BioVantage Resources

ACRE Grant-2010

Final Report

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PROJECT OVERVIEW

This project was to research the viability of a bioreactor system to efficiently produce algae biomass from agricultural waste. BioVantage has successfully concluded this research and has built a pilot-ready algae production system. In addition, the company has also performed its first preliminary field test with the system in Strasburg, Colorado.

Colorado's farm communities and agricultural producers face growing energy costs for treatment of their wastewater. As the need for additional treatment grows with the population in rural areas and with new EPA/NPDES regulations for agriculture, finding a solution to treatment that meets new stricter mandates while conserving electricity will become increasingly important. The EPA has announced that, among its proposed 2011-2013 priorities, it will increase its oversight of and enforcement actions against a number of sources of pollutants that violate the Clean Water Act, including Concentrated Animal Feeding Operations (CAFOs). This will increase the pressure on agricultural livestock producers in rural areas to find power-efficient and cost-effective solutions for their wastewater treatment.

To address this need, BioVantage has developed a novel photobioreactor system which grows algae for remediation of agricultural waste, and which has application in municipal and industrial wastewater treatment as well. As part of a total biological remediation method for wastewater, the system could offer significant power savings over classical compliant solutions, reductions in greenhouse gases, and a reduction in toxic sludge build-up in treatment ponds.

Algae-based remediation is a proven concept as an alternative to mechanical aeration, but natural processes alone do not achieve algal culture density high enough to enable rapid remediation. Therefore a natural system requires a relatively large land footprint, as influent is degraded slowly. The BioVantage method accelerates natural remediation processes by growing algae to very dense concentrations in its photobioreactor, and then introducing the algae periodically into the treatment pond (called "semi-continuous inoculation"). Installing our algae production system as part of a natural wastewater remediation process could save 40-85% on operating expenses over mechanical aeration treatment, while improving the effectiveness of remediation by 20-40% over current mechanical treatment methods. Moreover, the algae used as part of the process can potentially be harvested as a nutrient-rich slow-release fertilizer, or used for biofuel as that technology advances. (Estimates from LUX Research suggest that total potential recovered nutrient value from livestock operations--nitrates, phosphates, and potash--worldwide approaches $40 billion.)

A primer on microalgae

What we usually think of when we hear "algae" is the slimy green plants that grow in stagnant pools of water. These are macroscopic filamentous algae, long filaments that weave into mats. There are many species of these algae, which generally grow along the bottom of shallow water or on rocks or plants in the water. Mats may also float up to blanket the surface of the water. When these algae have run through their life cycle, they sink to the bottom and putrefy, depleting the water of oxygen.

This is not the same kind of algae produced by BioVantage. Instead, the company grows unicellular microalgae, a diverse group of over 30,000 species of microscopic plants which have a wide range of physiological and biochemical characteristics, and naturally consume high levels of nutrients and produce oxygen.

Photobioreactor

A photobioreactor ("PBR") is a device that grows photosynthetic microorganisms in a liquid suspension. In addition to light, the algae must be provided with specific nutrients, CO_2 must be added and oxygen removed, and other conditions optimized for the algae to achieve the best growth.

BioVantage has developed algae-specific methods for growth and regimens of specific nutrients in a highly controlled environment. Our PBR represents an improvement over other designs and open pond growth concepts, particularly because it mitigates the possibility of contamination of the algae, and provides optimized controlled conditions for growing. It is also modular and scalable for each individual solution, energy-efficient, cost-effective, programmable, and can be remotely managed. Its placement requires only a small amount of area, starting at about 80 square feet.

The photobioreactor growth tank, with the BioVantage light delivery system, and an early version of the chiller.

When algae does not have optimal conditions such as light, nutrients, or other contaminates it produces sugar based biofilms as a protection mechanism. These biofilms can prevent light penetration to the cells, inhibiting their growth, and promote the growth of unwanted

contaminants within the culture. The BioVantage high-growth PBR is a closed-loop system designed to control and minimize the production of biofilms while creating a very dense algal culture. Other types of PBRs depend on the use of sunlight, which includes wavelengths that are unwanted for algal growth and can accelerate the production of biofilms. The BioVantage tank system does not rely on external sources of light; instead, we use a proprietary light source combined with a specialized internal light delivery system.

The BioVantage algae production system involves two primary modules: one is the "medium preparation tank," a fully automated blending tank where requisite nutrients and filtered water are combined and balanced to a precise formula needed for the species being grown. This mixture is then supplied to the second component, the "growth tank," which contains the growing culture of organisms. Each growth tank is outfitted with lighting, monitoring sensors, nutrient delivery control, environmental control and a patent-pending, low-sheer mixing solution to maintain a homogenous culture. It is continually monitored to optimize the environment for the algae until they are ready to be delivered to the lagoon.

The entire system is controlled by proprietary software, which regulates inoculation regimens based on the demand of the waste stream as well as the production of replacement medium for the growth tanks. This system can be controlled on site and or remotely, so that any error conditions or needed changes to the regimen can be immediately diagnosed and addressed by BioVantage staff and or the onsite or remote facility staff.

Medium preparation system, with nutrient storage tanks and CO2

Algae growth

In order to perform the research under this grant, we obtained water samples from two agricultural sites in Colorado and isolated and purified certain algal strains from each. After extensive laboratory testing, we determined which strains would grow best for our purposes, as well as the optimal growth regimens for those strains. We grew each strain through ever-increasing sizes of flasks, until it was of sufficient volume to place into the PBR.

Once in the PBR, we were able to grow algae to densities which exceeded our projections. This indicates that the system is capable of producing algae at scaled-up and functional densities.

KEY FINDINGS AND RECOMMENDATIONS

The ACRE grant has enabled BioVantage to design and build a prototype PBR and to write and test the software that controls the entire production system. The 50 gallon system was installed at a former pig farm in Strasburg, Colorado, to test the field-readiness of the equipment. The results of that test demonstrated:

- That the medium growth system works as designed to deliver nutrients and CO2 to the growth tanks
- That the growth tank is capable of producing dense cultures of algae, as intended—in fact densities exceeded expectations by a factor of about two
- That the proprietary software can safely and reliably run the overall system
- That the available native strains of algae can be grown in the system efficiently.

These results suggest that the PBR will be effective for the purpose of inoculating wastewater treatment lagoons.

PROBLEMS ENCOUNTERED/MITIGATING CIRCUMSTANCES

No significant problems were encountered in designing or building the demonstration PBR, other than normal prototyping obstacles.

The first light block was redesigned several times in different configurations, in order to increase its light delivery and cooling efficiency. The lid and light block arrangement were redesigned to allow for better light distribution within the 50 gallon size growth tank.

The software code to run the automated system has been completed, and it had to be tested and further customized for this application.

The test at the Strasburg site suggested the need for greater conditioning of incoming electrical power to be certain that the system can operate in rural settings. This involved a certain amount of re-design in the electrical system.

One of the greatest challenges has proved to be maintaining climate control within the growth tanks with external sources. The company has worked through several solutions to this problem, and has not yet decided on which would be optimal.

NEXT STEPS

At this point, the company has designed and built a functioning, novel photobioreactor capable of growing algae. In order to further commercialize this technology, a number of additional steps will be necessary.

The first step would be to continue to optimize the design of the PBR, especially with respect to its climate control, light dispersement, and gas transfer into the medium. This will require experimenting with different designs for all three subsystems, as well as software modifications to accommodate such changes.

The second step would be to begin a pilot program to determine if we can re-create the data we've obtained at the next scale of the system. To that end, we are in negotiations with the Colorado School of Mines to develop a test bed at their facility in Golden, Colorado, where we could install the PBR and begin testing it under live conditions on an actual waste stream (rather than one created in the lab). We have submitted a grant proposal to the USDA under its SBIR program, requesting funding for certain experiments in the test bed. The test bed would allow us to better quantify the remediation abilities of algae, and to continue to refine the design of the entire system.

A third step would be to better understand the native algae species and strains in Colorado. In preparation for working on wastewater at the farm/ranch level, a library of algae species

indigenous to Colorado's agrarian regions is needed, and species suitable for bioremediation and bioenergy applications must be characterized. Research into nutrient needs, rate of growth, morphology, reproduction methods, and metabolic capabilities (what particular waste the algae grow on) will help to fully leverage this resource. Travel to various agricultural operations, including CAFOs, throughout the state would be undertaken to sample and isolate local organisms. Algal isolates will be analyzed both in our own laboratory and at the Colorado School of Mines in Golden, Colorado. This research will permit further development of natural wastewater treatment methods, and result in economically useful by-products such as biofuels and fertilizer.

Microbiologist checking algae samples in lab

NOTABLE ACCOMPLISHMENTS

In six months, BioVantage has designed, implemented, and optimized a complete algae production system, including medium preparation system, growth tanks, and software to automate control of the system and to report problems to operators for speedy resolution. The company has field-tested the equipment at a site in Strasburg, Colorado, and made adjustments to various elements of the system based on what was learned at that test site. The company has proven it can sample, isolate, and grow algae that will be effective in the system to appropriate densities for wastewater treatment. Research has determined that an anaerobic digestion element would be a beneficial addition to a closed-loop sustainable agricultural bioremediation system, and the company has analyzed several types of ADs for future inclusion in an operating field installation. Work has begun on the next steps of optimization of the system and BioVantage has applied for funding for further testing in agricultural settings from both the USDA and the Colorado Department of Agriculture. The company has designed and is negotiating for the placement of a test bed facility at the Colorado School of Mines in order to further this research and prepare for demonstration at the farm/ranch level.

ACCOUNTING OF PROJECT EXPENDITURES

Expenditure	Applicant/Budgeted	Applicant/Actual	ACRE/Budgeted	ACRE/Actual
Consultant Fees	$7,000.00	$466.66	$9,000.00	$7,150.00
Salaries/personnel	$57,876.00	$52,485.00	$0.00	$0.00
Travel	$400.00	$2,116.52	$0.00	$0.00
Printing	$1,200.00	$0.00	$0.00	$0.00
Supplies	$18,070.00	$3,172.29	$0.00	$0.00
Equipment lease/rental	$618.00	$0.00	$0.00	$0.00
Other Direct Costs	$50,650.00	$5,384.50	$41,000.00	$41,253.39
Indirect Costs	$8,491.00	$13,271.25	$0.00	$0.00
Total*	$144,305.00	$76,896.22	$50,000.00	$48,403.39
*Original matching permitted to change to $76,200 by ACRE				