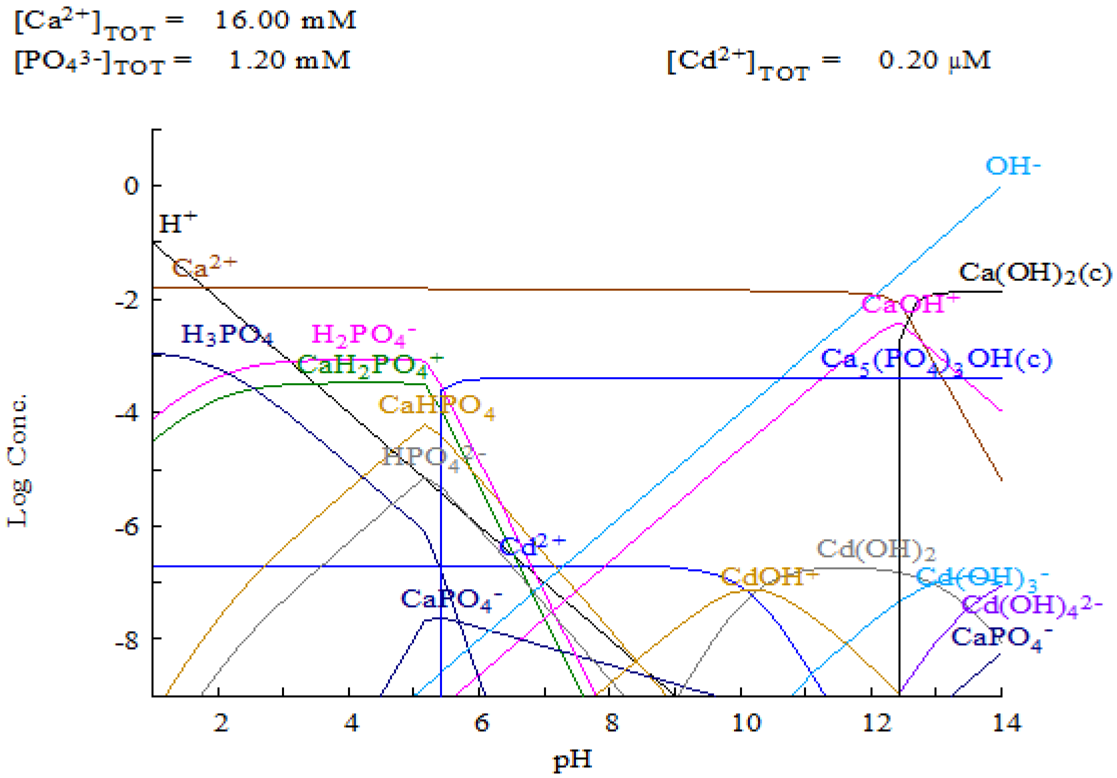
42. Troell, Max, P. Leif, Patrik Rönnbäck, Håkan Wennhage, Tore Söderqvist, and Nils Kautsky. 2004. When Resilience Is Undesirable: Regime Shifts and Ecosystem Service Generation in Swedish Coastal Soft Bottom Habitats. Beijer International Institute of Ecological Economics. http://geminis.dma.ulpgc.es/profesores/personal/jmpc/Master08(PrimeraEdici%F3n)/Resiliencia/Resili12s.pdf

43. Morand, Philippe, and Xavier Briand. 1999. "Anaerobic Digestion of Ulva Sp. 2. Study of Ulva Degradation and Methanisation of Liquefaction Juices." Journal of Applied Phycology 11 (2): 164–177

44. Bladh, Martin, Fredrik Löfstrand, Henrik Pernmyr, Rita B. Jönsson, and Carina Pålsson. 2011. Restriktioner Vid Nyttjande Av Marina Substrat För Biogasproduktion2011:12. Meddelandeserien. Länsstyrelsen i Kalmar län

Appendix 1.

Equilibrium diagram with realistic concentrations in the leachate, according to the Medusa program.



Cost and Benefit Analysis of Technological Solutions

PhosCad

Appendix 2:

Contents

Background and summary

The Cost and Benefit Analysis (CBA) provides an assessment of the technological solutions for removing the algae, recycling of phosphorous, reducing the level of cadmium and utilizing the residue for production of biogas and as fertilizer identified in the technical feasibility and ecological assessment study (See Appendix 1).

The analysis takes into account costs for collecting and reallocating the algae (2 000 m^3 and 10 000 m^3), investment costs (i.e. investments in new installations/plants), operational costs (e.g. costs for digestion, leaching, drying and disposal of residue/waste) and environmental cost (e.g. spreading of cadmium to soil and groundwater). Estimated costs for equipment and operation are rough and mainly given as examples of costs. Transport costs and buildings are not included in the analysis. The analysis takes into account benefits in the form of total municipal tax revenue (i.e. beach related tourism), output of biogas, output of fertilizer (i.e. digester residue which contains phosphorus and can be recirculated to farmland) and environmental benefits (i.e. reduced Cd, P and N in the sea).

The municipal tax revenue from beach related tourism is a key benefit. Total tourism related tax revenue in Trelleborg amount to 35 million SEK per year (Resurs AB, 2012). A study conducted by Sweco (2012) was able to make a rough estimate of the beach related tourism in the same municipality for 2010. Using the same assumptions as in the Sweco report the beach related tourism turnover was 42 % of the total tourism turnover in 2011. The CBA is based on the assumption that 42 % of the total tourism tax revenue comes from beach related tourism, i.e. 14.7 million SEK (0,42 x 35 million SEK) of the total tax revenue emanated from beach related tourism in 2011. The municipality of Trelleborg assumes that the beaches could not be used for recreational activities or tourism if the algae were not removed, i.e. the tax revenue from beach related tourism would almost or completely disappear. Quite possibly, however, beach related tourism would not completely disappear, i.e. some tourists would still frequent the beaches, as well as non-beach related tourism could possibly gain, e.g. tourists would visit other attractions instead. The conclusion is that the benefit, in the form of beach related municipal tax revenues most likely is overestimated.

An increase of the amount of algae collected (from 2 000 m^3 to 10 000 m^3) will not lead to increased tourism (beach related), since the additional amount of algae will be collected from beach areas which are not frequented by tourists.

Technology	Costs SEK/year (2000m^3)	Benefits SEK/year (2000m^3)	Costs SEK/year (10 000m^3)	Benefits SEK/year (10 000m^3)
Alternative 1	4,000,000	14,700,000	20,000,000	14,700,000
Alternative 2	4 499 000	15 210 000 - 16 965 000	20 845 000	17 247 000 - 25 977 000
Alternative 3	4 007 000	15 219 000 - 16 974 000	20 035 000	17 292 000 - 26 022 000
Alternative 4	4 843 000	15 207 000 - 16 962 000	22 990 000	17 232 000 - 25 962 000
Alternative 5	7 330 000	15 147 600 - 16 902 600	26 670 000	16 935 000 - 25 665 000
Alternative 6	4 000 000	15 145 000 - 16 900 000	20 000 000	16 922 000 - 25 652 000
Alternative 7	4 150 000	15 145 000 - 16 900 000	20 750 000	16 922 000 - 25 652 000

Comparison of methods

Method 1: Collect and reallocate the algae (Business-as-usual)

Currently the municipality collects approximately 2 000 m^3 (app. 100 tons) of algae from the beach recreation areas and pleasure boats harbours, and reallocate the algae to beach areas that are not used during the tourism seasons. During the autumn, after the tourism season, the algae are discharged in the sea.

Table 1. Amount of algae - 2 000 m^3 (app. 100 tons)

Costs		Benefit	
Collect and reallocate algae	4 million SEK/year[1]	Total municipal tax revenue (beach related tourism)	14,7 million SEK/year[2]
Total SEK/year	**4 000 000**	**Total SEK/year**	**14 700 000**

1 Current costs for the municipality (Trelleborg, 2012)

2 Total tourism related tax revenue 35 million SEK per year (Resurs AB, 2012). According to estimates 42 % of the tourism is beach related (Sweco, 2012). 35 million SEK x 0,42 = 14,7 million SEK per year.

Table 2. Amount of algae – 10 000 m^3 (app. 500 tons)

Costs		Benefit	
Collect and reallocate algae	20 million SEK/year[1]	Total municipal tax revenue (beach related tourism)	14,7 million SEK/year[2]
Total SEK/year	**20 000 000**	**Total SEK/year**	**14 700 000**

1 Current costs for the municipality (Trelleborg, 2012). 4million SEK x 5 = 20 million SEK/year

2 Total tourism related tax revenue 35 million SEK per year (Resurs AB, 2012). According to estimates 42 % of the tourism is beach related (Sweco, 2012). 35 million SEK x 0,42 = 14,7 million SEK per year. An increase of the amount of algae collected (from 2 000 m^3 to 10 000 m^3) will not lead to increased tourism (beach related), since the additional amount of algae will be collected from beach areas which are not frequented by tourists.

Method 2: Disintegration in water, conventional one stage digestion, biogas utilization, disposal of digester residue.

This method entails collecting algae from the beach bathing areas and harbours for pleasure boats and transporting it to a reactor installation (new investment in reactor and burner is needed). At the reactor installation site the algae are disintegrated in water and then undergo conventional one stage digestion, in order to produce biogas. The process water will be contaminated and needs to be treated. The digester residues contain low levels of phosphorous and have a high ratio Cd/P, which means disposal on non-farmland or possibly energy crops is most likely.

Table 1. Amount of algae – 2 000 m^3 (app. 100 tons)

Costs		**Benefit**	
Collect algae	4 million SEK/year[1]	Total municipal tax revenue (beach related tourism)	14,7 million SEK/year[2]
Investment in reactor and burner	370 000 SEK/year[3]	Production of biogas	65 000 SEK/year[4]
Dewatering and storage	90 000 SEK/year[5]	Reduced P in the sea	125 000-510 000 SEK/year[6]
Operating cost digester and dewatering (except heating)	26 000 SEK/year[7]	Reduced N in the sea	320 000-1 690 000 SEK/year[8]
Heating of digester	13 000 SEK/year[9]		
Possible spreading of Cd to soil and groundwater.	Negative impact on environment and health.		
Total SEK/year	**4 499 000**	**Total SEK**	**15 210 000 – 16 965 000**

1 Current costs for the municipality for collecting 2 000 m^3 is 4 million SEK/year (Trelleborg, 2012).

2 Total tourism related tax revenue 35 million SEK per year (Resurs AB, 2012). According to estimates 42 % of the tourism is beach related (Sweco, 2012). 35 million SEK x 0,42 = 14,7 million SEK per year. .

3 Investment in reactor and burner (260 m^3) approximately 2.9 million SEK. Economic lifetime 10 years and depreciation 370 000 SEK per year (Biogas Syd, 2010).

4 Approximately 13 000 m^3 methane, 130 000 kWh. Maximum value for heating 0, 5 SEK/kWh (Biogas Syd, 2010)

5 Screen filter and 100 m3 concrete basin, investment approximately 0.9 MSEK, depreciation 90 000 SEK year (Personal communication suppliers, 2013)

6 Calculated marginal cost for phosphorus reduction – source sewage plant (Gren et al, 2008)

7 Approximately 20 % of value of biogas in bigger plants but here at least twice as much (Biogas Syd, 2010)

8 Calculated marginal cost for nitrogen reduction – source sewage plant (Gren et al, 2008)

9 Approximately 20 % of produced biogas (Biogas Syd, 2010)

Table 2. Amount of algae - 10 000 m^3 (app. 500 tons)

Costs		**Benefit**	
Collect algae	20 million SEK/year[1]	Total municipal tax revenue (beach related tourism)	14,7 million SEK/year[2]
Investment in reactor and burner	500 000 SEK/year[3]	Production of biogas	325 000SEK/year[4]
Dewatering and storage	200 000 SEK/year[5]	Reduced P in the sea	622 000-2 552 000 SEK/year[6]
Operating cost digester and dewatering (except heating)	80 000 SEK/year[7]	Reduced N in the sea	1,6-8,4 million SEK/year[8]
Heating of digester	65 000 SEK/year[9]		
Possible spreading of Cd to soil and groundwater.	Negative impact on environment and health.		
Total SEK/year	**20 845 000**	**Total SEK**	**17 247 000 - 25 977 000**

1 Current costs for the municipality for collecting 2 000 m^3 is 4 million SEK/year (Trelleborg, 2012). 4million SEK x 5 = 20 million SEK/year

2 Total tourism related tax revenue 35 million SEK per year (Resurs AB, 2012). According to estimates 42 % of the tourism is beach related (Sweco, 2012). 35 million SEK x 0,42 = 14,7 million SEK per year. An increase of the amount of algae collected (from 2 000 m^3 to 10 000 m^3) will not lead to increased tourism (beach related), since the additional amount of algae will be collected from beach areas which are not frequented by tourists.

3 Investment in reactor and burner 1 300 m^3 approximately 4 million SEK. Economic lifetime 10 years and depreciation 500 000 SEK per year (Biogas Syd, 2010).

4 Approximately 65 000 m^3 methane, 650 000 kWh. Maximum value for heating 0, 5 SEK/kWh (Biogas Syd, 2010)

5 Screen filter and 500 m3 concrete basin, investment approximately 2 MSEK, depreciation 200 000 SEK year (Personal communication suppliers, 2013)

6 Calculated marginal cost for phosphorus reduction – source sewage plant (Gren et al, 2008)

7 Approximately 20 % of value of biogas, but probably higher (Biogas Syd, 2010)

8 Calculated marginal cost for nitrogen reduction – source sewage plant (Gren et al, 2008)

9 Approximately 20 % of produced biogas (Biogas Syd, 2010)

Method 3: Disintegration in water, co-digestion with low cadmium material, biogas utilization, digester residue as fertilizer.

This method entails collecting algae from the beach bathing areas and harbours for pleasure boats and transporting it to a biogas plant (new investment is not needed – the biogas will be produced in an existing plant). At the biogas plant the algae is disintegrated in water and then undergoes co-digestion with a great amount of low cadmium material (e.g. farmland residues). The digester residues can be recirculated to farmland, however the residue still contain all algae cadmium and small amounts of phosphorous, which means new cadmium will be introduced to the food chain without much input of phosphorus.

This method remains a theoretical alternative but not a real option. Since good digester residue from other sources will be contaminated with cadmium when co-digested with the algae, in practice it is very difficult to find an installation/plant which accepts the algae material.

Table 1. Amount of algae – 2 000 m^3 (app. 100 tons)

Costs		Benefit	
Collect algae	4 million SEK/year[1]	Total municipal tax revenue (beach related tourism)	14,7 million SEK/year[2]
Operating cost digester	7 000 SEK/per year[3]	Production of biogas	70 000 SEK/year[4]
New cadmium will be introduced to the food chain without much input of phosphor	Negative impact on environment and health.	The digester residue, which contain phosphorus content, can be recirculated to farmland	4 000 SEK/per year[5]
		Reduced P in the sea	125 000-510 000 SEK/year[6]
		Reduced N in the sea	320 000-1 690 000 SEK/year[8]
Total SEK/year	**4 007 000**	**Total SEK/year**	**15 219 000 – 16 974 000**

1 Current costs for the municipality for collecting 2 000 m^3 is 4 million SEK/year (Trelleborg, 2012).

2 Total tourism related tax revenue 35 million SEK per year (Resurs AB, 2012). According to estimates 42% of the tourism is beach related (Sweco, 2012). 35 million SEK x 0,42 = 14,7 million SEK per year.

3 Marginal costs estimated to 10 % of biogas value (Biogas Syd 2010)

4 Approximately 15 000 m^3 methane. Maximum value for heating. (Biogas Syd, 2010)

5 Based upon 20 SEK/kg P in fertilizer, which is high for mixed fertilizer (Brenntag 2013)

6 Calculated marginal cost for phosphorus reduction – source sewage plant (Gren et al, 2008)

7 Calculated marginal cost for nitrogen reduction – source sewage plant (Gren et al, 2008)

Table 2. Amount of algae - 10 000 m^3 (app. 500 tons)

Costs		Benefit	
Collect algae	20 million SEK/year[1]	Total municipal tax revenue (beach related tourism)	14,7 million SEK/year[2]
Operating cost digester	35 000 SEK/per year[3]	Production of biogas	350 000 SEK/year[4]
New cadmium will be introduced to the food chain without much input of phosphor	Negative impact on environment and health.	The digester residue, which contain phosphor content, can be recirculated to farmland	20 000 SEK/per year[5]
		Reduced P in the sea	622 000-2 552 000 SEK/year[6]
		Reduced N in the sea	1,6-8,4 million SEK/year[7]
Total SEK/year	**20 035 000**	**Total SEK/year**	**17 292 000 –** **26 022 000**

1 Current costs for the municipality for collecting 2 000 m^3 is 4 million SEK/year (Trelleborg, 2012). 4million SEK x 5 = 20 million SEK/year

2 Total tourism related tax revenue 35 million SEK per year (Resurs AB, 2012). According to estimates 42% of the tourism is beach related (Sweco, 2012). 35 million SEK x 0,42 = 14,7 million SEK per year. An increase of the amount of algae collected (from 2 000 m^3 to 10 000 m^3) will not lead to increased tourism (beach related), since the additional amount of algae will be collected from beach areas which are not frequented by tourists.

3 Marginal costs estimated to 101 % of biogas value (Biogas Syd 2010)

4 Approximately 75 000 m^3 methane. Maximum value for heating. (Biogas Syd, 2010)

5 Based upon 20 SEK/kg P in fertilizer, which is high for mixed fertilizer (Brenntag 2013)

6 Calculated marginal cost for phosphorus reduction – source sewage plant (Gren et al, 2008)

7 Calculated marginal cost for nitrogen reduction – source sewage plant (Gren et al, 2008)

Method 4: Leaching to remove cadmium, conventional one stage digestion in existing digester, biogas utilization, digester residue as fertilizer, leaching water treatment, disposal of cadmium rich waste

This method entails collecting algae from the beach bathing areas and harbours for pleasure boats and transporting it to a reactor for leaching of cadmium (new investment in reactor installation is needed). In a separate reactor acid and base is used for leaching and precipitation of cadmium and the algae (about 5 000 m^3) then undergo conventional one stage digestion in an existing plant. The leachate is neutralized and the cadmium precipitate needs to be taken care of. The digester residue, which contains phosphorous and low levels of cadmium, can be used as a fertilizer.

Table 1. Amount of algae – 2 000 m^3 (app. 100 tons)

Costs		**Benefit**	
Collect algae	4 million SEK/year[1]	Total municipal tax revenue (beach related tourism)	14,7 million SEK/year[2]
Investment in reactor for leaching of cadmium	110 000 SEK/year[3]	Production of biogas	60.000 SEK/year[4]
Acid and base for leaching and precipitation	400 000 SEK/year[5]	The phosphor content can be recirculated to farmland	2 000 SEK/per year[6]
Operating cost leaching	135 000 SEK/year[7]		
Operating cost digester	6 000 SEK/year[8]	Reduced P in the sea	125 000-510 000 SEK/year[9]
Treatment of 3 000 m^3 neutralized leachate	150 000 SEK/year[10]	Reduced N in the sea	320 000-1 690 000 SEK/year[11]
Disposal of cadmium precipitate	42 000 SEK/year[12]		
Total SEK/year	**4 843 000**	**Total SEK/year**	**15 207 000 – 16 962 000**

1 Current costs for the municipality for collecting 2 000 m^3 is 4 million SEK/year (Trelleborg, 2012).

2 Total tourism related tax revenue 35 million SEK per year (Resurs AB, 2012). According to estimates 42% of the tourism is beach related (Sweco, 2012). 35 million SEK x 0,42 = 14,7 million SEK per year.

3 Investment 1 300 000 SEK. Economic lifetime 10-20 years. Depreciation 110 000 per year, building not included (Personal communication, 2013)

4 About 13 000 m^3 methane. Maximum value for heating (Biogas Syd, 2010)

5 HCl 150 000 SEK/year and NaOH 250 000 SEK/year according to IVL experiments (Reference Brenntag Nordic AB, 2013)

6 Based upon 20 SEK/kg P, and 50 % loss of P in leaching (Lantmännen 2013 and IVL results)

7 Based upon 3 h/d, 150 d/year and 300 SEK/h (IVL, Rough Estimation, 2013)

8 Marginal costs estimated to 101 % of biogas value (Biogas Syd 2010)

9 Calculated marginal cost for phosphorus reduction – source sewage plant (Gren et al, 2008)

10 Connection and treatment fee to the STP, if the residual cadmium can be accepted (Trelleborg STP, personal communication, 2013)

11 Calculated marginal cost for nitrogen reduction – source sewage plant (Gren et al, 2008)

12 Cadmium rich sludge (1.8 ton DS) sent to Sakab, including dewatering to 30% DS (Personal communicationMarina Andersson Sakab, 2013)

Table 2. Amount of algae - 10 000 m³ (app. 500 tons)

Costs		**Benefit**	
Collect algae	20 million SEK/year[1]	Total municipal tax revenue (beach related tourism)	14,7 million SEK/year[2]
Investment in reactor for leaching of cadmium	300 000SEK/year[3]	Production of biogas	300.000 SEK/year[4]
Acid and base for leaching and precipitation	2 million SEK/year[5]	The phosphor content can be recirculated to farmland	10 000 SEK/per year[6]
Operating cost leaching	180 000 SEK/year[7]	Reduced P in the sea	622 000-2 552 000 SEK/year[8]
Operating cost digester	30 000 SEK/year[9]	Reduced N in the sea	1,6-8,4 million SEK/year[10]
Treatment of 15 000 m³ neutralized leachate	280 000 SEK/year [11]		
Disposal of cadmium precipitate	200 000 SEK/year[12]		
Total SEK/year	**22 990 000**	**Total SEK/year**	**17 232 000 –** **25 962 000**

1 Current costs for the municipality for collecting 2 000 m³ is 4 million SEK/year (Trelleborg, 2012). 4million SEK x 5 = 20 million SEK/year

2 Total tourism related tax revenue 35 million SEK per year (Resurs AB, 2012). According to estimates 42% of the tourism is beach related (Sweco, 2012). 35 million SEK x 0,42 = 14,7 million SEK per year. An increase of the amount of algae collected (from 2 000 m³ to 10 000 m³) will not lead to increased tourism (beach related), since the additional amount of algae will be collected from beach areas which are not frequented by tourists.

3 Investment 3 500 000 SEK. Economic lifetime 10-20 years. Depreciation 300 000 per year, building not included (Personal communication, 2013)

4 About 65 000 m³ methane. Maximum value for heating (Biogas Syd, 2010)

5 HCl 750 000 SEK/year and NaOH 1 250 000 SEK/year according to IVL experiments (Reference Brenntag Nordic AB, 2013)

6 Based upon 20 SEK/kg P, and 50 % loss of P in leaching (Lantmännen 2013 and IVL results)

7 Based upon 4 h/d, 150 d/year and 300 SEK/h (IVL, Rough estimation, 2013)

Personal communication, 2013)

8 Calculated marginal cost for phosphorus reduction – source sewage plant (Gren et al, 2008)

9 Marginal costs estimated to 10 % of biogas value (Biogas Syd 2010)

10 Calculated marginal cost for nitrogen reduction – source sewage plant (Gren et al, 2008)

11 Connection and treatment fee to the STP, if the residual cadmium can be accepted (Trelleborg STP, personal communication, 2013)

12 Cadmium rich sludge (9 ton DS) sent to Sakab, including dewatering to 30% DS (Marina Andersson Sakab, personal communication 2013)

Method 5: Dry digestion in two stages, biogas utilization, disposal of digester residue

This method entails collecting algae from the beach bathing areas and harbours for pleasure boats and transporting it to a plant for dry digestion (new investment is needed in construction of a plant suitable for dry digestion). The algae undergo dry digestion in two stages. The cadmium is not removed, but some biogas is formed. The digester residues contain low levels of phosphorous and have a high ratio Cd/P, which mean disposal on non-farmland or possibly energy crops is most likely.

Table 1. Amount of algae – 2 000 m³ (app. 100 tons)

Costs		Benefit	
Collect algae	4 million SEK/year[1]	Total municipal tax revenue (beach related tourism)	14,7 million SEK/year[2]
Construction and running of the plant, disposal of residue	3 330 000 SEK/year[3]	Production of biogas	2600 SEK/year[4]
Possible spreading of cadmium to soil and groundwater	Negative impact on environment and health.	Reduced P in the sea	125 000-510 000 SEK/year[5]
		Reduced N in the sea	320 000-1 690 000 SEK/year[6]
		"Simple" method	Low risk for technical problems
Total SEK	**7 330 000**	**Total SEK**	**15 147 600 – 16 902 600**

1 Current costs for the municipality for collecting 2 000 m^3 is 4 million SEK/year (Trelleborg, 2012).

2 Total tourism related tax revenue 35 million SEK per year (Resurs AB, 2012). According to estimates 42% of the tourism is beach related (Sweco, 2012). 35 million SEK x 0,42 = 14,7 million SEK per year.

3 Cost estimations are here based upon contract with Norup Bioraff AB and a total cost of 5 000 000 SEK for treatment of 500 m^3/year over a period of three seasons. Estimated total cost 10 000 000 SEK for treatment of 2 000 m^3/year over a period of three seasons. The contract includes demolition after the contract time, and gives a high cost since the investment is not fully used (Gradin 2013).

4 About 580 m^3 methane according to tests. Maximum value for heating (Biogas Syd, 2010)

5 Calculated marginal cost for phosphorus reduction – source sewage plant (Gren et al, 2008)

6 Calculated marginal cost for nitrogen reduction – source sewage plant (Gren et al, 2008)

Table 2. Amount of algae - 10 000 m^3 (app. 500 tons)

Costs		Benefit	
Collect algae	20 million SEK/year[1]	Total municipal tax revenue (beach related tourism)	14,7 million SEK/year[2]
Construction and running of the plant, disposal of residue	6 670 000 SEK/year[3]	Production of biogas	13 000 SEK/year[4]
Possible spreading of cadmium to soil and groundwater	Negative impact on environment and health.	Reduced P in the sea	622 000-2 552 000 SEK/year[5]
		Reduced N in the sea	1,6-8,4 million SEK/year[6]
		"Simple" method	Low risk for technical problems
Total SEK	**26 670 000**	**Total SEK**	**16 935 000 – 25 665 000**

1 Current costs for the municipality for collecting 2 000 m^3 is 4 million SEK/year (Trelleborg, 2012). 4 million SEK x 5 = 20 million SEK/year

2 Total tourism related tax revenue 35 million SEK per year (Resurs AB, 2012). According to estimates 42% of the tourism is beach related (Sweco, 2012). 35 million SEK x 0,42 = 14,7 million SEK per year. An increase of the amount of algae collected (from 2 000 m^3 to 10 000 m^3) will not lead to increased tourism (beach related), since the additional amount of algae will be collected from beach areas which are not frequented by tourists.

3 Cost estimations are here based upon contract with Norup Bioraff AB and a total cost of 5 000 000 SEK for treatment of 500 m^3/year over a period of three seasons. Estimated total cost 20 000 000 SEK for treatment of 10 000 m^3/year over a period of three seasons. The contract includes demolition after the contract time, and gives a high cost since the investment is not fully used (Gradin 2013).

4 About 2 900 m^3 methane according to tests. Maximum value for heating (Biogas Syd, 2010)

5 Calculated marginal cost for phosphorus reduction – source sewage plant (Gren et al, 2008)

6 Calculated marginal cost for nitrogen reduction – source sewage plant (Gren et al, 2008)

Method 6: Composting and disposal of the compost

This method entails collecting algae from the beach bathing areas and harbours for pleasure boats and transporting it to an area for composting (new investment is needed in approximately 2 000 and 10 000 m^2 composting area respectively). The algae is mixed with structure material (e.g. straw or bark) and put in piles, which need to be turned sometimes, in order to get even composting. The residues contain low levels of phosphorous and high ratio Cd/P, which mean disposal on non-farmland or possibly energy crops is most likely.

This method remains a theoretical alternative but not a real option, i.e. earlier tests with composting have failed, the material is difficult to compost, and the residue is not possible to sell. SYSAV are not willing to accept the material for composting.

Table 1. Amount of algae – 2 000 m^3 (app. 100 tons)

Costs		Benefit	
Collect algae	4 million SEK/year[1]	Total municipal tax revenue (beach related tourism)	14,7 million SEK/year[2]
Composting and disposal[3]	**Not realistic**	Reduced P in the sea	125 000-510 000 SEK/year[4]
Possible spreading of cadmium to soil and groundwater	Negative impact on environment and health.	Reduced N in the sea	320 000-1 690 000 SEK/year[5]
Total SEK	**4 000 000**	**Total SEK**	**15 145 000 –** **16 900 000**

1 Current costs for the municipality for collecting 2 000 m^3 is 4 million SEK/year (Trelleborg, 2012).

2 Total tourism related tax revenue 35 million SEK per year (Resurs AB, 2012). According to estimates 42% of the tourism is beach related (Sweco, 2012). 35 million SEK x 0,42 = 14,7 million SEK per year.

3 The material is difficult to compost, and the residue is not possible to sell. SYSAV are not willing to accept the material for composting (SYSAV2013a)

4 Calculated marginal cost for phosphorus reduction – source sewage plant (Gren et al, 2008)

5 Calculated marginal cost for nitrogen reduction – source sewage plant (Gren et al, 2008)

Table 2. Amount of algae - 10 000 m^3 (app. 500 tons)

Costs		**Benefit**	
Collect algae	20 million SEK/year[1]	Total municipal tax revenue (beach related tourism)	14,7 million SEK/year[2]
Composting and disposal[3]	**Not realistic**	Reduced P in the sea[4]	622 000-2 552 000 SEK/year
Possible spreading of cadmium to soil and groundwater	Negative impact on environment and health.	Reduced N in the sea[5]	1,6-8,4 million SEK/year
Total SEK	**20 000 000**	**Total SEK**	**16 922 000 – 25 652 000**

1 Current costs for the municipality for collecting 2 000 m^3 is 4 million SEK/year (Trelleborg, 2012). 4million SEK x 5 = 20 million SEK/year

2 Total tourism related tax revenue 35 million SEK per year (Resurs AB, 2012). According to estimates 42% of the tourism is beach related (Sweco, 2012). 35 million SEK x 0,42 = 14,7 million SEK per year. An increase of the amount of algae collected (from 2 000 m^3 to 10 000 m^3) will not lead to increased tourism (beach related), since the additional amount of algae will be collected from beach areas which are not frequented by tourists.

3 The material is difficult to compost, and the residue is not possible to sell. SYSAV are not willing to accept the material for composting (SYSAV 2013a)

4 Calculated marginal cost for phosphorus reduction – source sewage plant (Gren et al, 2008)

5 Calculated marginal cost for nitrogen reduction – source sewage plant (Gren et al, 2008)

Method 7: Drying, incineration and ash disposal

This method entails collecting algae from the beach bathing areas and harbours for pleasure boats and transport it to an area for drying (new investment is needed in large drying areas, up to 50 000 m^2, or in a more compact drying drum). The algae will need to be turned 2-3 times per season, while drying. The dried material will be transported to an incineration plant (new investment is not needed – the incineration will take place in an existing plant). The ashes from the incineration will be needed to be taken care of.

Table 1. Amount of algae – 2 000 m^3 (app. 100 tons)

Costs		Benefit	
Collect algae	4 million SEK/year[1]	Total municipal tax revenue (beach related tourism)	14,7 million SEK/year[2]
Area for drying (50 000 $m^{2)}$	TBC SEK/year[3]	Reduced P in the sea	125 000-510 000 SEK/year[4]
Turning of material	TBC SEK/year[5]	Reduced N in the sea	320 000-1 690 000 SEK/year[6]
Fee for incineration and disposal of ashes	150 000 SEK/year[7]		
Total SEK	**4 150 000**	**Total SEK**	**15 145 000 – 16 900 000**

1) Current costs for the municipality for collecting 2 000 m^3 is 4 million SEK/year (Trelleborg, 2012).

2) Total tourism related tax revenue 35 million SEK per year (Resurs AB, 2012). According to estimates 42% of the tourism is beach related (Sweco, 2012). 35 million SEK x 0,42 = 14,7 million SEK per year.

3) TBC

4) Calculated marginal cost for phosphorus reduction – source sewage plant (Gren et al, 2008)

5) TBC

6) Calculated marginal cost for nitrogen reduction – source sewage plant (Gren et al, 2008)

7) 750 SEK/ton wet material, 50% DS (SYSAV 2013b)

Table 2. Amount of algae - 10 000 m^3 (app. 500 tons)

Costs		**Benefit**	
Collect algae	20 million SEK/year[1]	Total municipal tax revenue (beach related tourism)	14,7 million SEK/year[2]
Area for drying (50 000 m$^{2)}$	TBC SEK/year[3]	Reduced P in the sea[4]	622 000-2 552 000 SEK/year
Turning of material	TBC SEK/year[5]	Reduced N in the sea[6]	1,6-8,4 million SEK/year
Fee for incineration and disposal of ashes	750 000 SEK/year[7]		
Total SEK	**20 750 000**	**Total SEK**	**16 922 000 – 25 652 000**

1 Current costs for the municipality for collecting 2 000 m^3 is 4 million SEK/year (Trelleborg, 2012). 4million SEK x 5 = 20 million SEK/year

2 Total tourism related tax revenue 35 million SEK per year (Resurs AB, 2012). According to estimates 42% of the tourism is beach related (Sweco, 2012). 35 million SEK x 0,42 = 14,7 million SEK per year. An increase of the amount of algae collected (from 2 000 m^3 to 10 000 m^3) will not lead to increased tourism (beach related), since the additional amount of algae will be collected from beach areas which are not frequented by tourists.

3 TBC

4 Calculated marginal cost for phosphorus reduction – source sewage plant (Gren et al, 2008)

5 TBC

6 Calculated marginal cost for nitrogen reduction – source sewage plant (Gren et al, 2008)

7 750 SEK/ton wet material, 50% DS (SYSAV 2013b)

References

Biogas Syd: Gårdsbaserad biogasproduktion – Lönsamhetsberäkningar (Farm based biogas production – Calculations of profitability), June 2010. www.biogassyd.se

Brenntag Nordic AB, price November 2013.

Gradin 2013. Cost for contract with Norup Bioraff AB.

Resurs AB, 2012. TEM rapport Ekonomiska och sysselsättningsmässiga effekter av turismen i Trelleborgs kommun inklusive åren 2008-2011.

SYSAV, 2013a. Personal communication Anders Persson and Ann Thorén, SYSAV.

SYSAV, 2013b. Personal communication Ann-Christine Hallberg, SYSAV.

Sweco, 2012. Stranderosion i Trelleborgs kommun.

Trelleborg, 2012. § 154 Uppförande av Biogasanläggning för insamling, hantering, rötning och omhändertagande av alger vid Smyge reningsverk

SAKAB, 2013. Personal communication Marina Andersson, SAKAB.

Trelleborg STP 2013. Personal communication. MatildaGradin

Trelleborg STP 2013. Connection fees 2013.

Calculation of Environmental Benefits

PhosCad

Appendix 3:

Contents

Introduction

The Calculation of Environmental and Social Benefits describes how the environmental benefits of removing algae from the shore have been calculated.

Removal of the algae is not only important for the tourism industry but also brings about important environmental and social benefits, since the content of phosphorous, cadmium and nitrogen in the algae is extracted from the Baltic Sea. Currently the municipality of Trelleborg collects 2 000m^3 of seaweed and algae from the beaches and harbours. There is a potential up to 200 000 m^3 every year, if algae can be harvested also in shallow water, (Davidsson & Turesson, 2008). However there is no full scale technique for this yet. With available technique it is estimated that about 10 000m^{3}of algae can be removed from the coastline (Davidsson, 2007). Removing 10 000 m^3, instead of 2 000 m^{3,} from the beaches and sea, would not necessary result in increased tourism since the algae would be removed from areas which are not frequented by tourists, but would mean that more phosphorous, cadmium and nitrogen would be extracted from the Baltic Sea.

Calculations

Table 1 shows the amount of cadmium, phosphorous and nitrogen which would be extracted from the sea if 2 000m^3 respectively 10 000m^3 of algae was collected from the beaches and sea (Ek et al, 2013).

Table 1: Removal of Cd, P and N (2 000m^3 and 10 000m^3 of algae)

Removal compounds	Cd (kg/year)	P (kg/year)	N (kg/year)
Removal 2 000 m3/year	-0.12	-220	-2300
Removal 10 000 m3/year	-0,6	-1 100	-11500

In a study conducted by Gren et al. (2008) costs of measures for reducing nitrogen and phosphorus to the Baltic Sea for different target formulations are calculated. Sources of nitrogen and phosphorus compounds are wastewater treatment plants, private sewage and leakage from forest and agricultural land. The measures are categorized as follows:

1) *Reductions in nutrients at the source*, which includes among others nitrogen fertilizers and reductions in livestock (e.g. cattle, pigs, and poultry).

2) *Reductions in leaching of nutrients into soil and water for given nutrient emission levels*, which includes among others, increased area of grass land and cultivation of catch crops.

3) *Reductions in discharges into the Baltic Sea for given emissions at sources and leaching into soil and water* and includes construction of wetlands at river mouths along the coastal water of the Baltic Sea.

The marginal cost for different measures for reducing phosphorus, nitrogen and cadmium depends on the removal compound, e.g. the measures for reducing nitrogen from livestock range from 23-52 Euro while the measures for reducing nitrogen from fertilizer production range from 1-50 Euro.

In the business framework the costs for different measures for reducing phosphorus and nitrogen are used to calculate the benefits for removing the algae. The assumption is that removing the algae, i.e. extracting phosphorus, nitrogen and cadmium from the Baltic Sea, the deduction is that other measures, which otherwise would have been needed for reducing phosphorus and nitrogen, need not to be implemented. Thus the benefits are cost savings, in the form of measures which not need to be implemented, which are calculated using the marginal cost for different measures. Deduces

Table 2 shows the calculated marginal cost per kg nitrogen reduction to the Baltic Sea from Gren et al, (2008), and the benefits from removing 2000m^3 or 10000m^3 algae from the shore in Trelleborg.

Table 2: Marginal costs for nitrogen reduction at emission source and calculated benefits for removing 2 000m^3 or 10 000m^3 of algae

Removal compounds	**Marginal costs* (€$_{2005}$/kgN)**	**Marginal costs (SEK$_{2005}$/kgN)**	**Benefits from removing 2000m^3 (kSEK/year)****	**Benefits from removing 10000m^3 (kSEK/year)*****
NOx	23-40	213-371	490-853	2450-39600
Livestock reductions	23-52	213-3445	490-853	2450-38500
Fertilizer reduction	1-50	9-464	21-1070	107-5340
Sewage treatment	15-79	139-733	320-1690	1600-8430
Private sewers	54-81	201-751	462-1730	2300-8640

* The marginal costs show the reduction to coastal waters

** Marginal cost for relevant measure x amount of nitrogen removed (2 300 kg)

*** Marginal cost for relevant measure x amount of nitrogen removed (11 500 kg)

In the business plan framework the benefits for removing nitrogen are calculated using the marginal cost for sewage treatment, since nitrogen emissions are relevant for Trelleborg sewage treatment plant (See Appendix 1 for more details). Table 2 shows that the marginal cost for measures reducing nitrogen emissions from sewage treatment is 139-733 SEK/ kg N and that the benefits from removing 2000m^3 algae is 320 000-1 690 000 SEK/year. If 10 000m^3 algae are removed the benefit would be between 1.6-8.4 million SEK/year.

Table 3 shows the calculated marginal cost per kg phosphorous reduction to the Baltic Sea from Gren et al, (2008), and the benefits from removing 2000m^3 or 10000m^3 algae from the shore in Trelleborg.

Table 3: Marginal costs for phosphorus reduction at emission source and calculated benefits for removing 2 000m^3 or 10 000m^3 of algae

Removal compounds	Marginal costs* (€2005/kgP)	Marginal costs (SEK_{2005}/kgP)	Benefits from removing 2000m^3 (kSEK/year)	Benefits from removing 10000m^3 (kSEK/year)
P free detergents	11-100	102-927	22-204	112-1020
Livestock reductions	1190-4540	11043-42130	2430-9270	12150-46300
Fertilizer reduction	1-4140	9.28-38418	2-8450	10-42300
Sewage treatment	61-250	566-2320	125-510	622-2552
Private sewers	255-480	2366-4454	520-980	2600-4900

In the business plan framework the benefits for removing phosphorus are calculated using the marginal cost for sewage treatment, since phosphorus emissions are relevant for Trelleborg sewage treatment plant (See Appendix 1 for more details). Table 3 shows that the marginal cost for measures reducing phosphorus emissions from sewage treatment is 566-2320 SEK/kg P and the benefits from removing 2000m^3 algae is 125 000-510 000 SEK/year and between 622 000-2.5 million SEK/year if 10 000m^3 algae are removed.

Table 4 summarizes the marginal costs of nitrogen and phosphorus reductions to the Baltic Sea from measures affecting sewage treatment. From table 6 we can see that the marginal cost is between 139-733 SEK/kg nitrogen for removing compounds from improved sewage treatment. The social economic benefits from removing 2000m^3 algae is between 320 000-1 690 000 SEK/year and between 1 600 000-8 430 000 from removing 10 000m^3 algae. The corresponding marginal cost for phosphorus which is 566-2320 and the socio economic benefits from removing 2000m^3 algae are between 125 000 - 510 000 and between 622 000 - 2 552 000 from removing 10 000m^3 algae.

Table 4: Marginal costs for nitrogen and phosphorus reductions to the Baltic Sea from measures affecting sewage treatment.

Removal compounds	Marginal costs* (€$_{2005}$/kg)	Marginal costs (SEK$_{2005}$/kg)	Benefits from removing 2000m^3 (kSEK/year)	Benefits from removing 10000m^3 (kSEK/year)
Sewage treatment (N)	15-79	139-733	320-1690	1600-8430
Sewage treatment (P)	61-250	566-2320	125-510	622-2552

Conclusions

This section has shown that land measures provide low cost measures for nitrogen reductions and phosphorous free detergents and that improved sewage cleaning is a low cost measure for phosphorus reductions. The socio economic benefits of removing 2000m^3 are largest for reducing compounds from sewage treatment and private sewers for nitrogen. Whereas the socio economic benefits of removing 2000m^3 are largest for reducing compounds livestock.

References

Davidson, Åsa 2007. Detox AB: *Tång och alger som en naturresurs och förnyelsebar energikälla.* (Seaweed and algae as a natural resource and renewable energy source) Rapport Steg 1 till Trelleborgs kommun.

Davidsson, Åsa & Ulfsdotter Turesson, Eva, 2008. Detox AB: *Tång och alger som en naturresurs och förnyelsebar energikälla.* (Seaweed and algae as a natural resource and renewable energy source) Rapport Steg 2 till Trelleborgs kommun.

European Commission, 2002.*Eutrophication and health.*

Kemiklaieinspektionen, 2012. *Samhällsekonomisk kostnad för frakturer orsakade av kadmiumintag via mate.*

Larsson, B, 2013. Personal communication with Bengt Larsson Tekniska förvaltningen.

Naturvårdsverket, 2009. *What's in the sea for me?*

Resurs AB, 2012. TEM rapport Ekonomiska och sysselsättningsmässiga effekter av turismen i Trelleborgs kommun inklusive åren 2008-2011.

Resurs AB, 2012. TEM rapport Ekonomiska och sysselsättningsmässiga effekter av turismen på Öland inklusive åren 2008-2011.

Sweco, 2012. Stranderosion i Trelleborgs kommun.

Swedish Chemicals Agency, KEMI Report, 2011. Kadmiumhalten måste minska – för folkhälsans skull En riskbedömning av kadmium med mineralgödsel i fokus Rapport från ett regeringsuppdrag.

Trelleborgs kommun, 2011. Uppförande av biogasanläggning för insamling, hantering, rötning och om händertagande av alger vid Smyge reningsverk.

WSP, 2011. Biogas, tillväxt & sysselsättning - Hur påverkar produktion och användning av biogas tillväxt och sysselsättning i Biogas Östs region?

Internet sources

Oanda.com <http://www.oanda.com/lang/sv/currency/historical-rates/≥2013-11-19

Balticsearevial.se <www.balticsearevival.se> 2013-11-01.

SMP, Svenska Miljörapporteringsportalen. www.naturvardsverket.se

Tullstorpsprojektet. www.tullstorpsan.se

Estimation of Transport Costs – Drying, incineration and ash disposal

PhosCad

Appendix 4

The suggested method *Drying, incineration and ash disposal* entails collecting algae from the beach bathing areas and harbours for pleasure boats and transport it to an area for drying (new investment is needed in a large drying are, up to 50 000 m^2, or in a more compact drying drum). The algae will need to be turned 2-3 times per season, while drying. The dried material will be transported to an incineration plant (new investment is not needed – the incineration will take place in an existing plant). The ashes from the incineration will be needed to be taken care of.

The Sysav incineration plant is located in Malmö, which is located approximately 40 kilometers from where the algae are collected. A normal 3-axle truck transport with large or small trailer can load 30 - 50 m^3 and costs approximately 15 SEK/1 km. Rough estimates indicate that it will take approximately 1 hour to drive back and forth from the beach to the incineration plant and 1 hour to load on and off the algae. Chauffer cost is estimated to 300SEK/hour (Bäckström 2013).

Table 1 summarizes the costs to collect 2000m^3 algae. The total transport cost is between 72 000SEK - 120 600SEK.

Table 1: Transport cost for loading 2000m^3 algae from the beach

Load m^3	Cost per km	Cost per/hour Chauffer	Number of trips	Costs
30	150	300	134 (67)*	120,600**
50	150	300	80 (40)	72,000***

* Number in parenthesis is the trips for one way

**134 trips equals 5 360 km x 15 SEK per km = 80 400 SEK + chauffeur cost 300 x 67 trips back and forth = 20 100 SEK + chauffeur cost 300 SEK x 67 trips back and forth loading and offloading = 20 100. In total 80 400 + 20 100 + 20 100 = 120 600 SEK

***80 trips equals 3 200 km x 15 SEK per km = 48 000 SEK + chauffeur cost 300 x 40 trips back and forth = 12 000 SEK + chauffeur cost 300 SEK x 40 trips back and forth loading and offloading = 12 000. In total 48 000 + 12 000 + 12 000 = 72 000 SEK

Table 2 summarizes the costs to collect 10 000m^3 algae. The total transport cost is between 360 000SEK – 601 200 SEK.

Table 2: Transport cost for loading 10 000m^3 algae from the beach

Load m^3	Cost per 10 km	Cost per/hour Chauffer	Number of trips	Costs
30	150	150	668 (334)*	601,200
50	300	300	400 (200)	360,000

* Number in parenthesis is the trips for one way

**668 trips equals 26 720 km x 15 SEK per km = 400 800 SEK + chauffeur cost 300 x 334 trips back and forth = 100 200 SEK + chauffeur cost 300 SEK x 334 trips back and forth loading and offloading = 100 200. In total 400 800 + 100 200 + 100 200 = 601 200 SEK

***400 trips equals 16 000 km x 15 SEK per km = 240 000 SEK + chauffeur cost 300 x 200 trips back and forth = 60 000 SEK + chauffeur cost 300 SEK x 200 trips back and forth loading and offloading = 60 000. In total 240 000 + 60 000 + 60 000 = 360 000 SEK

Reference

Bäckström, S., 2013. Personal communication with Sebastian Bäckström, IVL Swedish Environmental Research Institute