

**EDSGN100 Design Project #2  
Final Design Report**

**Water Treatment Innovation**

**Introduction to Engineering Design  
EDGSN 100 Section 025**

Team #7

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**Submitted to: Prof. SMITH  
Date: 12/16/2013**

## 1.0 Introduction

In this project we faced the task of identifying and then making a current system on the Penn State campus more sustainable utilizing Aluminum, we discussed various options and concepts. We were able come up with a practical solution to help Penn State's water treatment system. We came with concept involving aluminum coagulants, reverse osmosis membranes and algae turfs to help our current waste water system to produce potable water.

Our process is environmentally friendly and ecologically sustainable. We also realized we can produce bio-fuels with the algae we used and methane released as a resultant of the waste treatment.

Our task was to identify opportunities across the campus to take advantage of aluminum's intrinsic properties for the purpose of increasing the efficiency or sustainability of products and product systems. Looking at our current options as to where can we apply Aluminum's properties, but we were particularly fascinated with one property of Aluminum i.e. corrosion resistance, so we looked where could apply this on campus. After some research, we decided to select our water treatment plant, and visited, it to look at where can improve the wastewater treatment system. After realizing the fact, current system produces water that is not potable. We decided to research on potable drinking water.

Many properties such as its lightweight, strength, recyclability, corrosion, resistance, durability, ductility, formability and conductivity make aluminum a valuable material. Due to this unique combination of properties, the variety of applications of aluminum continues to increase. Aluminum is a very light metal with a specific weight of 2.7 g/cm<sup>3</sup>, about a third that of steel. For example, the use of aluminum in vehicles reduces dead weight and energy consumption while increasing load capacity.

Aluminum naturally generates a protective oxide coating and is highly corrosion resistant. Different types of surface treatment such as anodizing, painting or lacquering can further improve this property. It is particularly useful for applications where protection and conservation are required.

Aluminum is 100 percent recyclable with no downgrading of its qualities. The re-melting of aluminum requires little energy: only about 5 percent of the energy required to produce the primary metal initially is needed in the recycling process.

## 1.2 Initial Problem Statement

**Our initial statement as given by ALCOA: Identify opportunities across the campus to take advantage of aluminum's intrinsic properties for increasing the efficiency or sustainability of products and product systems.**

## 2.0 Customer Needs Assessment

In order to make potable water we have to follow the government (EPA) regulations for clean water, but we decided to create a few standards for our consumers. But we decided to better our current EPA standards. In order to make the customer needs table we took into consideration various aspects of water clarity such as turbidity, absence of chemicals (such as chlorine) in the water, water should not have any odor or sediments present in it and lastly whether water contains any contaminants. We matched this to metrics to get a better understanding of the customer needs/requirements.

Needs	Metric											
	Presence of Aluminum (0.05 to 0.2 mg/L)	Presence of Chloride (250 mg/L)	Color (15 color units)	Presence of Copper (1.0 mg/L)	Corrosivity (Noncorrosive)	Presence of Fluoride (2.0 mg/L)	Presence of Iron (0.3 mg/L)	Presence of Manganese (0.05 mg/L)	Odor (3 Threshold odor number)	pH (6.5-8.5)	Presence of Sulfate (250 mg/L)	Presence of Zinc (5 mg/L)
The water appears clear, without color or murkiness.			•									
The water tastes clean, absence of chemicals leaving a taste.						•				•		
The water does not have an odor.									•			
The water does not contain any remaining sediment.	•	•		•			•	•			•	•
The water does not contain harmful contaminants.					•							

### 2.1.1 Target Specification

In order to have a certain benchmark we had to create targets for our project in order to meet our customer needs. So we created a table which shows Water quality standards for pH, dissolved oxygen and other nutrients in water, we decided that we select some particular solids found in waste water and to reduce their quantities in water.

Standards for specific classes are provided in this section.

Pollutant	Priority/non-priority	effects to the body	EPA standards	Our Target
Cyanide	P	Nerve damage or thyroid problems	0.2mg/L	0.01mg/L
Ammonia	P	skin problems, carcinogen	0.010mg/L	0mg/L
Nitrate (measured as nitrogen)	P	harmful for babies, may result in shortness of breath	10mg/L	5mg/L
Lead	P	Kidney problems and high blood pressure	0.015mg/L	0mg/L
BOD	P	diarrhea, harmful to the kidney	2.5/L	0/L
pH	P		6.5-8.5	6.5-7.5

## 2.2 Revised Problem Statement

- To improve the efficiency of coagulation/ sedimentation and filtration in our waste-water treatment system on campus to make our treated waste water potable.

## 3.0 External Search

Throughout our redesign project, we used many sources including literature, patent, product dissection, and benchmarking sources. Each of these sources provided us with the necessary information into further our knowledge about water treatment.

### 3.1 Literature Review

Literature sources we found for our concept include sources from the Internet, encyclopedias, and stories/magazine articles.

<http://www.uark.edu/ua/cars/Subpages/Research/Ecosystems%20Services/algae%20biofuels.html>- here we found out information about the bio-fuel we can make from the algae.

- [http://www.enst.umd.edu/sites/default/files/\\_docs/LewisReport.pdf](http://www.enst.umd.edu/sites/default/files/_docs/LewisReport.pdf)- this research report talked about how algae turf scrubber and gave us an insight into the technology and how does it work.
- <http://large.stanford.edu/courses/2010/ph240/cash2/>- this research helped us to find out information how we can utilize energy from the methane produced from the treatment
- <http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-8544/BAE-1762web.pdf> - this research helped us find out about action of the aluminum coagulant

<http://www.water.epa.gov/drink/contaminants/>- set the government standards in the area of contaminants found in waste water

## 3.2 Patent Search

- Patent: US 8177978-Reverse Osmosis Membranes- This invention is related to thin film composite or TFC membranes including nanoparticles and/or other additives, and more particularly to such membranes used for reverse or forward osmosis to purify water. Reverse osmosis membranes, made by interfacial polymerization of a monomer in a nonpolar (e.g. organic) phase together with a monomer in a polar (e.g. aqueous) phase on a porous support membrane are known as TFC membranes and are used where flux and substantial rejection characteristics are required, for example in the purification of water. Various materials have been added to TFC membranes to increase flux without reducing rejection characteristics and have met with limited success. Such membranes are also subject to fouling resulting in reduced flux as contaminants, for example from the brackish or seawater to be purified, build up on the surface of the discrimination layer of the TFC membrane.
- Patent: US 4333263 Algal Turf scrubber- A method of producing an algal turf for use as a scrubber of carbon dioxide, nutrients and pollutants as well as biomass production is disclosed. A growing surface for spores or benthic microalgae is provided on a water surface. The growing surface is subjected to periodic water surge action to promote metabolite cellular-ambient water exchange and light is provided, natural or artificial to promote growth. The growing turf is harvested before being overgrown by larger microalgae

(As found in the original patent claim)

## 4.0 Internal Search

Through brainstorming we were able to come up with a variety of ideas that we thought could better our concept in order to appeal to the consumer's needs.

## 4.1 Concept Generation

We came up with these concepts which helped us to decide about how we are going to intervene in the current system



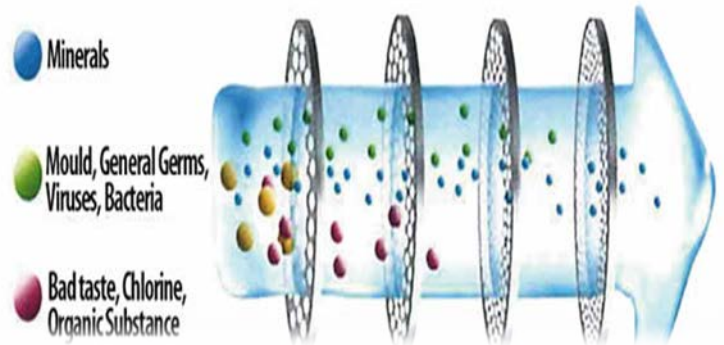
## Aluminum infrastructure

ALUMINIUM PIPES form one of the most hydraulically efficient sewer systems because of the smooth interior surface, longer lengths and cheap costs.



## Nano filtration

The primary filtering media in these systems is an **RO membrane**. Depending on your application, we offer different **reverse osmosis membranes** suited for sea water desalination, brackish water, and high flow commercial applications.



**Aluminum coagulant-** Coagulants and flocculants are formulated to assist in the solids/liquid separation of suspended particles in solution. Such particles are characteristically very small and the suspended stability of such particles (colloidal complex) is due to both their small size and to the electrical charge between particles. Conditioning a solution to promote the removal of suspended particles requires chemical coagulation and/or flocculation.

A liquid inorganic coagulant (Aluminum sulfate) has a cationic charge, it is formulated to promote the coagulation of precipitated particles and assist in their rapid settling during wastewater treatment.



**Algal Turf Scrubbing** is a cutting-edge solar/algal technology that harnesses attached primarily filamentous algae of many genera and species to capture the energy of sunlight and build algal biomass from CO<sub>2</sub>. A highly efficient capturer of nutrients from fresh, brackish, and seawater, and a wide variety of waste and industrially polluted waters, **ATS** performs point and non-point water cleaning services from aquarium to landscape scales. By combining algal-produced oxygen, at super-saturated levels, with solar or artificial **UV**, many toxic, organic compounds can be degraded by **ATS** systems. **ATS** naturally injects oxygen into source waters counteracting the hypoxic tendencies of degraded water bodies.

**ATS** produces a low cost harvestable algal biomass at an order of magnitude greater rate than agricultural and forestry products at the same latitude. Currently used commercially to sequester nutrients while producing cattle fodder and organic fertilizer, the **ATS** algal product can also be converted to paper and construction materials and can be used to sequester carbon. **ATS**-produced algal biomass can be converted to energy products such as biodiesel, gasohol, and methane. Using newer techniques, such as more complex substrate screens, 10-20X as much biofuel can be obtained from **ATS**, per unit area, as from agricultural products such as corn and soy.

## Algal turfs



## 4.2 Concept Selection

The concept selection tables are made below based on criteria like: Durability, Price, Environmental Impact, and Effectiveness of water treatment and ease of production.

Selection Criteria	Concepts				
	A Aluminum Infrastructure	B Aluminum Nanoparticle Coagulation	C Membrane Nanofiltration	D Reverse Osmosis Membrane Filtration	D Algae Treatment with Aluminum Channel
Durability	0	0	-	0	0
Price	0	+	0	0	0
Environmental impact	0	+	+	+	+
Effectiveness of Water Treatment	0	+	+	+	+
Ease of Production	0	-	0	0	+
Sum +'s	0	3	2	2	3
Sum 0's	5	1	2	3	2
Sum -'s	0	1	1	0	0
Net Score	0	2	1	2	3
Rank	5	2	4	2	1
Continue?	Yes	Combine	No	Combine	Yes

In this table we set each of our developed concepts side by side in an attempt to assess which ideas would move on to the next phase of selection. Using aluminum infrastructure as our base reference we determined based on five selection criteria, which concepts were better at achieving our goals of sustainability. We gave each selection a plus (+) or minus (-) in each category based on whether it was more or less effective in meeting the criteria compared to our reference concept. In the end, after adding up the pluses and minuses we were able to compare each design by their net scores. In conclusion, we found that the aluminum nanoparticle coagulation and the reverse osmosis membrane filtration were effective in meeting the criteria but could be even more effective if they were combined. Algae treatment with an aluminum channel proved to be the most effective and would also move on to the next phase with the aluminum infrastructure.



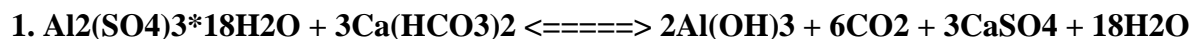
Concepts							
A Aluminum Infrastructure (Reference Concept)				CD Coagulation with Reverse Osmosis Filtration		E Algae Treatment with Aluminum Channel	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Durability	15%	4	0.60	3	0.45	4	0.60
Price	15%	3	0.45	4	0.60	4	0.60
Environmental Impact	30%	2	0.60	5	1.50	4	1.20
Effectiveness of Water Treatment	30%	1	0.30	5	1.50	5	1.50
Ease of Production	10%	2	0.20	3	0.30	4	0.40
Total Score			2.15	4.35		4.30	
Rank			3	1		2	
Continue?			No	Combine with D		Combine with BC	

If you look at the table above the process of selecting the best possible design began with assessing the weight of each selection criteria based on its relative importance. As a group, we felt in terms of sustainability that environmental impact and effectiveness of water treatment were more important and deserved more weighting than durability, price, and ease of production. From there, we began to evaluate a certain rating for each concept in each category of selection criteria based on how it compares to the reference concept, aluminum infrastructure. Then, multiplying the rating by the weight (relative importance) of each selection category we found a weighted score that demonstrated the how effective each design concept was at meeting the selection criteria. The addition of these weighted scores gave us a number that we could compare between design concepts. Finally, we concluded based on the total scores that the coagulation and reverse osmosis membrane filtration idea combined with the algae treatment would be the most effective design idea at meeting our goals for sustainability.

## 5.0 Final Design

The below picture is of an aerobic digester where **Aluminum sulfate, a.k.a. "filter alum", is commonly used as a coagulant in water treatment systems. In water treatment it is used primarily for the removal of tiny particles (called colloids, measured as total suspended solids) in the raw water which are too small to settle by gravity.**

**When alum is added to water it undergoes the reaction below. The alum reacts with bicarbonate to form Aluminum hydroxide, a precipitate.**

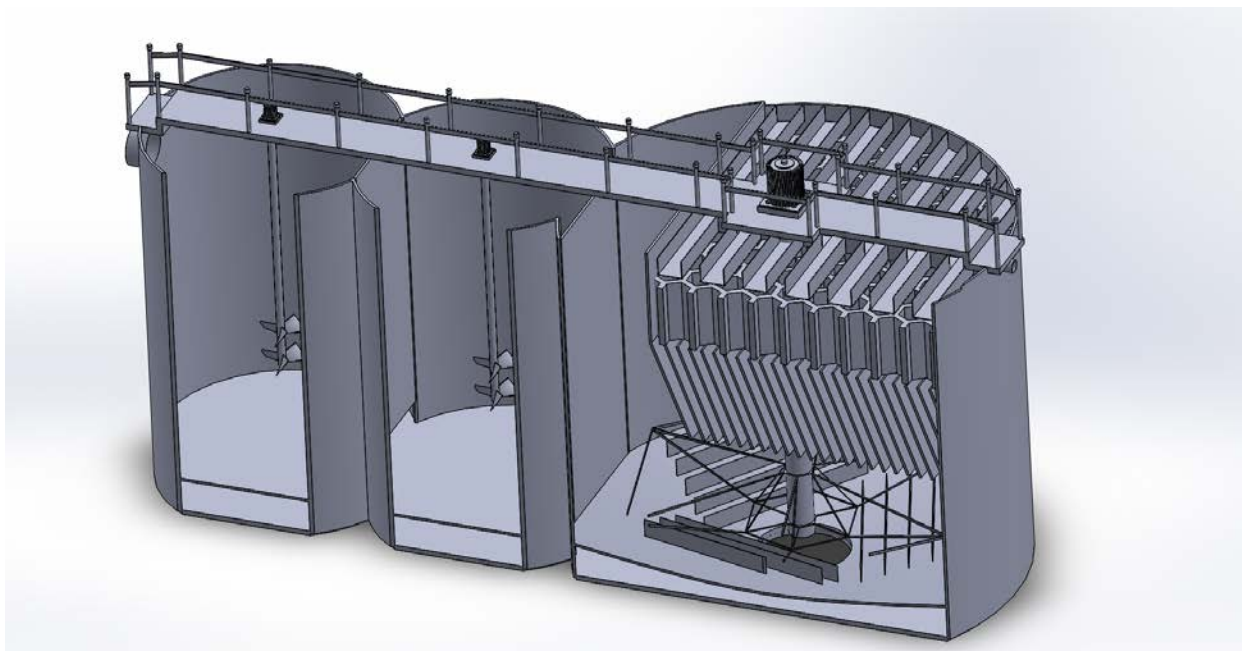


In a water treatment facility, the coagulant is added to the water and it is rapidly mixed, so that the coagulant is circulated throughout the water in machines as **shown below**. The coagulated water can either be filtered directly through a medium filter (such as sand and gravel), a microfiltration or ultrafiltration membrane, or it can be moved to a settling tank. In a settling tank, or clarifier, the heavy particles settle to the bottom and are removed, and the water moves on to the filtration step of the treatment process.

Coagulation can successfully remove a large amount of organic compounds, including some dissolved organic material, which is referred to as Natural Organic Matter (NOM) or Dissolved Organic Carbon (DOC).

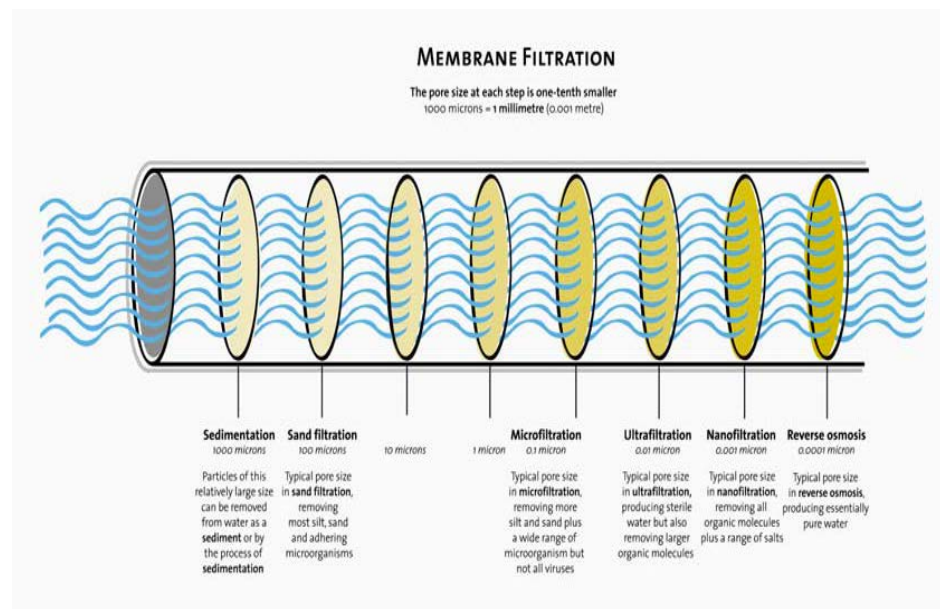
Coagulation can also remove suspended particles, including inorganic precipitates, such as iron. A large amount of DOC can give water an unpleasant taste and odor, as well as a brown discoloration.

Municipal water treatment plant can save money by using less chlorine, and the water will be safer, because trihalomethanes (THMs) are a dangerous by-product that results from the reaction of chlorine with NOM.

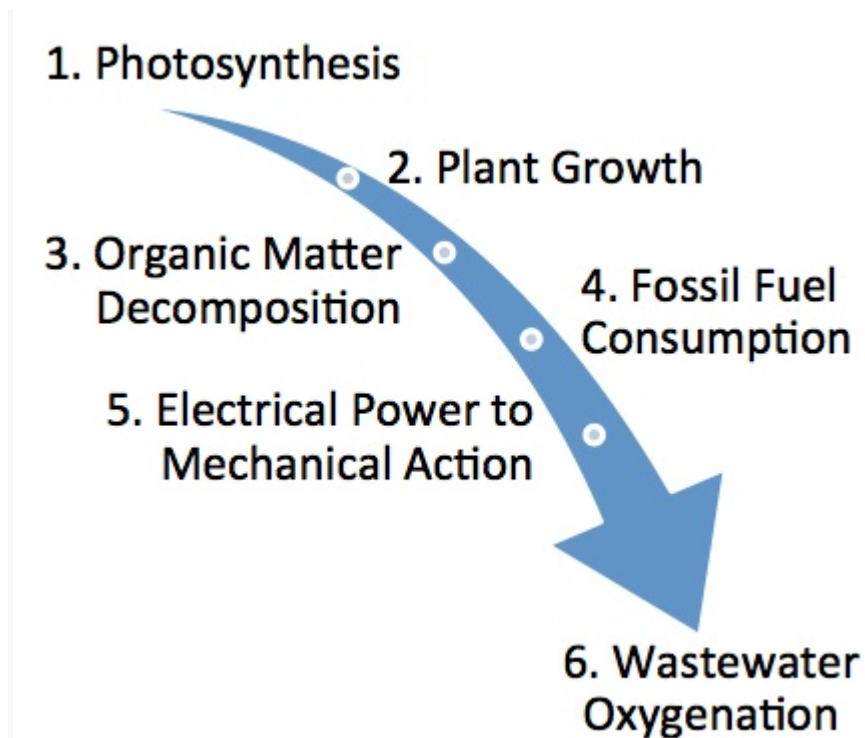


Then the water will be transferred to the reverse osmosis membranes where A membrane filtration system will act. Particles with a diameter greater than one millimeter, such as gravel and sand, are removed through the sedimentation process. Particles with a diameter greater than 100 microns (or 0.1 millimeter), such as fine sand, are removed through sand filtration. As the pore size decreases, a greater proportion of material is retained as the water passes through the filter. Often, a combination of several sizes of filters is used, so that large particles do not clog up too quickly. By using finer material, such as sand or expanded clay, or applying a coagulant, it is possible to remove small particles between one and 100 microns in size.

In water treatment plants, filtration removes a large number of contaminants, but still requires disinfection to produce drinking water that is safe.



The processed water will then move into an algae turf scrubber. The algae turf scrubber consists of a community of natural algae, attached to screens that are placed in the shallow treatment channels or raceways. The process involves pumping water over the screens, allowing the algae to perform its function. Algal turf scrubbing (ATS) is a novel wetland technology that has been designed and engineered to promote natural wastewater treatment processes. Algal turf scrubbing improves water quality by passing a shallow stream of wastewater over the surface of a gently sloped flow-way. The flow-way is colonized by a natural heterogeneous assemblage of periphyton consisting of cyanobacteria, filamentous algae and epiphytic diatoms together with aerobic bacteria and fungi. Algal photosynthesis provides oxygen for aerobic breakdown of wastewater by heterotrophic bacteria. Pollutants are extracted from the wastewater by several processes including assimilation, adsorption, filtration and precipitation. The algal turf is harvested periodically to remove the accumulated periphyton biomass and associated pollutants from the system. The major advantage mass cultured microalgae has over conventional aerobic wastewater treatment systems is reduced cost due to the decrease in energy input. At the heart of any aerobic wastewater treatment system is the need to supply oxygen in adequate concentration to the various microbes that will decompose the pollutants in the wastewater stream to stable compounds. In a conventional aerated activated sludge wastewater treatment system, the oxygen is supplied through a multi-step process described below and shown in Figure 1.



**Figure 1.** The six steps required to deliver dissolved oxygen (DO) into solution in a conventionally operated wastewater treatment system.

1. Plants grow using the energy from the sun in a process called photosynthesis.
2. Plants die and decompose.
3. The decomposition of organic material over eons results in the creation of fossil fuels.
4. Fossil fuels are harvested and used as an energy source to generate electricity.
5. Wastewater treatment plants convert this electrical energy to mechanical action in the form of paddles or blowers.
6. This mechanical action puts atmospheric oxygen into solution as dissolved oxygen (DO) for wastewater microbe respiration and extracts nutrients from waste water such as Nitrogen, Phosphorous etc.

Basic engineering principles teach us that at each step of this process, energy is lost and thus costs increase.

Conversely, in a microalgae wastewater treatment system, oxygen is supplied as a direct product of the photosynthesis process. Thus, the six-step process of supplying oxygen and removing nutrients in a conventional activated sludge wastewater treatment system is replaced by the much less energy intensive two-

step oxygenation process where wastewater oxygenation is created by the action of microalgae respiration during the process of photosynthesis.

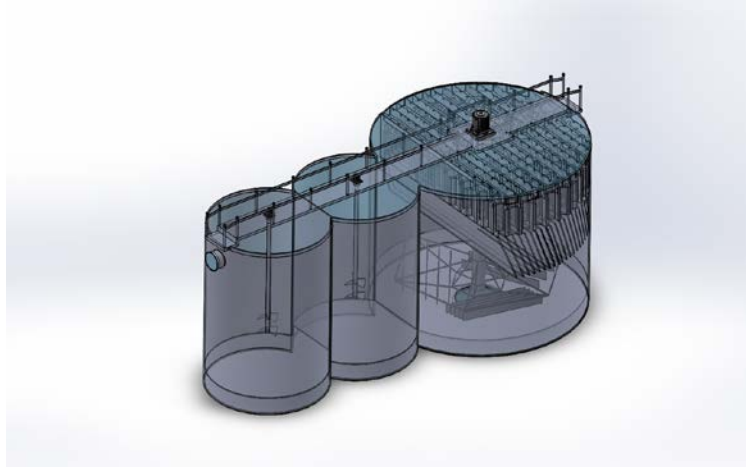
***Hence algae turf scrubber***, managed in a controlled environment, is a proven low initial capital cost, low operational cost supplement or alternative to mechanically aerated wastewater treatment systems. Microalgae-based wastewater treatment systems are particularly advantageous in low land-cost areas where sunlight and warm temperatures are plentiful.

Algae turf scrubber

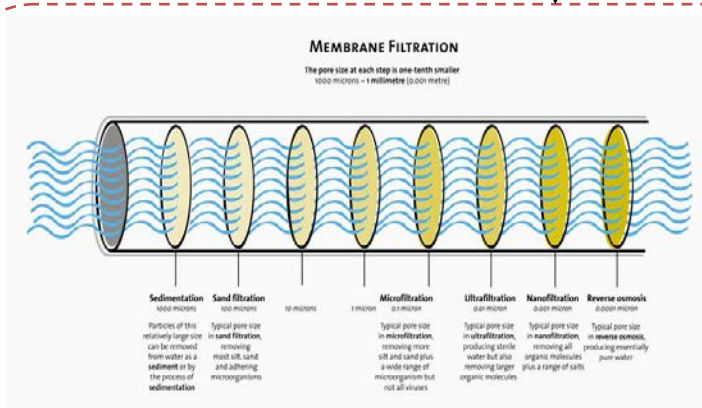
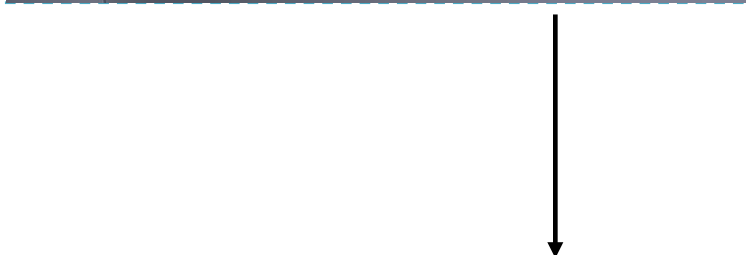
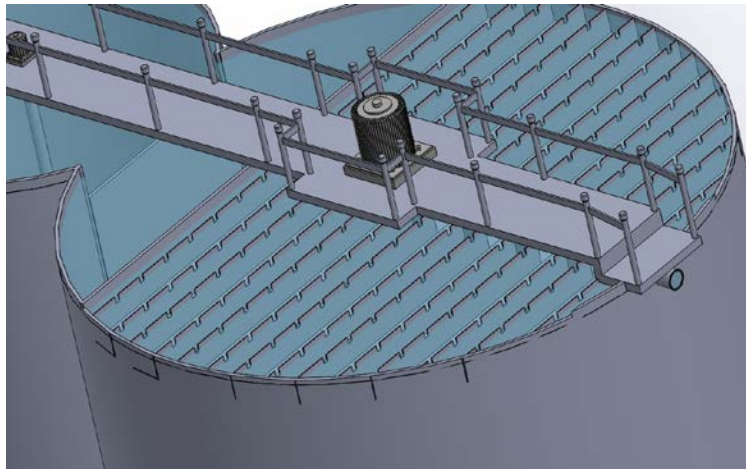


## ***5.1 Design Drawings and Parts List***





This is our sludge digester where the aluminum coagulant will be added and rapidly mixed, so that the coagulant is circulated throughout the water in machines as shown. This allows the faster sedimentation of solid particles. The heavy particles settle to the bottom and are removed.



The RO membrane where the particles with a diameter greater than 100 microns (or 0.1 millimeter), such as fine sand, are removed through sand filtration. As the pore size decreases, a greater proportion of material is retained as the water passes through the filter.





The Algal Turf scrubber will add oxygen to the waste water and remove micro-nutrients such as ammonia, nitrogen and phosphorous.

## 5.2 Bill of materials

We came up with the costs of the total design by looking up the costs of each of the products we used and then totaled it

Part Number	Part Name	Qty	Function	Material	Dimensions	Cost
1	Aluminum Channel	350ft	For the ATS	Aluminum	350ft*1ft	= <b>\$10,503.50</b>
2	Reverse Osmosis Membrane	4	For filtration	Polythene composite	7.9"*40"	\$720.59
3	Aluminum Sulfate	31.6mg	For sedimentation	Aluminum sulfate	-	\$14.35/day \$5,238.76 annually

## 6.0 Final Specifications

By our concepts we came up with our final specifications and the table shows the final specifications versus the targets we set. We believe using the technology we have suggested the final specification will be the below. We will reduce the values of BOD, nitrogen, ammonia and lead by drastic levels

Pollutant	Priority/non-priority	effects to the body	Our Target	Final Specification
Cyanide	P	Nerve damage or thyroid problems	0.01mg/L	0.01mg/L
amonia	P	skin problems, cacinogen	0mg/L	~0mg/L
Nitrate (measured as nitrogen)	P	harmful for babies, may result in shortness of breath	5mg/L	~0.25mg/L
Lead	P	Kidney problems and high blood pressure	0mg/L	~0mg/L
BOD	P	diahorrea, harmful to the kidney	0/L	21.2mg/L
pH	P		6.5-7.5	6.5-8

## 6.0 Conclusions

The world is facing formidable challenges in meeting rising demands of clean water as the available supplies of freshwater are decreasing continuously with increasing population our project aims to provide a 'sustainable solution to it'. The aluminum coagulant allows faster sedimentation. Nano-materials are having various significant characteristics that make them particularly attractive as separation media for water purification. They are having much large surface areas than bulk particles. They also have high capacity/selectivity for toxic substances in aqueous solutions.

The algae that we use in the scrubber process can be used to produced bio-fuels (in form of butanol easily by Ramsey fermentation)

- At the conclusion of our project we would like to propose that a lot of energy can be harvested from the algae and the methane released as part of the natural waste-water treatment process and that a power-plant next to our concept would be able pay-off itself in 11 years.  
methane produced: 1.50ft<sup>3</sup>/lb of garbage

We hope our concept will become an essential component of industrial and public waste water treatment systems as more progress is made in technology in terms of economically efficient and ecofriendly technology development.

## References

- Patent :US 8177978-Reverse Osmosis Membranes
- Patent: US 4333263 Algal Turf scrubber
- <http://www.uark.edu/ua/cars/Subpages/Research/Ecosystems%20Services/algae%20biofuels.html>
- [http://www.enst.umd.edu/sites/default/files/\\_docs/LewisReport.pdf](http://www.enst.umd.edu/sites/default/files/_docs/LewisReport.pdf)
- <http://large.stanford.edu/courses/2010/ph240/cash2/>
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- <http://www.sciencefriday.com/video/09/16/2011/purifying-water-with-pond-scum.html>
- <http://www.water.epa.gov/drink/contaminants/>

- [http://www.academia.edu/2472427/Nanotechnology\\_An\\_Emerging\\_Future\\_Trend\\_in\\_Wastewater\\_Treatment\\_with\\_its\\_Innovative\\_Products\\_and\\_Processes](http://www.academia.edu/2472427/Nanotechnology_An_Emerging_Future_Trend_in_Wastewater_Treatment_with_its_Innovative_Products_and_Processes)
- <http://www.safewater.org/PDFS/knowthefacts/conventionalwaterfiltration.pdf>
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