Oilgae Guide to Algae-based Wastewater Treatment

A Sample Report

This e-book provides representative sample content to assist in evaluating the Oilgae Guide to Algae-based Wastewater Treatment.

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The Oilgae Guide to Algae-based Wastewater Treatment is a detailed report on treating municipal and industrial wastewater using algae. This sample preview provides inputs on the focus areas of the report, the complete list of contents, and sample data from each chapter of the report.

The Oilgae Guide to Algae-based Wastewater Treatment was last updated in Nov 2009 and has 461 pages.

Preface to the Report

Algae are important bioremediation agents, and are already being used by many wastewater facilities. The potential for algae in wastewater remediation is however much wider in scope than its current role.

The *Oilgae Guide to Algae-based Wastewater Treatment* was prepared by Oilgae (www.oilgae.com) as a response to the tremendous need in the market for a detailed resource that provides a compendium of practical data, insights and case studies for algae-based wastewater treatment efforts worldwide.

The focus of the report is to provide guidance that can facilitate actions on the part of the academia and the commercial sector. Hence, inputs and data that have been provided have a slant towards real life case studies and experiments.

While the thrust of the report is on wastewater bioremediation using algae, the report also provides detailed references on deriving biofuels from algae. Algae are currently researched for their ability to be the potential feedstock for biofuels. Combining algae biofuels with wastewater remediation provides significant economic synergies for the process.

The *Oilgae Guide to Algae-based Wastewater Treatment* will be an invaluable resource for companies, communities and academia seeking expert intelligence on using algae for wastewater remediation.

This guide has been prepared by Oilgae (www.oilgae.com), the leader in information and industry research support for the global algae-fuel industry.

The report was last updated in the first week of Nov 2009.

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Section 1 – Municipal and Industrial Wastewater Treatment Using Algae

Section 2 – Algae for Fuels

Section 3 – References

1 Wastewater Treatment Concepts

This chapter will provide a clear understanding about the critical role of algae in wastewater treatment, and also provides inputs on advantages of algae-based wastewater treatment over the traditional methods used.

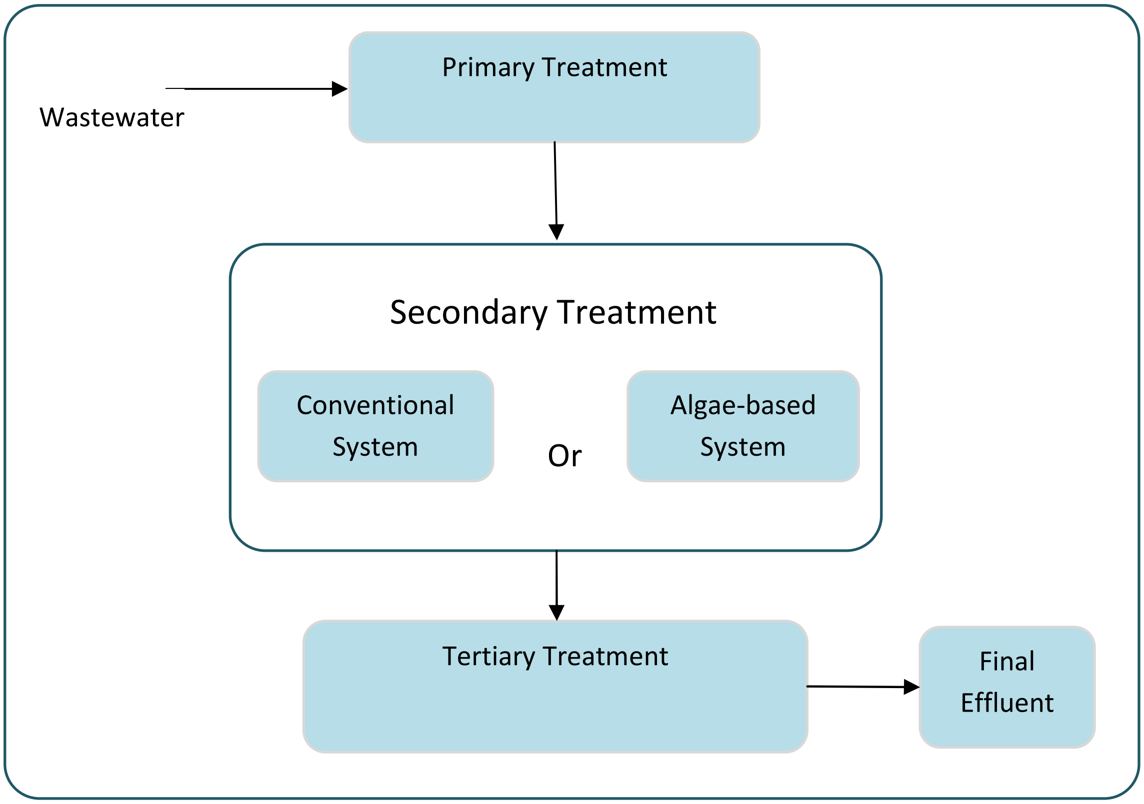
Sample Content: Problems with Current Practices

The major disadvantages associated with current wastewater treatment practices are:

- Many wastewater treatment processes generate large amounts of sludge that must be sent off-site for disposal. Handling and disposal of this sludge is typically the largest single cost component in the operation of a wastewater treatment plant.
- Most wastewater treatment processes cannot effectively respond to diurnal, seasonal, or long-term variations in the composition of wastewater. A treatment process that may be effective in treating wastewater during one time of the year may not be as effective at treating wastewater during another time of the year.
- High energy requirements will make many wastewater treatment methods unsuitable for low per-capita energy consumption countries.
- High operation and maintenance requirements, including production of large volumes of sludge (solid waste material), make them economically unviable for many regions.

Sample Content: Where Do Algae Play a Role?

Conventional Wastewater Treatment Vs Algae-based Wastewater Treatment



Sample Content: Algae-based Wastewater Treatment vs. Traditional Methods

Using algae for wastewater treatment offers some interesting advantages over conventional wastewater treatment.

> *Advantages of algae wastewater treatment*
>
> - Cost effective
> - Low energy requirement
> - Reductions in sludge formation
> - GHG emission reduction
> - Production of useful algal biomass

1. *Cost Effective* - It has been shown to be a more cost effective way to remove biochemical oxygen demand, pathogens, phosphorus and nitrogen than activated sludge process and other secondary treatment processes (Green et al., 1996).

2. *Low Energy Requirements* - Traditional wastewater treatment processes involve the high energy costs of mechanical aeration to provide oxygen to aerobic bacteria to consume the organic compounds in the wastewater, whereas in algae based wastewater treatment, algae provides the oxygen for aerobic bacteria. Aeration is an energy intensive process, accounting for 45 to 75% of a wastewater treatment plant's total energy costs. Algae provide an efficient way to consume nutrients and provide the aerobic bacteria with the needed oxygen through photosynthesis. Roughly one kg of BOD removed in an activated sludge process requires one kWh of electricity for aeration, which produces one kg of fossil CO_2 from power generation (Oswald, 2003). By contrast, one kg of BOD removed by photosynthetic oxygenation requires no energy inputs and produces enough algal biomass to generate methane that can produce one kWh of electric power (Oswald, 2003).

3. *Reductions in Sludge Formation* - In conventional wastewater treatment systems the main aim is to minimize or eliminate the sludge. Industrial effluents are conventionally treated using a variety of hazardous chemicals for pH correction, sludge removal, colour removal and odour removal. Extensive use of chemicals for effluent treatment results in huge amounts of sludge which forms the so called hazardous solid waste generated by the industry and finally disposed by depositing them in landfills. In algae wastewater treatment facilities, the resulting sludge with algal biomass is energy rich which can be further processed to make biofuel or other valuable products such as fertilizers. Algal technology avoids use of chemicals and the whole process of effluent treatment is simplified. There is considerable reduction in sludge formation.

4. *The GHG Emission Reduction* – The US Environmental Protection Agency (EPA) has specifically identified conventional wastewater treatment plants as major contributors to greenhouse gases. Algae based wastewater treatment also releases CO_2 but the algae consume more CO_2 while growing than that is being released by the plant, this makes the entire system carbon negative.

5. *Production of Useful Algal Biomass* – The resulting algae biomass is a source of useful products such as biodiesel. Previous research in the early 1990's by the National Renewable Energy Laboratory (NREL) showed that under controlled conditions algae are capable of producing 40 times the amount of oil for biodiesel per unit area of land,

compared to terrestrial oilseed crops such as soy and canola (Sheehan et al., 1998). However, their results also showed that large-scale algae cultivation for energy production was uneconomical at that time and suggested future research into waste - stream integration (Sheehan et al., 1998). It is hoped that the economics will be ultimately improved by combining biodiesel feedstock production with agricultural or municipal wastewater treatment and CO_2 fixation.

Algae can be used to make bioethanol and biobutanol and by some estimates can produce vastly superior amounts of vegetable oil, compared to terrestrial crops grown for the same purpose. Algae can be grown to produce hydrogen. In 1939 a German researcher named Hans Gaffron, while working at the University of Chicago, observed that the algae he was studying, *Chlamydomonas reinhardtii* (a green-algae), would sometimes switch from the production of oxygen to the production of hydrogen. Algae can be grown to produce biomass, which can be burned to produce heat and electricity.

2 Municipal Wastewater Treatment Using Algae

With the help of real-life case studies, this chapter introduces the various stages and advantages of algae-based wastewater treatment methods. This chapter also evaluates the cost and economics of algae-based municipal wastewater treatment

Sample Content: Algae-based Municipal Wastewater Treatment Process

Municipal wastewater is usually treated to get rid of undesirable substances by subjecting the organic matter to biodegradation by microorganisms such as bacteria. The biodegradation involves the degradation of organic matter to smaller molecules (CO_2, NH_3, PO_4 etc.), and requires constant supply of oxygen. The process of supplying oxygen is expensive, tedious, and requires a lot of expertise and manpower. These problems are overcome by growing microalgae in the ponds and tanks where wastewater treatment is carried out. The algae release the O_2 while carrying out the photosynthesis which ensures a continuous supply of oxygen for biodegradation. . Algae - based municipal wastewater treatment systems are mainly used for nutrient removal (removal of nitrogen and phosphorous). The added benefit is the resulting biomass that can be used as biofuel feedstock.

Sample Content: Algae-Based Municipal Wastewater Treatment Process

Pathogen Removal

Many different mechanisms play a role in disinfection in high rate ponds. These include predation, sunlight, temperature, dissolved oxygen, pH, sedimentation and starvation (Fallowfield et al., 1996). Algal photosynthesis causes an increase in the pH due to the simultaneous removal of CO_2 and H+ ions (Fallowfield et al., 1996) and the uptake of bicarbonate when the algae are carbon limited (Craggs et al., 1997). According to Rose et al. (2002a) a pH of 9.2 for 24 hours will provide a 100% kill of E. coli and most pathogenic bacteria and viruses. Pahad and Rao (1962) also found that E. coli could not grow in wastewater with a pH higher than 9.2.

Sample Content: Algae-Based Treatment System – Design and Construction

To construct algae based wastewater treatment system it is essential to consider both wastewater treatment as well as algal cultivation. Cell retention time, nutrient addition rate, water depth, and degree of mixing are the common parameters consider for growth of algae. In addition to these parameters BOD reduction, TDS reduction, pH, Nitrogen removal rate and Phosphorus removal rate are commonly considered for wastewater treatment. Hence the system should be designed accordingly to allow the growth of algae as well as wastewater treatment.

Two types of wastewater treatment systems are currently available for algae based treatment which can be incorporated in secondary treatment stages.

- Waste Stabilization Pond Systems (WSPs)
- High Rate Algal Ponds(HRAP)

Waste Stabilization Pond Systems

> *Role of Algae in WSPs*
>
> Wastewater treatment in Waste Stabilization Ponds (WSPs) is "green treatment" achieved by the mutualistic growth of microalgae and heterotrophic bacteria.The algae produce oxygen from water as a by-product of photosynthesis. This oxygen is used by the bacteria as they aerobically bio-oxidize the organic compounds in the wastewater. An end-product of this bio-oxidation is carbon dioxide, which is fixed into cell carbon by the algae during photosynthesis.

High Rate Algal Pond Systems

Role of Algae in HRAP

> The HRAP is a combination of intensified oxidation ponds and an algal reactor. HRAP are shallow, paddlewheel-mixed open raceway pondsand provide far more efficient wastewater treatment. Than conventional oxidation ponds, this is primarily as a result of intense algal photosynthesis providing saturated oxygen to drive aerobic treatment and assimilation of wastewater nutrients into algal biomass.

Sample Content: Advantages of Municipal Wastewater Treatment Using Algae

Advantages of Municipal Wastewater Treatment Using Algae

> - Suitable for extreme growth conditions (pH, salt, etc.)
> - Removes heavy metals
> - Produce oxygen with low energy input
> - Fixes CO_2
> - Produces biomass
> - Greater feasibility
> - Ease of handling
> - Low cost and flexibility of culture

All these advantages are explained in detail in this section

Sample Content: Cost of Municipal Wastewater Treatment Using Algae

Key issues discussed in this section for cost-effective wastewater phycoremediation are:

- Optimal Treatment Systems & Processes
- Cost-effective Harvesting Systems
- Exploiting the Value of End-products and Processes

Optimal Treatment Systems & Processes

Wastewater treatment using algae are implemented either using simple oxidation ponds or with high rate algal ponds. In a few cases, especially where high productivity of algal biomass is desired, companies are exploring the possibility of using closed systems such as photobioreactors as well.

The following are our observations in the context of optimal systems and processes for wastewater phycoremediation:

- Based on reviews and researches done so far regarding economics of algae-based wastewater treatment, it can be concluded that photobioreactors are not economic for such treatments in the short and medium term (even if it is intended to derive significant economic benefits from the sale of algal biomass). Such a closed and controlled environment for cultivation will become viable only after the costs of such systems come down dramatically.

More such critical perspectives and insights are provided for all the three issues mentioned above, viz. Optimal Treatment Systems & Processes, Cost-effective Harvesting Systems and Exploiting the Value of End-products and Processes.

Sample Content: Research & Updates

- During the U.S. Department of Energy’s Aquatic Species Programme (ASP), it was found that for the algae remediation of wastewater, energy outputs were twice the energy inputs, based on digester gas production and requirements for pumping the wastewater, mixing the ponds, etc. The overall economics were very favorable because of the wastewater treatment credits.
- In Virginia (USA), researchers at Old Dominion University have successfully piloted a project to produce biodiesel feedstock by growing algae at municipal wastewater treatment plants. The researchers hope that these algae production techniques could lead to reduced emissions of nitrogen, phosphorus and carbon dioxide into the air and surrounding bodies of water. The pilot project is producing up to 70,000 gallons of biodiesel per year - Jan, 2008.
- Kingsburgh Sewage Project in Durban Aims at Fuel from Algae – May 2008 - Durban is helping to develop a new liquid fuel technology which involves harvesting tiny plants and nutrients from local wastewater works. Unlike other plant-based biofuels which require vast tracts of fertile farmland or the diversion of food crops into fuel tanks, the Durban experiment involves growing algae in semi-purified wastewater and then converting these microscopic plant organisms into a liquid fuel that can power diesel cars and trucks. Engineers are about to start converting part of the Kingsburgh sewage treatment works into a biodiesel farming experiment as part of a two-year scientific pilot project run by the Durban University of Technology's school of water and wastewater technology.

3 Industrial Effluent Treatment Using Algae

This chapter provides details of how an algae-based system can be used to treat industrial wastewater. It describes in detail the algae-based industrial wastewater treatment systems being used by thirteen different types of industries. This chapter also provides the reader insights and case studies on the role of algae in various industrial wastewater treatments. It also provides comparative cost analyses of various algae-based treatment systems implemented in different industries.

Sample Content: Composition of Major Industrial Effluents

The compositions as well as properties of industrial wastewaters differ considerably from domestic waste. The following table gives a comparison between the typical range of BOD and suspended solids (S.S.) load for industrial and municipal domestic wastewater.

Typical range of BOD and S.S. load for industrial and municipal wastewater

Origin of waste	Biochemical oxygen demand (BOD) kg/ton product	Total Suspended solids (TSS) kg/ton product
Domestic sewage	0.025 (kg/day/person)	0.022 (kg/day/person)
Dairy industry	5.3	2.2
Yeast industry	125	18.7

Starch & glucose industry	13.4	9.7
Fruits & vegetable canning industry	12.5	4.3
Textile industry	30 - 314	55 - 196
Pulp & paper industry	4 - 130	11.5 - 26
Beverage industry	2.5 - 220	1.3 - 257
Tannery industry	48 - 86	85 - 155

Source: *Industrial Wastewater Treatment Plants Self-monitoring Manual, Chapter 2, 2002*

Sample Content: Algal Strains Used In Various Industrial Effluent Treatments

Industrial wastewaters are extremely varied and the microorganisms employed to treat these industrial wastewaters also vary accordingly. Some of the algae strains which are used commonly are listed.

- *Phormidium bohneri* – Removal of nitrogen and phosphorus
- Spirulina (Arthrospira) - Removal of nitrogen and phosphorus
- *Spirogyra condensate* - Biosorption of chromium
- *Scenedesmus acutus* – Removal of cadmium

Sample Content: Algae Based Effluent Treatment Plant for Industrial Wastewater

Heavy metal removal

Biomass immobilization is an efficient mean of retaining biomass during WWT (Nicolella et al., 2000) and microalgae immobilization in polymeric material such as carrageenan, chitosan, or alginate has been reported by various authors (Chevalier and De la Nou¨ e, 1985; Lau et al., 1995; Robinson et al., 1998).

It is also possible to recover valuable elements such as gold and silver after appropriate treatment of the loaded microbial biomass. 'The metal bioremoval process mainly combines two types of mechanism.

- Passive uptake
- Active uptake

Passive uptake (metabolism-independent) **-** It is called biosorption, and it occurs when the metal ion binds to the cell wall according two different ways: a) ion exchange where monovalent and divalent ions in the cell wall are displaced by heavy metal ions; and b) the complex formation between metal ions and functional groups present at the cell wall. Biosorption is reversible and rapid (it is completed in 5-10 min). The amount of metal accumulated per unit of biomass is proportional to the concentration of metal ion in the solution.

Sample Content: Industry Specific Algae based Waste Treatment and Effluent Treatment

This section provides extensive details on current wastewater treatment practices and the role algae plays or has the potential to play, for the following industries:

- Poultry
- Dairy
- Aquaculture
- Textiles
- Pulp and Paper
- Distillery & Breweries
- Leather
- Foods
- Petrochemicals
- Pharmaceuticals
- Chemicals
- Mining
- Metalworking

For each of the industries mentioned, we provide details on the following headings:

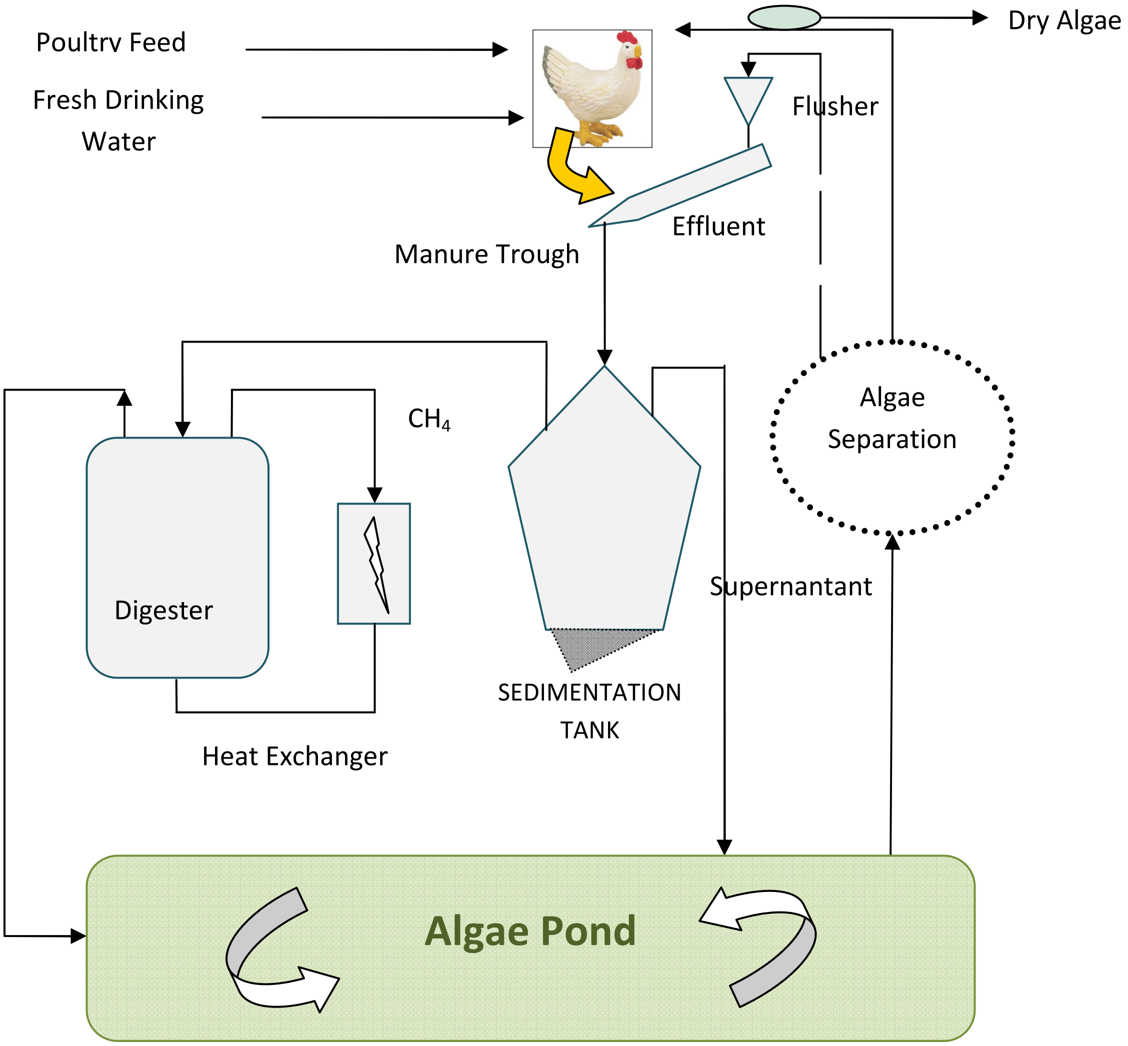
- Details of the industry's wastewater characteristics
- Current treatment practices
- Algae based wastewater treatment process
- New and emerging technologies for this industry's wastewater treatment

Poultry Industry

Industry	Poultry
Product	Poultry muscle (chicken, turkey, duck, ratite, etc.) into meat
Effluent Description	Fats, proteins and carbohydrates from meat, fat, blood, skin and feathers and also grit and other inorganic matter, high levels of nitrogen, phosphorus, and chlorine, pathogens like salmonella and campylobacter.
Effluent Treatment Objectives	Reduce sludge. Remove N, P and to neutralize odors and to remove pathogens.
Current Treatment Process	Separation and sedimentation of floatable solids, anaerobic and aerobic treatment, biological nutrient removal, chlorination and usage of filters.
Algal treatment process	Nutrient assimilation using High Rate Algal Ponds (HRAP)

Sample Content: Algae-based Wastewater Treatment Technology – Poultry Industry

Process of Algae Wastewater Treatment for Poultry Industry



Source: FAO

Sample Content: Aquaculture Industry

Case study

Kent BioEnergy Facility near Mecca, CA

The company now holds a variety of patents and exclusive licenses for aquaculture wastewater treatment systems, algae-based water recycling systems, and algae-based environmental remediation technology. It also has patents pending for making algae easier to harvest, methods for maintaining algae monocultures (ensuring that a pond has just one species of algae), and for genetically modifying algae to enhance algal production of valuable oils that can be used to make fuels.

Sample Content: Chemical Industry

Case study

Chemfab Alkalis Ltd. Pondicherry, India

The factory uses ground water during processing at various stages to extract useful chemicals from crude sea salt. The effluent water that is discharged has a very high salinity and TDS. A team carried out research work on treatment of waste water employing various species of microalgae including a few freshwater as well as marine forms to remove nutrients and bring down TDS. Successful results were obtained with immobilized cells of micro- algae. Work is underway to extend this technique to field conditions.

Sample Content: Advantages of Industrial Wastewater Treatment Using Algae

- Low energy requirement
- Cost effective
- Removes heavy metals
- Biomass produced
- CO_2 fixed

Examples of Benefits of Phycoremediation of Wastewater

(Based On Data from Implementation in the Alginate Industry)

Cost parameter	Conventional Effluent Treatment	Phycoremediation	Annual cost benefit
Acidity - High levels of dissolved carbon dioxide	Neutralization with caustic soda	Algal treatment to absorb the acidic contents and neutralize the effluent	Rs. 50 lakhs spent for caustic soda annually is saved (100%). The total cost for the utilities (labor / electricity etc) used in the operation is almost identical. At around Rs. 2 lakhs p.a. *
Sludge formation	Evaporation of effluents deposits sludge. That needs to be buried in a land fill. About 290 tonnes of sludge produced annually.	Algal remediation produces a nutrient rich, commercially valuable fertilizer that is highly demanded in the market. There is no residual sludge.	The sludge disposal used to cost an estimated Rs. 3 lakhs annually. This cost is saved. * Additionally revenues from the sale of algal biomass fertilizer.
Structures and space.	11,000 Sq m of masonry tank for evaporating the effluent	3000 sq m of tank for containing and evaporating the effluent.	About 75% of the effluent treatment facility space is released. This very valuable real estate structural space is now being used for other productive uses.

Sample Content: Case Studies

Old Dominion University

Jan, 2008

> Algae will be grown in treated wastewater that will flow through the rooftop tanks. As they grow, the algae take in nutrients from the water that otherwise would be discharged into the Elizabeth River. This amounts to an extra scrubbing of the wastewater to make it better for the environment.

Scientists and engineers from the Old Dominion University, with a little help from a crane, lifted three algae cultivation tanks to a rooftop of the Virginia Initiative Plant wastewater treatment facility near campus to formally begin a collaboration that promises to be very environmentally friendly.

Faculty members and graduate students from the College of Sciences and the Frank Batten College of Engineering and Technology are working on a pilot project of the Virginia Coastal Energy Research Consortium (VCERC) to produce biodiesel fuel from algae.

Algae will be grown in treated wastewater that will flow through the rooftop tanks. As they grow, the algae take in nutrients from the water that otherwise would be discharged into the Elizabeth River. This amounts to an extra scrubbing of the wastewater to make it better for the environment.

The microscopic algae crop will be dried and converted to biodiesel by means of a proprietary reactor developed by ODU scientists. Preliminary tests of the process in the fall of 2007 (using algae that grew naturally) produced algal-based biodiesel fuel that has been used to power the engine of a remote-controlled vehicle.

Sample Content: Research & Experiments

Cleansing Wastewater with Algae – Sintef Fisheries / Irish Seaweed Centre Project

Source: Sintef Fisheries and Aquaculture - March 2006

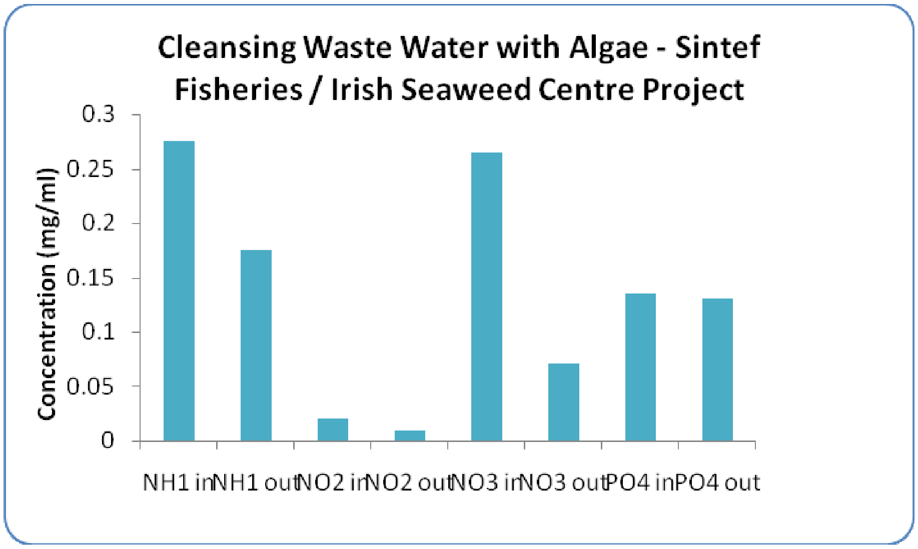
This was a Joint, INTERREG IIIC-financed project between SINTEF Fisheries and Aquaculture, and the Irish Seaweed Centre at the Martin Ryan Institute and Oyster Creeks Seafoods in Ireland.

Land-based aquaculture systems release water with high values of nutrients. Marine algae use most of these to produce biomass. This principle has been used to clean the water using algae in the effluent, by the research team. The resulting biomass can be a source of valuable chemicals for use in the food and drug industries.
This cleansing technology for aquaculture effluents was tested in the joint project in Ireland.

The technology was tested with the algae Porphyra and Ulva. These two were chosen because both algae have a high growth rate and a high N-content, and will therefore be able to function as effective cleaners.

The results from the experiment showed a clear reduction in the level of nutrients in the wastewater containing the algae.

The following chart, which provides the results of the experiment, shows the reduction in concentration for N and P.



Notes:

In: concentration of NH1 in the effluent entering the tank containing algae

Out: concentration of NH1 in the effluent exiting the tank containing algae

The technology is expected to have excellent potential in integrated aquaculture by adding value to fish farming.

The best culture conditions from the previous experiment (CO_2 addition and light of 15000 lux) was then applied in a running high rate algal pond ("end pipe" treatment) as a continuous culture (128 liters, mixing rate of 10 cm second-1, retention time of 4 days) for 12 days at steady state. The result showed an algal production of 0.181 mg l-1 day-1 (chlorophyll-a) and nutrient removal rate of: 23.3 % (TAN), 22.2 % (NO_2 --N), 2.2 % (NO_3 --N), and 7.8 % (PO_4 3--P).

The algae showed a better growth and nutrient removal when cultured in condition with CO_2 aeration and a light intensity of 15000 lux. Nutrient removal capacity of the algae was better with semi-continuous culture, followed by continuous and batch culture. However, the algal production was higher in batch culture followed by continuous and semi-continuous culture.

4 Nutrient Requirements of Algae

This chapter provides a better understanding of the nutrient requirements of algae and enables the reader to decide on the additional nutrients to be added for growing algae in wastewater.

Sample Content: Phosphorus Requirements

Phosphorus is a key nutrient element required for normal growth of algae. Although the concentration of organic phosphate in natural waters often exceeds that of inorganic phosphate, the major form in which microalgal cells acquire phosphorus is as inorganic phosphate. Phosphorus is rarely limiting in wastewater derived from animal husbandry, however, nitrogen may become limiting. The optimum N: P ratio for phytoplankton growth generally is about 15: 1, and high ratios (i.e., about 30: 1) suggest P limitation, whereas low ratios of about 5: 1 suggest N- limitation (Darley, 1982).

5 Harvesting of Algae from HRAP

Harvesting is an important aspect to be considered in the algae-based wastewater treatment process, owing to its significant contribution to the cost of operations. Cost-effective phycoremediation requires optimal algae harvesting methods to be used. This chapter provides a thorough understanding of various methods of harvesting employed for algae grown in wastewater.

Sample Content: Introduction

Choosing a harvesting method depends mainly on the types of algae species that are growing in the wastewater treatment system. Species control in wastewater treatment systems will greatly aid in algal harvesting by favouring filamentous or easily settleable algae (Benemann et al 1980).

Examples of microalgae wastewater systems in Northern California and their harvesting methods are listed below

Location	Area (ha)	System Design	Algae Harvest
Napa	140	Deep Ponds	Harvest Flocculants
St. Helena	8	Raceway (2 ha)	Terminal Settling ponds
Sunnyvale	180	Deep Ponds	Harvest Flocculants
Hollister	13	Raceway (5 ha)	Land Disposal

Source: http://www.osti.gov/bridge/servlets/purl/137315-0uSjuX/webviewable/137315.pdf

6 End Uses of Algae Grown in Wastewater

This chapter lists the various end uses of algae produced from wastewater and provides detailed inputs on the market size and market price for each product.

Sample Content: Fuel Applications of Wastewater Grown Algae

Algae can be used to produce many types of biofuels. Among them:

- Biodiesel, by transesterification of algal oil.
- Bioethanol (C_2H_6O) by fermentation and distillation of sugars
- Biobutanol ($C_4H_{10}O$), which can be produced from the green waste left over from the oil extraction.
- SVO (Straight Vegetable Oil), which is algal oil directly used as a fuel. It requires modifications to a normal diesel engine.
- Biogas (methane) production was the focus of most of the early work in biofuels from microalgae, when these were considered mainly for their applications in wastewater treatment.
- Other hydrocarbon fuel variants, such as JP-8 fuel, gasoline, etc.

The scope of applications and the current and potential market sizes for the above energy products are already significant, and are expected to be much larger in future.

Sample Content: Non-fuel Applications of Wastewater Grown Algae

A summary list of non-fuel applications of wastewater grown algae:

- Animal & Fish Feed - Shrimp feed, Shellfish Diet, Marine Fish Larvae Cultivation
- Chemicals & Fertilizer
- Biopolymers & Bioplastics
- Paints, Dyes and Colorants
- Lubricants
- Pollution Control
  - CO_2 Sequestration
  - Uranium/Plutonium Sequestration

- Fertilizer Runoff Reclamation
- Sewage & Wastewater Treatment

7

Challenges Associated with Growing Algae in Wastewater

This chapter presents a comprehensive list of challenges associated with algae-based wastewater treatment systems.

Sample Content: Challenges Associated With Algae-based Wastewater Treatment Systems

Algae-based wastewater treatment technology is suited for tropical countries where the temperature is warmer and sunlight is optimum. Environmental factors play a major role in algae cultivation. Maintenance of optimum temperature and lighting in algae ponds are difficult. Apart from these environmental factors, there are a number of biological problems and operational problems can arise in the mass cultivation of microalgae using wastewater. These include contamination and grazing. Control measures for avoiding contamination by bacteria and other algal species are sterilization and ultra-filtration of the culture medium. Grazing by protozoans and diseases like fungi can eventually be treated chemically.

Some of the key challenges are described below:

Land requirement

The principal disadvantages of algal pond systems are that they require much larger areas of land than other forms of sewage treatment. Thus, design engineers must consider local land prices and soil suitability in selecting the least cost method of wastewater treatment. In many cases, ponds will be the treatment system of choice, as suitable land is often available at relatively low cost.

8 Companies in the Algae - based Wastewater Industry

This chapter provides detailed profiles of a number of algae-based wastewater treatment companies, from diverse regions worldwide such as USA, New Zealand, Australia and India. It provides insights about the concepts, processes and technologies used by these companies.

Sample Content: Company Profiles

Sunrise Ridge Algae, Inc.

Main line of activity: Production of Biofuels from Algae Grown in Wastewater

Headquartered at: Austin (TX), USA

SunriseRidge Algae is a Texas, USA Corporation engaged in research, development and commercialization of algae biomass technology for reduction of water and greenhouse gas pollutants and production of renewable fuel feedstocks and animal feeds.

Sunrise Ridge was founded in Houston in 2006 and has algae-growing operations in Austin, Texas, at the City of Austin's Hornsby Bend wastewater sludge treatment plant.

Process & Technology

The company has demonstrated that algae can remove nutrient pollutants from the wastewater. The company is working to integrate wastewater treatment, carbon dioxide consumption and bio-oil production to create a highly efficient process for cleaning up pollution while generating revenues from biofuel sales. This process may be interesting to municipal utilities, industrial companies and agricultural firms, since it helps solve many of their pollution issues.

Sunrise Ridge Algae's pilot facility uses clear plastic bags to grow algae, fed with municipal wastewater and CO_2. A circulation system (inset top) is used for churning the wastewater. The harvested algae are then dewatered (inset bottom). However, the systems face high infrastructure costs, and an indoor system may require artificial lighting, which increases energy costs. A key issue at Sunrise Ridge is lowering the costs of the greenhouses while maintaining a high production of algae, insuring a return on capital invested in the system. Maintaining a high production rate is dependent on selecting algae strains with high oil content that grow well in the greenhouse environment. Oil content can vary from 4 to 50 percent by weight, depending on the species and growing conditions.

CO_2 is created at many wastewater treatment plants when sludge is incinerated or processed in an anaerobic digester to produce biogas (a mixture of methane and CO_2). Sunrise Ridge takes CO_2 from the plant's flue stacks and bubbles it through the plastic greenhouses. The enclosed greenhouses maintain desired CO_2 concentrations by preventing the gas from bubbling out into the atmosphere. In initial testing, algae reduced nitrate levels in the wastewater to as low as two part per million.

Highlights

- With a goal to produce biodiesel, ethanol and animal feed supplements, the company has a focus on using wastewater to grow algae.

http://www.sunrise-ridge.com

9 Algae Cultivation in Wastewater – Q&A

This chapter provides answers to specific questions that are frequently asked about some of the critical aspects in algae-based wastewater treatment.

Sample Content

Is it possible to combine wastewater from different industries and treat them with algae?

Yes, it is possible to use different waste such as piggery waste, poultry waste and aquaculture waste and then do a primary treatment to treat it with sludge. A research effort from researchers from SARDI Aquatic Sciences Centre, South Australian Research Development Institute (2003) revealed that a combination of poultry waste, piggery waste and aquaculture wastes are excellent sources for algae wastewater treatment.

Will toxins affect algal growth in wastewater?

Yes, certain toxins can severely affect algae growth in wastewater. Consider the following experiment: An experiment determined the toxic effect of four metals, cadmium (Cd), copper (Cu), mercury (Hg) and lead (Pb), on the tropical microalga *Tetraselmis Chuii*. It evaluated the lethal effect daily, through the cellular count. In the control treatment (not exposed to any metal) the team observed an increase in cellular density. In all treatments exposed to metals, the team observed a decrease in cellular density, which accelerated in 48 h, after which it became less pronounced. The metal that caused the most lethal effect was Pb, which killed 50% of the microalgal population at a concentration of 0.40 mg/l. This concentration was 3 times lower than that of mercury and 13 times lower than those of cadmium and copper.

Content of Selected Heavy Metals in a Sample Wastewater Treatment Plant

Metal	Influent (mg.l^{-1})		Effluent (mg.l^{-1})		RE*	Solid Fraction (mg.kg^{-1} dm)	
	Min-max	Mean ± SD	Min-max	Mean ± SD	(%)	Min-max	Mean ± SD
Cd	0.01-0.80	0.29 ± 0.31	0.006-0.01	0.008±0.002	97.3	0.6-15.2	7.45±5.90
Pb	0.02-1.70	0.66 ± 0.71	0.02-0.23	0.125±0.082	80.3	3.8-45.2	35.38±15.68
Cu	0.50-2.10	1.22 ± 0.64	0.03-0.10	0.067±0.035	94.5	37.5-45.2	41.40±2.42
Zn	0.32-14.5	7.15 ± 5.86	0.12-0.44	0.27±0.12	96.2	201.2-310.2	252.40-34.96

*: Removal efficiency

Source: *http://www.ramiran.net/doc05/Folia/Vargova.pdf*

Other questions for which answers are provided in this chapter:

1. At which stage of wastewater treatment are algae introduced?
2. What are the natural microfloras of microalgae present in the wastewater?
3. Worldwide, which are the regions that are most suited to algae-based wastewater treatment?
4. Is it possible to grow macroalgae in wastewater for bioremediation?
5. Is it possible to treat acidic effluents with algae?
6. Which are the algal strains suitable for basic effluents?
7. As wastewater already contains nutrients, is there any need for additional nutrients for algae cultivation in wastewater?
8. Are there any algae predators present in wastewater?
9. What are the monitoring techniques used in algae wastewater treatment?
10. To what extent are algae capable of reducing heavy metals from wastewater?
11. What is the potential of algae wastewater treatment for anaerobic digestion effluents?
12. Is it possible to use algae to treat organic pollutants like phenolic wastes? Which algal strains are suitable to treat wastewater with high phenolic content?
13. What are the constraints in using wastewater grown algae for animal feed?

10 References

This chapter lists organizations and universities involved in algae-based wastewater treatment research, to enable researchers and entrepreneurs to interact with them.

Sample Content: Universities in Algae-based Wastewater Treatment Research

University of Minnesota, USA

May, 2009

Officials in St. Paul, Minnesota, USA believe a pilot project to grow algae at the city's wastewater plant will clean the water before it's pumped back into the Mississippi River and provide biomass for biofuels.

The process will also take nitrogen and phosphorus out of the water that can be used to make fertilizer:

A team of researchers from the University of Minnesota partnered with the Metropolitan Council for the project, using centrate—liquid waste separated from the solids—to grow several species of algae that can thrive in wastewater.

The project started in 2006 on a much smaller scale, using wastewater in labs, and recently moved to Met Council's treatment plant.

The project will use an enclosed photobioreactor that allows the algae to grow in a smaller area. Officials believe they could produce daily 1,000 to 4,000 gallons of oil to turn into biodiesel.

Source: http://domesticfuel.com/2009/05/18/st-paul-wastewater-plant-to-grow-algae-for-biomass/

Sample Content: Wastewater Treatment – Latest Innovations

Heavy Metal Removal: The MetFloc™ "Floc & Flow" Process

2007

The MetFloc™ Metals Removal Process removes all heavy metals from wastewater, is not pH sensitive, and is highly efficient even in the presence of interfering agents (EDTA, ammonia, sulfates, phosphates, etc.). It encompasses pollution prevention, waste minimization, and resource recycling.

Process:

1. Wastewater is pumped from a holding tank into the 80 gallon batch reaction tank.
2. The semi-automated system is initiated by the operator when prompted by the display.
3. When the tank is full, the pH controller begins injecting the MetFloc chemical into the reaction tank until the pH reaches the desired set point depending upon the metals
4. The selected polymer for the application is automatically injected into the tank in the correct proportion
5. The solids are then collected in a dual filter bag system that retain the solid floc
6. Treated water collects in the bottom of the unit and is automatically transferred by the sump pump to the sewer or to a holding tank for final discharge.

Source:
http://www.wastechengineering.com/newsletters/mail54AA_heavy_metal_removal.htm
http://www.pavloschemicals.com/

Microalgae Growth-Promoting Bacteria as ''Helpers'' for Microalgae: A Novel Approach for Removing Ammonium and Phosphorus from Municipal Wastewater

Luz E. de-Bashan et al, 2003

A combination of microalgae (Chlorella vulgaris or C. sorokiniana) and a microalgae growth-promoting bacterium (MGPB, Azospirillum brasilense strain Cd), co-immobilized in small alginate beads, was developed to remove nutrients (P and N) from municipal wastewater.

The methods include:

1. Immobilization procedures
2. Design and construction of a device for production of alginate beads
3. Municipal wastewater source
4. Water analyses of treated wastewater
5. Experimental design and statistical analysis

This study is the first report demonstrating that the new co-immobilization technology is capable of reducing nutrients (N and P) from regular municipal wastewater. Although the removal by the current co-immobilization system is still small (under 1mg/l), it has potential in new approaches to biologically removing nitrogen and phosphorus from wastewater.

Source: http://www.bashanfoundation.org/gmaweb/pdfs/DomesticNP.pdf

Simultaneous Nitrification, Denitrification and Phosphorus Removal

Deepak Pant, 2006

Simultaneous nitrification and denitrification (SND) via the nitrite pathway and anaerobic-anoxic enhanced biological phosphorus removal (EBPR) are two processes that can significantly reduce the COD demand for nitrogen and phosphorus removal. The combination of these two processes has the potential of achieving simultaneous nitrogen and phosphorus removal with a minimal requirement for COD.

A lab-scale sequencing batch reactor (SBR) was operated in alternating anaerobic-aerobic mode with a low dissolved oxygen concentration during the aerobic period, and was demonstrated to accomplish nitrification, denitrification and phosphorus removal. Under anaerobic conditions, COD was taken up and converted to polyhydroxyalkanoates (PHA), accompanied with phosphorus release.

In the subsequent aerobic stage, PHA was oxidized and phosphorus was taken up at the end of the cycle. Ammonia was also oxidized during the aerobic period. These experiments also showed that denitrifying glycogen-accumulating organisms rather than denitrifying polyphosphate-accumulating organisms were responsible for the denitrification activity.

Source: http://www.ncbi.nlm.nih.gov/pubmed/15656309

Section 2 - Algae for Fuels

This is a reference section and has been provided for a better understanding of the emerging algal biofuels industry

11. Energy from Algae - Introduction

12. Algal Strain Selection

13. Algae Cultivation

14. Algae Grown in Open Ponds, Closed Ponds & Photobioreactor

15. Photobioreactors

16. Harvesting

17. Biodiesel from Algae

- Increasing the Oil Yields from Algae
- Examples of Research & Case Studies of Increasing Oil Yields in Algae

17.6 Methods to Extract Oil from Algae
17.7 Converting Algae Oil into Biodiesel

- Concepts
- Transesterification
- Problems with Transesterification
- Tranesterification By-products
- New Developments in Transesterification
- Transesterification Factoids
- Challenges in Conversion of Algae Oil to Biodiesel

18. Hydrogen from Algae

18.1 Introduction
18.2 Methodologies for Producing Hydrogen from Algae
18.3 Factoids
18.4 Current Methods of Hydrogen Production
18.5 Current & Future Uses of Hydrogen
18.6 Why Hasn't The Hydrogen Economy Bloomed? – Problems with Hydrogen

19. Methane from Algae

19.1 Introduction
19.2 Methods of Producing Methane from Algae
19.3 Methane from Algae – Other Research & Factoids
19.4 Traditional Methods of Methane Production
19.5Methane – Current & Future Uses
19.6 What's New in Methane?

20. Ethanol from Algae

20.1 Introduction
20.2 Ethanol from Algae - Concepts & Methodologies

- Fermentation of Algae Biomass
- Fermentation of Left-over Algae Cake

21. Other Energy Products – Syngas, Other Hydrocarbon Fuels, Energy from Combustion of Algae Biomass

22. Algae Meal / Cake

23. Cost of Making Oil from Algae

24. Potential for Existing Companies in Related Industries Entering Algae Energy Domain

Section 3 – References

25. Apex Bodies, Organizations, Universities & Experts

Sample Content: Universities & Research Institutes

Arizona State University, USA

Arizona State University signs biodiesel microbe pact with BP and Science Foundation Arizona – November, 2007 - Arizona State University announced a partnership with BP and Science Foundation Arizona to develop photosynthetic bacterium to produce biodiesel. The microbes use only solar energy and a controlled environment, which can be established in Arizona's desert lands. Arizona has recently emerged as a leading state for research and production of micro-algae based biodiesel. Numerous algae ventures have been in the news lately, with ventures such as PetroSun, Solazyme, Valcent and GreenFuel working on projects which are primarily located in Arizona and Georgia.

26. Culture Collection Centers

26.1 Introduction

26.2 List of Algae Culture Collection Centre

Country	Centre	Mode of ordering
Australia	CSIRO Microalgae Research Centre http://www.cmar.csiro.au/microalgae/supply.html	Fax or Mail
Canada	University Of Toronto Culture Collection http://www.botany.utoronto.ca/utcc/	Online, Fax and Phone
	Canadian Centre For Culture Collection http://www.botany.ubc.ca/cccm/	Mail, Phone or Fax
Czech Republic	Culture Collection of Algae of Charles University of Prague http://botany.natur.cuni.cz/algo/caup.html	Mail, Phone or Fax
	Culture Collection of Algal Laboratory (CCALA) Institute of Botany, Academy of Sciences of the Czech Republic www.butbn.cas.cz	Online

Price of the Wastewater Treatment Using Algae Report

The price of the Wastewater Treatment Using Algae Report is **US $1000**

This price includes:

> **Free Updates:** Customers who buy the report get three updated versions released subsequent to their purchase, at no additional cost
>
> **Expert Assistance:** Customers also get to use the expertise of professionals @ Oilgae for no cost or for highly subsized rates
>
> **Customizability:** Oilgae can provide minor customizations and enhancements to the report usually at no additional cost.

You can purchase the report using a credit card from here -
http://www.oilgae.com/ref/report/wastewater_treatment/purchase.html

To know more about the report, visit -
http://www.oilgae.com/ref/report/wastewater_treatment/wastewater_treatment.html

If you are interested in purchasing the report or knowing more about it, please send a send a note to **Narsi Santhanam** – email: narsi@clixoo.com , Mobile: +91-98413-48117 (India)