Phycoremediation of Landfill Permeate: A Mini Life Cycle Analysis

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BioEnergy Summer School

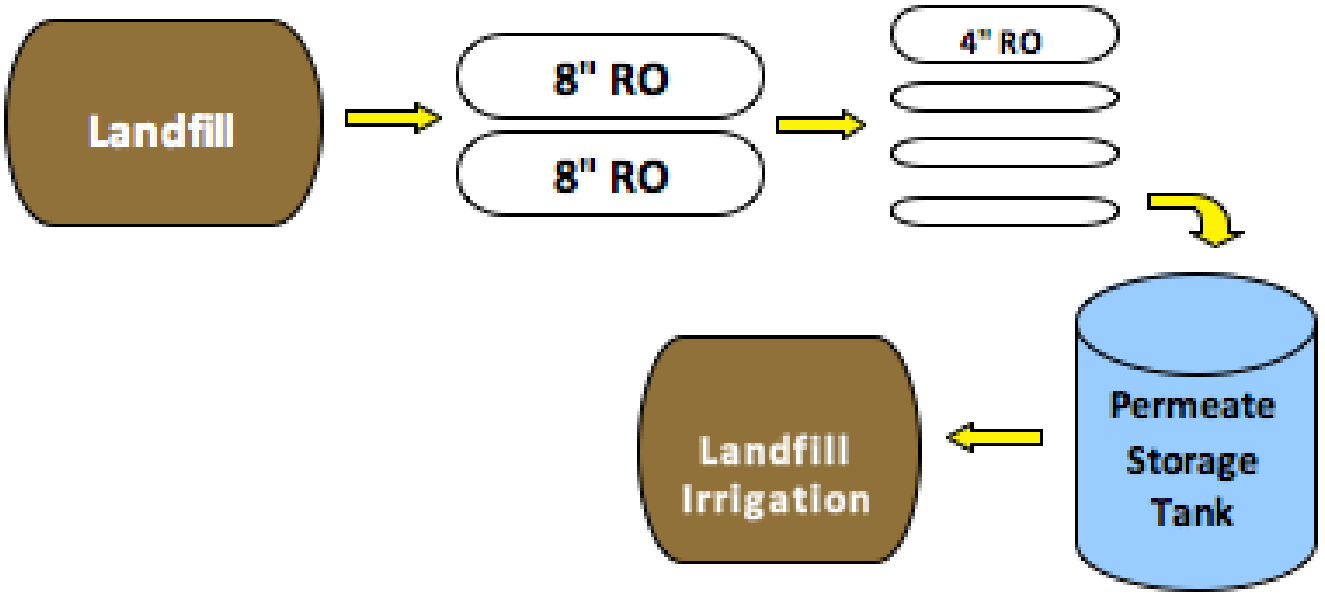
Landfills in Review

- Leachate from landfills is a current and pressing sustainability issue.
- Remediation Methods
  - Current: Transport to water treatment facility
  - Emerging: On-site biological, chemical or physical processes
  - Limited: Constructed wetlands
  - Experimental: Reverse osmosis, algae

Alachua County Southwest Landfill

- Current Treatment Method: Reverse Osmosis
  - Collection pipes drain into 40-ft. sump for storage
  - Pumped through 8” and 4” spiral wound membrane RO systems
  - Lowers ammonia levels to 5.1 ppm
  - Final permeate used for landfill cover irrigation

Current System Flow Chart



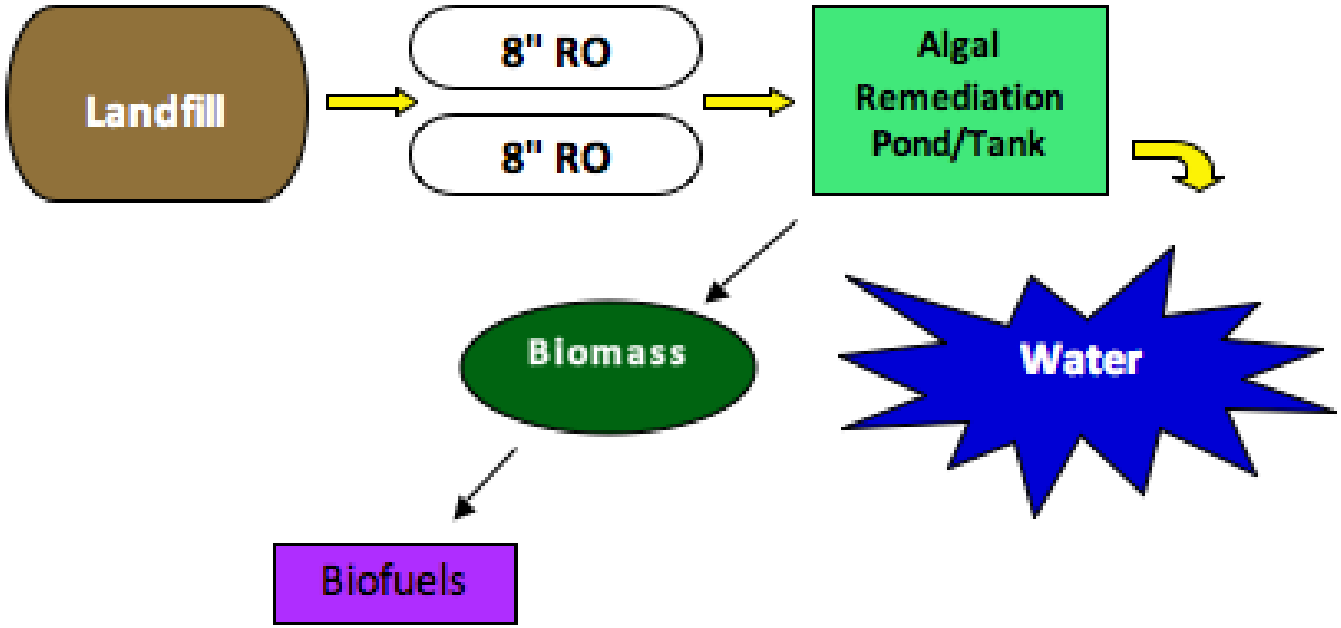
Phycoremediation

- Phycoremediation is the use of algae for the removal of pollutants from wastewater and the capture of CO_2 emissions (Olguin 2003).
  - Extensively researched in ecological engineering
  - Algae are effective at removing many organic and inorganic water contaminants

Benefits of Phycoremediation

- Less energy consumed (solar powered)
- On-site remediation
- Water that meets treatment standards
- Algal biomass can be used for fertilizer, animal feed and biofuels
  - Microalgal biofuel production may only be economically viable when coupled with remediation (Pittman *et al.* 2011).

Phycoremediation Flow Chart



Objective

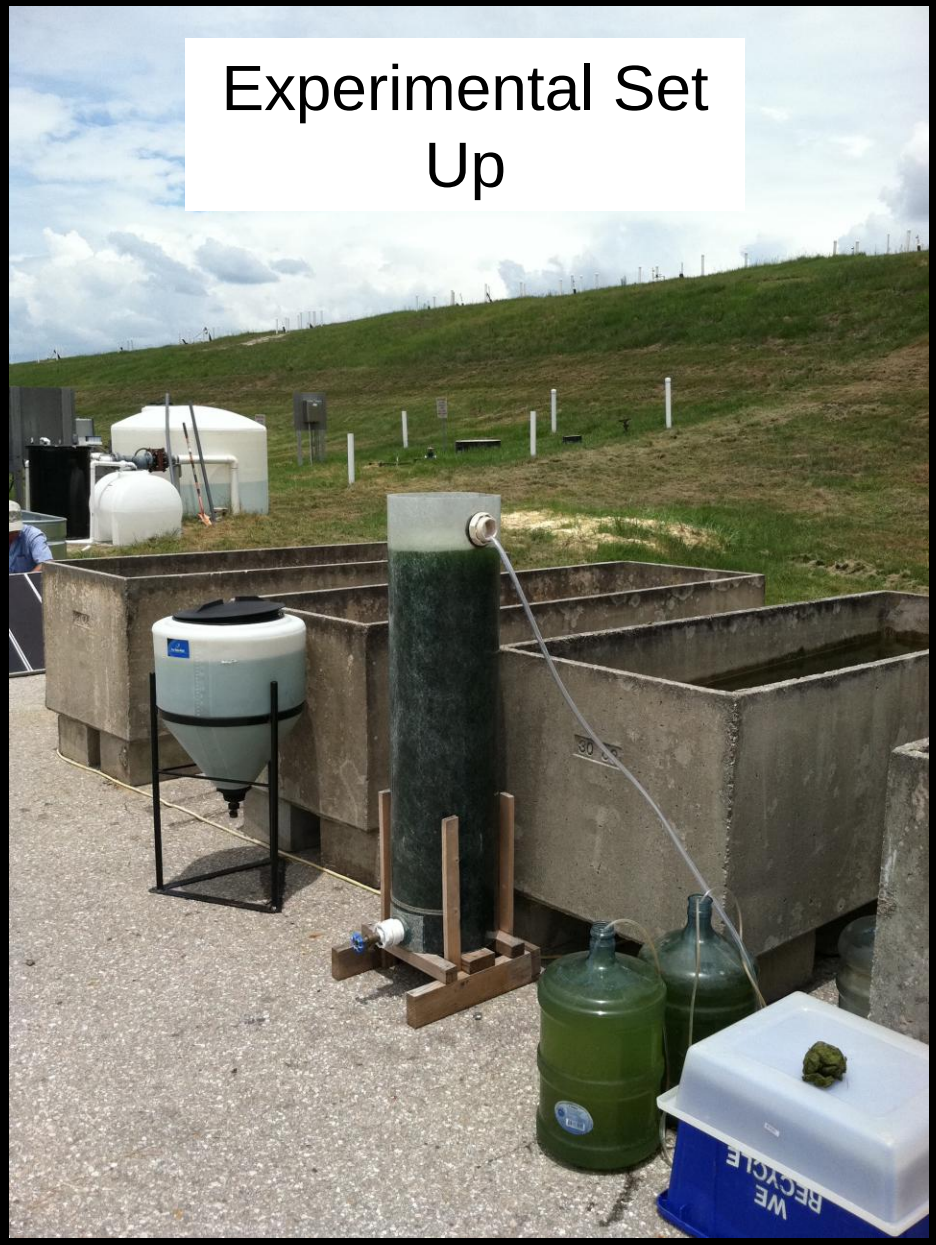
- Evaluate the cost and efficiency of phycoremediation compared to the second stage reverse osmosis system currently in place at ACSWL.

Methodology

- Four cultivation chambers were set up at ACSWL.
- Two chambers served as abiotic controls (filled with 790 L of permeate)
- Two chambers were filled with 50% permeate and 50% algal inoculum (790 L total)
- One control chamber and one inoculated chamber were mixed with a 1/6 Hp impeller pump. The remaining chambers were mixed with an air pump powering air stones.

Algal Inoculum

Cultivation Chamber

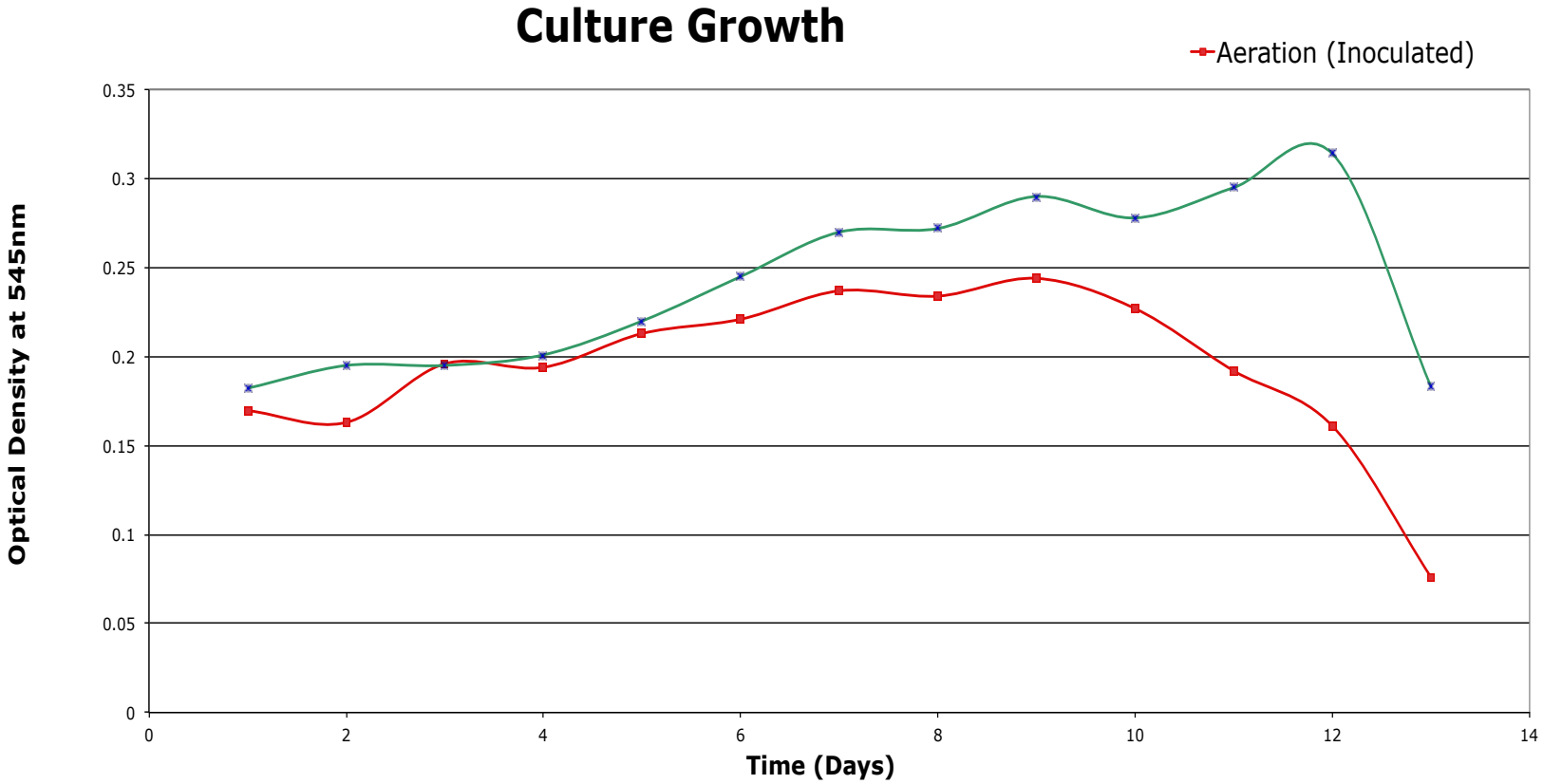


Experimental Set Up

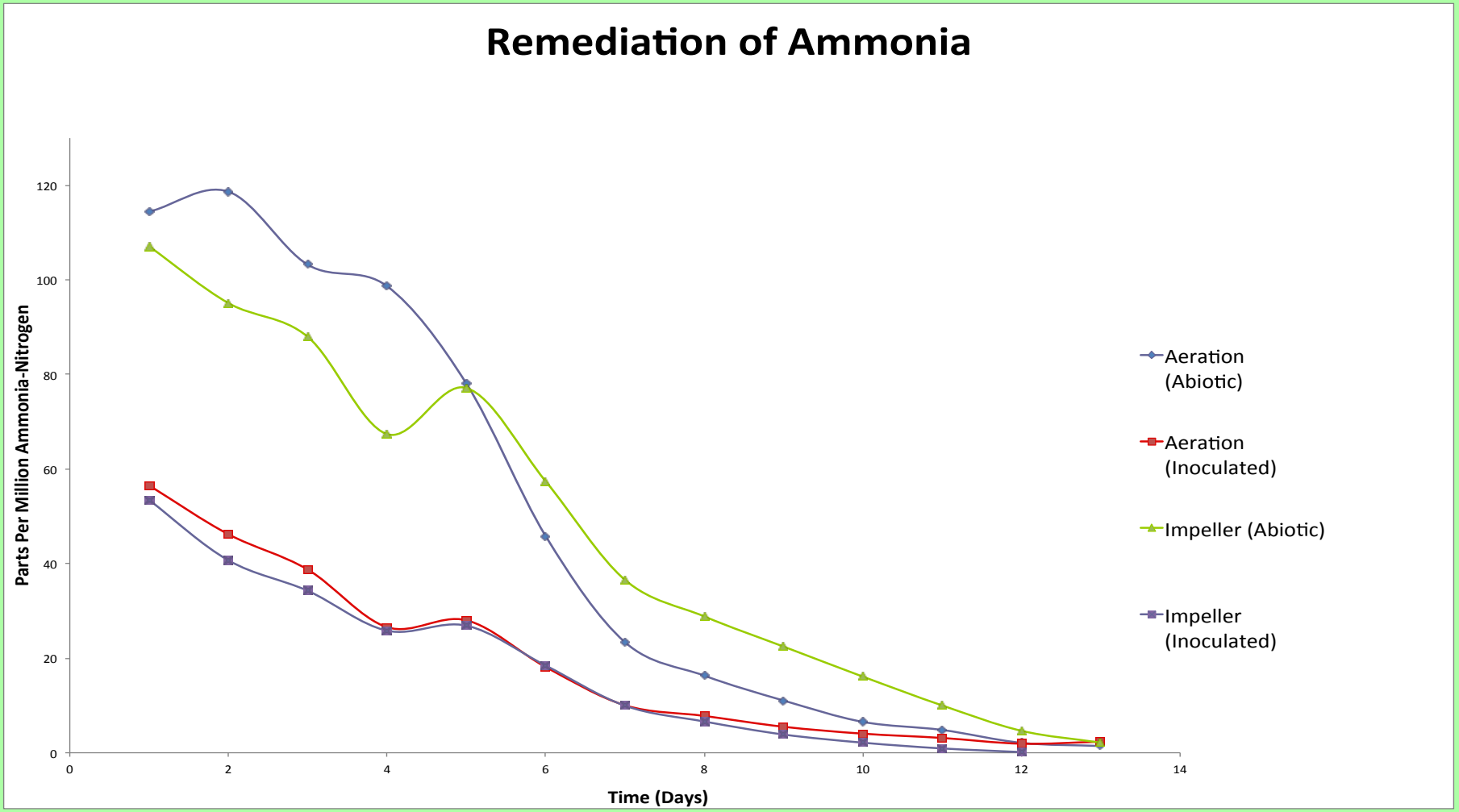
Methodology (cont.)

- Samples were taken daily for 13 days and measurements were taken for:
  - Ammonia
  - Optical density
- The energy consumption, cost and efficiency were then analyzed for the two remediation systems (RO and phycoremediation)

Results



Growth occurred in both chambers, but a higher growth rate was found with the impeller pump.



The chambers reduce ammonia levels below Groundwater Cleanup Target Levels of 2.8 ppm (FL DEP), partially by volatilization.

Combined 2-stage RO System

Cost of Reverse Osmosis

Assumptions

24 hours, 7 days/week	
Max Daily Treatment	4,500 gal.
Volume to be Treated	5,000,000 gal.
Time Needed	1,111 days
	159 weeks
	3 years

Capital Cost

4" RO System	$12,648.49
Building	$1,500.00
Electrical	$2,000.00
Plumbing	$500.00
Controls	$15,050.00
2 x 8" Pressure Vessels	$900.00
4 x 4" Membranes	$1,600.00
6 x 8" Membranes	$1,500.00
Storage Tank	$550.00
Irrigation System	$1,250.00
Permits	$2,500.00
Misc/Fittings/Shipping	$490.00
	$42,788.49

Labor

Hourly Part Time/Task	10 $/hr
	3 hrs
Salary	$30.00/day

Electricity Usage Estimate

Unit Cost	$0.145/kWh
1.0 Hp Leachate Sump Pump	18 kWh/day
1.0 Hp Indoor Pump	18 kWh/day
1.0 Hp Irrigation Pump	18 kWh/day
8" RO High Pressure 7.5 Hp Pump	134 kWh/day
Lighting and Control	12 kWh/day
Total	**254 kWh/day**

Cost of Algal Remediation (based on experimental design)

Assumptions

24 hours, 7 days/week	
Max Daily Treatment	26 gal.
Volume to be Treated	5,000,000 gal.
Time Needed	192,308 days
	27,473 weeks
	528.3 years

Capital Cost

Building	$1,500.00
Electrical	$2,000.00
Plumbing	$500.00
Controls	$15,050.00
2 x 8" Pressure Vessels	$900.00
6 x 8" Membranes	$1,500.00
7.5 Hp Pump	$2,300.00
1/6 Hp Sub. Pump	$68
PVC	$105.00
Permits	$2,500.00
Misc/Fittings/Shipping	$490.00
	$26,913.00

Labor

Hourly Part Time/Task	10 $/hr
	3 hrs
Salary	$30.00/day

Electricity Usage Estimate

Unit Cost	$0.145/kWh
1.0 Hp Leachate Sump Pump	18 kWh/day
8" RO High Pressure 7.5 Hp Pump	134 kWh/day
1/6 Hp Sub. Pump	2.0 kWh/day
Lighting and Control	12 kWh/day
Total	**166 kWh/day**

RO with Algal Remediation

Combined Two Stage RO System

Membrane Replacement	
4" Replacement Membrane	$400.00
# of 4" Membranes	4
8" Replacement Membrane	$250.00
# of 8" Membranes	6
System Membrane Replacement	$3,100.00

Operational	
Anti-Scalant 5 gal. (1 unit $24.62)	$1.03/day
Filter Cartridge (1 unit $20.00)	$1.42/day
Electricity	$36.83/day
Membrane Replacement (1 set)	$2.79/day
	$42.01/day

Total Cost 1 Set
$110.52/day
$122,809.79/Total Vol.

RO with Algal Remediation

Membrane Replacement	
8" Replacement Membrane	$250.00
# of 8" Membranes	6
System Membrane Replacement	$1,500.00

Operational	
Anti-Scalant 5 gal. (1 unit $24.62)	$1.03/day
Filter Cartridge (1 unit $20.00)	$1.42/day
Electricity	$24.07/day
Membrane Replacement (1 set)	$1.35/day
	$27.87/day

Total Cost 1 Set
$58.01/day
$11,155,776.96/Total Vol.

Theoretical Cost of Algal Remediation (1 ha./528,344 gal./20 cm deep Pond)

Assumptions

24 hours, 7 days/week	
Max Daily Treatment	66,043 gal.
Volume to be Treated	5,000,000 gal.
Time Needed	75.7 days
	10.8 weeks
	.21 years

* Theoretical costs adapted (Benemann 1986).

Capital Cost

Paddlewheel	$20,000.00
Site Preparation	$1,000.00
Growth Ponds	$9,250.00
Inoculum System	$1,500.00
Harvesting System	$1,500.00
Process Control	$500.00
Buildings/Vehicles	$3,500.00
Electrical	$1,000.00
Engineering	$2,500.00
Working Capital	$3,000.00
2 x 8" Pressure Vessels	$900.00
6 x 8" Membranes	$1,500.00
7.5 Hp Pump	$2,300.00
Permits	$2,500.00
	$50,950.00

Labor

Hourly Part Time/Task	$10/hr
	3 hrs
Salary	$30.00/day

Electricity Usage Estimate

Unit Cost	$0.145/kWh
Paddlewheel	20 kWh/day
1.0 Hp Leachate Sump Pump	18 kWh/day
8" RO High Pressure 7.5 Hp Pump	134 kWh/day
Lighting and Controls	12 kWh/day
	184 kWh/day

Membrane Replacement

8" Replacement Membrane	$250.00
# of 8" Membranes	6
System Membrane	$1,500.00

Operational

Anti-Scalant 5 gal. (1 unit $24.62)	$1.03/day
Filter Cartridge (1 unit $20.00)	$1.42/day
Electricity	$26.68/day
Membrane Replacement (1 set)	$1.35/day
	$30.48/day

Total Cost 1 Set

$733.53/day

$55,528.34/Total Vol.

Algal Pond with Paddle Wheel

Conclusions

- Phycoremediation uses much less energy.
- Phycoremediation of landfill permeate has great potential. Small scale would take hundreds of years, but full scale takes a fraction of the time.
- 1 ha. pond, 20 cm deep would take just .21 years for total remediation at a much lower cost.
- Growth needs to be optimized for biomass production.
- Future studies should focus on growth optimization and cost-effective pretreatment alternatives to RO.

References

- Olguin, E.J. (2003) Phycoremediation: key issues for cost-effective nutrient removal processes. Biotechnology Advances. 22: 1-2 81-91. DOI: 10.1016/j.biotechadv.2003.08.009
- Pittman, J.K., A.P. Dean, and O. Osundeko (2011) The Potential of Sustainable Algal Biofuel Production Using Wastewater Resources. *Bioresource Technology*. 102:1 17-25. DOI: 10.1016/j.biortech.2010.06.035
- Renou, S., J.G. Givaudan, S. Poulain, F. Dirassouyan, and P. Moulin (2008) Landfill leachate treatment: Review and opportunity. *Journal of Hazardous Materials*. 150: 3 468-493. DOI: 10.1016/j.jhazmat.2007.09.077