Test facility for algae-based water treatment

Report 2009

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On behalf of:
Trelleborg Municipality

Summary
The biological treatment of algae enables the procurement of nutrients such as nitrogen and phosphorus for biomass production. The biological treatment is made by means of solar energy and thus cost savings are achieved compared to systems that use more costly energy sources. While the produced biomass can be used for bioenergy production. In this project, biological treatment of algae (BRA project), tested technology is developed by Clearwater Energy Nordic AB and adapted to the purification of water from the catchment areas of agricultural land. Smaller tests have been performed previously. The BRA project tested the technology on a larger scale, approximately 200 m2 of former wetlands were used. The system makes use of biological technologies that are most active at warmer temperatures and the majority of data collection should continue during the spring and summer of 2010.

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1.Background

Trelleborg participates in and implements comprehensive projects to improve water quality in freshwater and coastal areas in the Baltic Sea. Eutrophication of the Baltic Sea is one of the major environmental problems in the region, both locally, nationally and internationally. Eutrophication is caused by anthropogenic emissions of nutrients, especially nitrogen and phosphorus. Emission sources can be point sources, such as from sewage treatment plants, or diffuse, for example from agriculture. In order to reduce emissions several strategies can be used, such as reducing the use of nutrient substances in the community or to pick up substances before they reach the environment.

Clearwater Energy Nordic AB (CWE Nordic AB) develops systems for the purification of nutrient-rich water and biomass production. Trelleborg Municipality contacted and met with CWE Nordic AB in the autumn of 2008 when the municipality found the presented methodology very interesting not only for municipal water treatment strategies, but also for the creation of biomass for biogas production. At the beginning of May 2009 a one year contract was signed between CWE Nordic AB and Trelleborg for the feasibility study, construction and testing of a trial facility in Trelleborg.

In this project, which is entitled Biological Purification of Algae (BRA project); algae based systems are tested and used to capture nutrients in the water before they reach the environment. The system is in a development stage and the BRA project takes it to a larger scale. The system takes up nutrients through a fully biological system, using solar energy and without the use of chemicals. The goal is to make the system so flexible that it can be used for the purification of many different types of water, such as sewage, drainage and diffuse pollution from agriculture. The BRA project tested the system under real conditions on a large scale during all seasons with water from the Tullstorp stream which flows into the Baltic Sea. This water transports large amounts of nutrients from agriculture and one aim of the BRA project is to test the system's treatment capacity.

Today, with climate change, environmental threats and changes in energy generation, environmentally friendly solutions for energy production are in demand. The BRA project produces a biomass that is very suitable for energy production. This biomass is carbon neutral, grown in areas not used as arable land and its biological composition makes it particularly suitable for biogas production. BRA Project's second objective is to take advantage of eutrophication substances as a food resource in order to produce biomass for energy creation.

2. The Project's Goal

The BRA project's goal is to design and customize CWE Nordic’s algae based systems to the catchment areas of agricultural land. Also, to examine and evaluate the CWE Nordic systems purification ability and it’s potential for biomass production. CWE Nordic still has the pilot projects ongoing and has tested the wastewater. This, together with data from the test facility, has provided valuable information for applications on water from the river basin, from farmland and from sewage.

3. Project Implementation

3.1 Exploratory

The BRA project includes a feasibility study to examine whether there are conditions for applying the technology of CWE Nordic AB in the Tullstorp stream and its immediate vicinity. The pilot study was carried out in autumn 2008/ spring 2009 and reported to the municipality of Trelleborg. The results from the pilot study showed that there were good opportunities to build a test facility of CWE Nordic's technology and that the water was well suited for the growth of algae. The pilot study revealed a number of possible sites to build a test facility.

3.2 Location of test facility

The BRA-project is being carried out in an already landscaped pond (in Källstorp, real estate 10:3) with inlet and outlet to and from the Tullstorp stream. The BRA project received the allocated location with the help of Trelleborg Municipality and Naturvårdsingenjörerna AB. The site is located a few kilometers south (downstream) from Jordberga farm and about eight kilometers inland from the Baltic Sea. Other ongoing projects in the Tullstorp stream are carried out further upstream. The dam is an excavated wetland, of approximately 3000 m2, and was built in 2003. The BRA project uses a small portion of the existing dam, about 200 m2 which is located between the inlet and outlet.

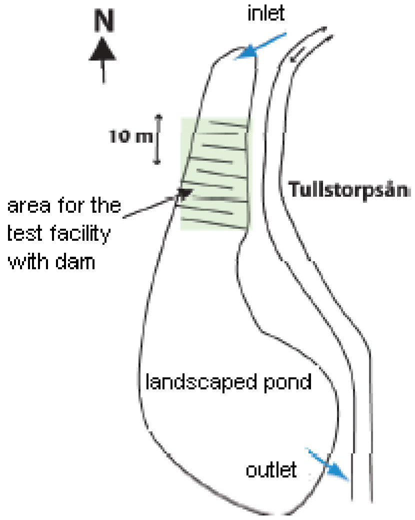


Figure 1. Overview of the installation at Källstorp

The site's suitability for the BRA project was examined early in the summer of 2009 and with small test structures during the summer-autumn 2009. When land owners announced that the sites should be restored to their original state, a lot of care spent on adaptations and materials of construction has been made in order to meet this requirement. This has been tested with various structures. Meanwhile, observations of the natural water levels and fluctuations in the pond have given support to enable flexibility and continuity in system designs.

During the summer it was noted that there was a very low flow in the dam and that the upper part was dry, which creates the need for a barrier at low flows. The low flow meant that the facility could not be built until the problem of lack of water was solved. Much of the algae that occur naturally in the pond dried out at times of low flow, even in the deep end when the algae were mainly close to the shore. In autumn the entrance to the dam was cleared, which raised the water level by nearly one meter. The water level can be regulated at the outflow, but the high rainfall and high river flow varies the water level in the pond. At times of low flow adjustments may be needed regarding the form of the dam during spring and especially summer.

3.3 Design of test facility

The test facility is built in a part of the existing dam (the upper part is shown in Figure 1) at Källstorp. Any water entering through the inlet to the pond from Tullstorpsån system must pass through before it reaches the deeper part of the dam (Figure 1). The wastewater then goes into the Tullstorpsån via an outflow at the bottom of the deep end of the pond. Treatment efficacy of the test facility is measured by comparing the input and output levels in the water to and from the test facility. Water movement is controlled by partition walls which give it a meandering path of motion (Picture 1).

Picture1. Meandering pattern is created using the channel-like walls.

The test facility's main area was completed in November 2009. An extension of the surface will occur before the end of the year, while some modifications will be made to facilitate analysis and stabilize the system.
The facility will provide the best possible conditions for the algae and bacteria. The organisms found naturally in Tullstorpsån, algae that already exists in the pond and in Tullstorpsån (which is abundant during the warm season) will be used in the system.
Abundant filamentous algae (Cladophora), which is a symptom of eutrophication, will be used for biomass production and to increase the system's cleaning function. In the long term, if the presence of Cladophora decreases downstream in the river due to malnutrition, the system has fulfilled its function. The structure should be as close as possible to sources of nutrient leakage in order to capture nutrients before they reach a larger area.
The test facility consists of a system for both bacteria and algae; the majority of construction has been to prepare this system. The material used is made of natural substances, such as clay and natural fibers, that have a positive impact on the aquatic environment by stabilizing the sediment and enhancing growth along the pond edge. Only at the test facility has the habitat composition been changed directly.

A barrier consisting of plants has been built in the shallow end of the pond, downstream of the assembled channel walls. The barriers function is to reduce turbidity in the rest of the dam during construction work and to keep algae materials in the area.

The test location is designed to be permanent with minimal maintenance. However, if needed, the facility can be dismantled, removed and the pond can be fully restored. A recovery operation is not in the budget, but the design is adapted to provide a low cost of recovery and provide minimal impact during reconstruction work.

3.4 Data analysis of the system and surrounding factors

It is known that Tullstorpsån has high levels of nutrients and that these substances create eutrophication problems. The BRA project was initiated by Trelleborg Municipality as one of the projects associated with the improvement of water quality in Tullstorpsån. There is a wide variety of nutrients that pass through Tullstorpsån, and other rivers in Trelleborg, and the flow of the river varies considerably (for details see report series Trelleborg rivers, Water quality, Trelleborg Municipality). It is therefore important that the data collection system functions for at least one year (all seasons). During the seasons there is a wide variation in physical parameters, together with large fluctuations in nutrients, it is therefore necessary to analyze the system in all seasons. The system is affected by parameters such as temperature, solar radiation and nutrients.

Water samples are collected regularly before and after the inlet to the test facility and sent for analysis at an accredited laboratory. The analysis is mainly of nutrients (ammonium, nitrate nitrogen, nitrite nitrogen, total phosphorus and total nitrogen), total organic carbon TOC, Color, Conductivity, pH and Alkalinity. Oxygen dissolved in the water is measured directly on site using an oxygen electrode. Currently there are two temperature logs on site, but more logs will be added. Continuous measurements can be used to both evaluate and optimize the system.

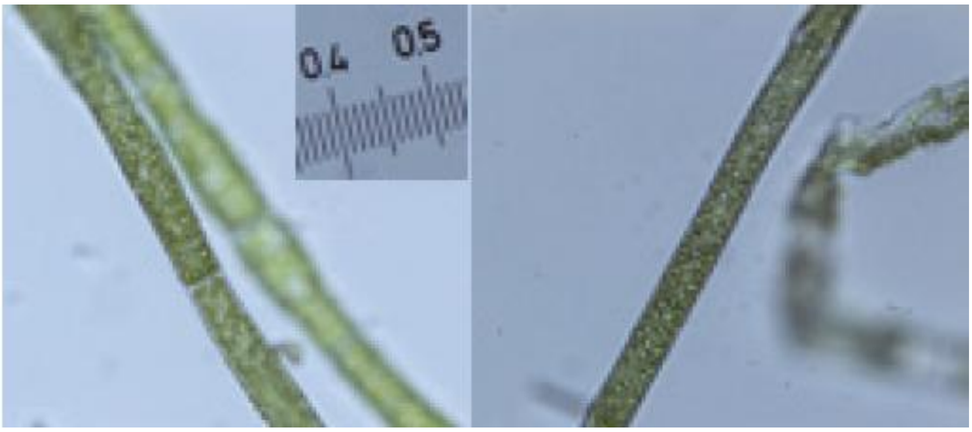
Solar insolation varies by factors such as season and cloud cover and it can have both rapid (minutes / seconds) and slow (years / months) variations. The units used for its measurement are the amount of 400-700 nm photons, i.e. particles of light in the visible wavelengths and in the wavelengths that are mainly used in photosynthesis. Solar radiation will in part be measured directly on the CWE site, but mainly by using the Swedish Meteorological and Hydrological Institute (SMHI) database, as this provides a longer and more tangible perspective. The database source string is free to use and is available via the Internet at SMHI website under the Environmental Protection Agency and Radiation Safety Authority (http://produkter.smhi.se/strang/).

Calculations of water flow and speed is complex in systems with varying bottom substrates, as this creates local variations in flow and speed.

4. Results and conclusions

4.1 The presence of algae

The algae to be used in the system is naturally present in Tullstorpsån, the dam and surrounding areas of the municipality. The presence of algae is high in much of the year and they are both grown on substrates and free flowing. Both free-flowing and phase growing algae are useful in the system. This means that local varieties can be used in the system, which is preferable. Picture 2 shows the microscope images of the algae, *Cladophora sp.*, Collected in the pond in Källstorp and Tullstorpsån.



Picture2. Cladophora sp. from the Källstorp damn (left) and from Tullstorpsån (right). The same scale for both images (scale mm; one part-bar are one hundredth of an mm).

The amount of algae in the pond directly outside Tullstorpsån fell sharply in November, which is probably a combination of lower temperature, high water flow and speed of washing away the algae. At Äspö wetland, located in the immediate area and can be used as a reference point, the algae disappeared almost entirely during the month of November, which is probably mainly due to lower temperatures when the flow in the wetland system is low. Small amounts of algae were found in the upper dam of the BRA project even during the month of November and experiments with small amounts of algae show that algae can continue even during the month of November. When the flow is controllable in the pond it does suggest that the growing season of algae in the pond may extend up to November. This would then provide a longer growing season than, for example, Stockholm. Where the season extends until about October, which was recorded at CWE Nordic's pilot plant for outgoing sewage. See paragraph below on solar radiation.

4,2 Growth and photosynthesis

The growth of algae varies with several factors such as light and temperature, as shown in CWE Nordic laboratory tests. Although varieties of algae can also be an important factor. With these variations growth can vary by between 2-8% per day.

At 15°C and 140 μmol photons m-2 s-1 is the growth of algae in local Tullstorpsån water, approximately 7% daily resulting in a doubling of the biomass at 11 days.
In high summer heat and increased light volume growth is expected to increase further. However, growth is inhibited when it gets too "crowded", so it is important that the algae be harvested frequently. If the farms near the facility can produce biogas it could be an interesting alternative for the use of algae, in addition the biomass can also be used as soil fertilizer.

The pilot study showed that Cladophora oxygen production begins to level off around 200 μmol photons m-2s-1 (Fig. 2), which is a light level that can be achieved even in the middle of the day in late November (Fig. 3). Although the temperature is low during November (Figure 4), it is expected to give oxygen production. Overall, the amount of light in Trelleborg has been much higher in November compared with Västerhaninge, Stockholm where Nordic CWE has a pilot plant (Table 1). This suggests that conditions are better in Trelleborg for this type of technology. Please note that the units in Figure 2 and 3 are micromoles per square meter per second, while in Table 1 it is mole per square meter.

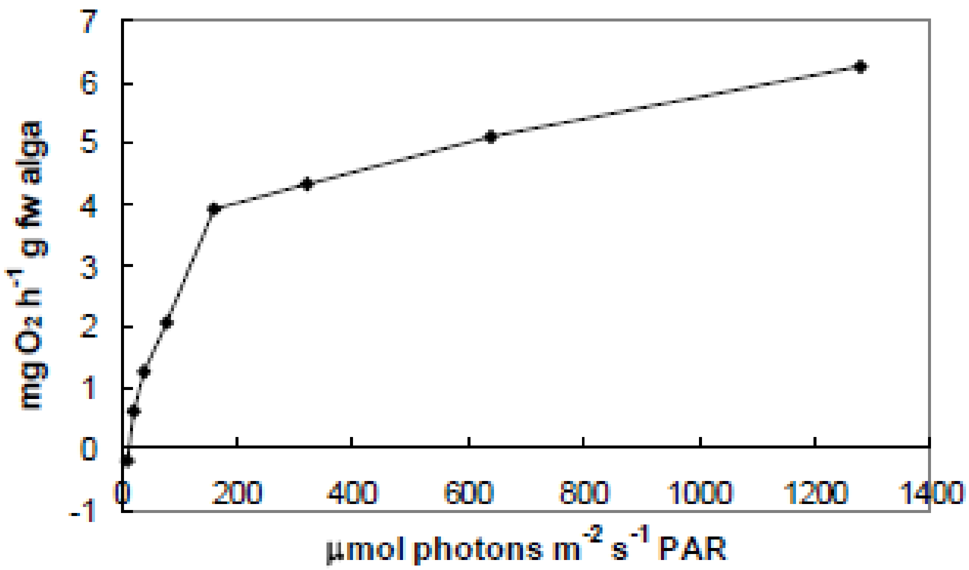


Figure 2. Photosynthesis rate as a function of light intensity of photo synthetically active radiation (PAR) at 22 °C by a piece of *Cladophora sp* in water collected from Tullstorpsån.

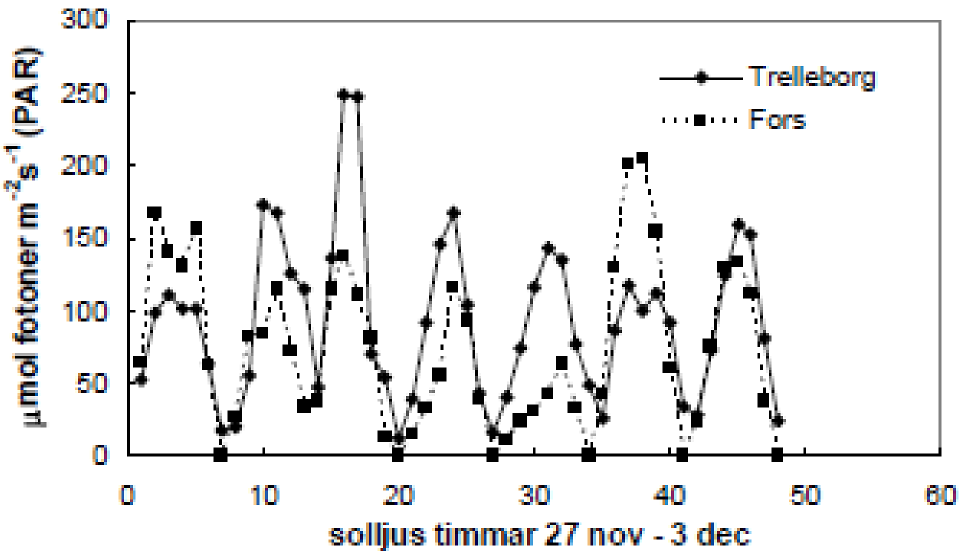


Figure 3. An example of the photo-synthetically useful amount of light at test facility at Källstorp, Trelleborg, and the pilot plant at Fors,sewage treatment plant, Västerhaninge, Stockholm.
Data based on extraction from SMHI. Only light hours per day is shown.

Fors, Stockholm	
Månad	fotoner mol m^2
2009 08	933.0
2009 09	640.4
2009 10	238.8
2009 11	59.4
Trelleborg	fotoner mol m^2
Månad	
2009 08	943.7
2009 09	562.0
2009 10	254.6
2009 11	104.7

Table 1. The light quantity per month per square meter. (Data from SMHI)
(please note “fotoner mol” is “mol photons”).

4.3 Other

Conductivity in October, upstream and downstream of the dam, at the point where the test facility is located, gave the same values, indicating that the upper dam had a low treatment effect in the autumn without the test facility. Conductivity values were 282-287 µS/cm, which can be regarded as high. The water in Trelleborg rivers have naturally high conductivity values partly because of the lime-rich waters, but high values also depends on high concentrations of nutrients. Conductivity values of around 50 mS / m are frequently reported. CWE is awaiting results from Nordic AB Alcontrol to correlate the conductivity values in the pond with nutrient concentrations.

The water flow varies during the season, which in turn creates differences in the water level of the dam (variations of more than one meter). After regulation at the exit variability was decreased, with peaks at approximately 0.5 meters of variation. During the summer the reduced flow of the river cannot be compensated by the control of outflow from the pond. Minor variations (± 1 dm) have a negligible impact on the system, but larger variations can create significant disruption. The best way to handle level changes is with the use of a dam embankment. Alternatively, a buffer dam can be built before the location of the purification system.

High flows in Tullstorpsån also appears to contain significant amounts of sediment. Sediment flux is not quantified but measurements show that the particle content in the water does not significantly affect the amount of light to the algae, and sedimentation of algae can be reduced by a high flow rate. However, the long-term impact is expected to be that parts of the system need flushing occasionally.

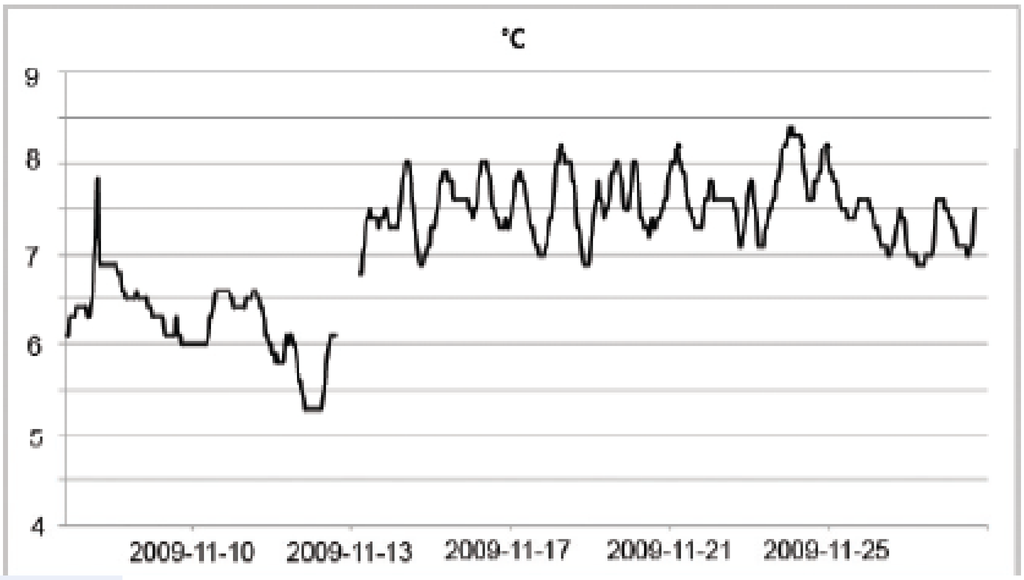


Figure 4. Water temperature in the test facility

The water temperature in the BRA project is logged as far as November (Figure 4). The temperature is very important for the functioning of the installation and data shows that the temperature is high enough for activity even in November. The test location now has two temperature logs, which can be used to investigate the comparative system activity (biological activity may increase the temperature slightly).

Experience in the design of the facility has been valuable. We have focused on the marginal influence at the site, where a wetland is already landscaped with high natural value. These working methods have been labor-intensive. A small effect occurred next to the pond in the shape of wheel tracks from a vehicle, which could easily be restored after a period grass growth. The machine in question can work large areas in less time, and time-consuming work can be minimized depending on the area's character.

5. Expectations

The system consists of an algal-bacterial system that takes advantage of the nutrients which might otherwise cause eutrophication. Reduced microbial nutrients are also taken up by organisms, resulting in biomass production. At the test facility the biomass growth can be measured on a large scale, it is intended that the biomass is harvested and used for energy production. Trials have shown that these algae are very well suited for biogas production. According to reports on Trelleborg's rivers, the amount of de-nitrification at 3ºC gives good hope of de-nitrification taking place even in November in a fully established system as temperatures much higher than 3ºC have been measured in the test facility at that time. The measured temperature levels should also allow the nitrification bacteria the opportunity to establish itself. In the spring both biomass growth and increased treatment efficacy are expected when both temperature and solar radiation increase.