FINAL TECHNICAL REPORT

DOE Award Number: DE-SC0000581

Recipient: Center of Excellence for Hazardous Material Management (CEHMM)

Project Title: CEHMM Alternative Energy Research and Education

Project Director/Principal Investigator: Douglas C. Lynn, Executive Director

Consortium/Teaming Members: none

Distribution Limitation: none

EXECUTIVE SUMMARY

The Center of Excellence for Hazardous Materials Management (CEHMM) was awarded \$1,849,716.00 on June 2, 2009, award number DE-SC0000581. This grant was used for alternative energy research and education.

The primary focus of this grant was the protection of the environment through the development of a renewable feedstock, algae, as a source for biofuel. Algae are a consumer of carbon dioxide rather than a contributor of this gas. Algae ameliorate carbon dioxide levels attributable to the burning of fossil fuels like coal and at the same time can be used as a source of fuel.

CEHMM began research on the use of algae as a source for biofuel in 2006. Initial studies entailed the analysis of a variety of species cultured in aquaria. Subsequently, those species most robust and with a relatively high lipid content were grown outdoors in small open tanks to assess their viability outside the laboratory. Based on these outdoor tests two 1/8-acre open raceway ponds were constructed beginning in late 2007 and became fully operational in the spring of 2008. A marine alga monoculture was successfully grown year around, and data were collected daily by pond from the time of inoculation. This database is a treasure trove of information regarding chemical, biological and physical parameters which reflect the success of these outdoor cultures. CEHMM has successfully developed and implemented one of a kind crop protection techniques, at commercial scale, to address predation and infestation as well as a nutrient feeding regime, all of which now constitute trade secrets. CEHMM experimented with a variety of harvesting techniques, the results of which have been documented. Finally, a pilot plant extraction facility was built at the CEHMM algae pond facility. CEHMM can grow and harvest algae, concentrate this alga to a level compatible with the extraction equipment and operate the extraction plant to generate algae oil from the lipids found in the CEHMM algae culture. There are now three 1/4-acre open raceway ponds and the two original 1/8-acre pond in which the CEHMM marine alga is grown. CEHMM has demonstrated the ability to grow and harvest year-around with consistent biomass production rates exceeding two tons per month per acre.

An economic model has been developed in consultation and collaboration with New Mexico State University and Sandia National Laboratories. This model suggests that a commercial facility based on the CEHMM paradigm is very economically feasible.

Algal oil derived at the CEHMM algal facility can be converted into biodiesel. The rural setting of the CEHMM facility means biodiesel produced in quantity could potentially compete with petroleum diesel in the agricultural market. In addition to fuel, the residual biomass created by the extraction process holds promise in the areas of food supplements for livestock, nutraceutical applications and a protein source.

PROJECT SUMMARY

Goals and Objectives:

Critical success factors of the algae biofuels project are:

- (1) Ability to grow and harvest a volume of algae to make sufficient quantity of algae oil and hence biofuels so the product is competitive with petroleum diesel.

Algae oil has been produced and analyzed. This oil can be converted to biodiesel using published techniques. CEHMM is seeking private investment capital to develop a commercial facility based on the experiences at our algal site.

- (2) Maintenance of sufficient lipid content in the algal cultures to make the whole process economically competitive;

The CEHMM alga has been analyzed by SRS, Inc., the supplier of our extraction equipment, and found to be the most consistent alga with high lipid content. SRS, Inc. has honed their extraction process based on the CEHMM algae.

- (3) Adequate pond acreage needed to support a commercial demonstration scale;

Subsequent to the construction of the first two 1/8-acre ponds, a third 1/4-acre pond was built after a ground water permit modification was received from the State of New Mexico. That pond was inoculated in 2009. A second permit modification from the State was obtained in 2010 to add twenty additional 1/4-acre ponds at the CEHMM site. To date two new 1/4-acre ponds have been built and are in the process of being inoculated. This brings the total number of ponds to five with the promise of many more. The quantity of feedstock produced is the limiting factor in the production of algal oil, i.e., the more algae feedstock available, the more oil produced.

- (4) Use of residual biomass as a source of protein, animal feed additive or a basis for the development of nutraceuticals.

An independent laboratory, Eurofins, evaluated the residual biomass generated after the lipid is removed. This analysis suggests that all the proposed goals for biomass use contained in the CEHMM original grant proposal can and will be met.

Project Activities:

Open raceway ponds have been built, ancillary equipment such as paddles and aerators have been installed, and a marine monoculture grown in these ponds for over two years. All of the preliminary objectives have been met. The final piece was the installation of an experimental extraction unit in 2009. This unit has produced algae oil which has been converted to biodiesel in the laboratories of SRS, Inc., the manufacturer of the extraction plant. Figure 1 shows one of

the ¼- acre ponds in the foreground and buildings which house the proprietary extraction equipment in the back.

Figure 1. CEHMM outdoor raceway pond and buildings which house extraction equipment

The CEHMM approach was the use of open raceway ponds to cultivate the algae as opposed to photo-bioreactors. Data collected on a daily basis substantiate the claim that the CEHMM marine alga can be grown on a continuous basis in an outdoor setting.

A variety of harvesting techniques were investigated during the grant period. The time at which algae harvest is initiated depends on a variety of factors. The health of the culture as measured by certain biological and chemical factors is important. Our experience has found that during periods of high growth, the algae ponds do best if the level of harvest is increased.

Routine samples are taken and evaluated microscopically to assess levels of predation and presence of invaders. Techniques have been developed to address these issues. The fact that the alga being cultured is marine and there are no naturally occurring marine waters nearby is a buffer against most predation or invasion.

The vitality of the culture is typically measured by turbidity and photo-optics. The higher the turbidity, the more robust the culture and the greater the need to harvest.

The three harvesting techniques tested at the CEHMM site included chemical flocculation, concentration of algal biomass using hollow tube membrane technology and a standard centrifuge. The results of these approaches are illustrated in the graphs below.

Figure 2. Harvesting by Flocculation

Figure 3. Harvesting by Mechanical Means

Figure 4. Harvesting by Centrifuge

Currently, CEHMM uses a centrifuge to attain an algae concentration adequate for the extraction equipment. CEHMM continues to experiment with flocculation as a cheaper and less energy intensive alternative. Flocculation, even as a pre-treatment prior to the use of a centrifuge, will cut down the time the centrifuge must run and, hence, reduce the energy required.

CEHMM has successfully extracted oil from algae using the SRS, Inc. equipment. Currently the extraction process is done in batch mode but research is underway to convert the hardware to run continually. Algal oil extracted by this equipment has been converted to biodiesel in small quantities to attain proof of principal. Figure 5 shows containers with algal oil produced by the equipment on which the containers sit.

Figure 5. Algal oil produced at the CEHMM research facility

Products Developed:

CEHMM has developed a website, www.cephmm.org, with information on the projects. Collaborations have been fostered with New Mexico State University, Sandia National Laboratories and SRS, Inc.

CEHMM developed the ability to address predation and infestation in open raceway ponds. A feeding regime was developed which has a positive influence on the growth rate of the algal cultures. CEHMM documented these developments through the design of a database which was written by CEHMM personnel. The feed, the techniques to address predation and infestation, and the ability to maintain a pure culture have been protected through trade secrets.

A database contains all the data gathered on a per pond basis since inoculation. There are some video clips posted on the CEHMM web site which describe project developments. An economic

model based on the CEHMM algal research and development has been authored by Dr. Meghan Starbuck in collaboration with Dr. Amy Sun at Sandia National Laboratories.

One of the components of CEHMM's alternative energy research is to develop a curriculum that is conducive for implementation into public or private school systems at grade levels kindergarten through 12th grade. The curriculum was completed in 2009, is in compliance with state of New Mexico standards and benchmarks, and is ready for implementation in selected test bed schools. This helps to develop student awareness toward applied research and stimulates interest that will motivate students to pursue careers in alternative energy. The local high school is in the process of using algae as a component of their science research requirements. Disciplines such as this will be critical in the development of a future workforce for the emergence of this national agenda for alternative energy.