COOPERATIVE EXTENSION SERVICE
University of Kentucky – College of Agriculture

Biosystems and Agricultural Engineering Update

UK RESEARCH PROJECTS ON ALGAE BASED CO_2 MITIGATION FOR COAL-FIRED POWER PLANTS

Introduction

The use of microalgae-based bio-mitigation (AEN-116) suffers from a range of challenges primarily related to system complexity and scale-up issues that are driven more by economic constraints than technical limitations. It should be noted that only biological carbon capture and recycling has the potential to generate a revenue stream to offset, at least in part, the overall cost of implementation. When considerations such as local climate, political and economic constraints, and the geographical location of most coal-fired power plants are included, the development of a rational strategy for microalgal carbon capture is even more urgent. Combining these considerations with the abundance of native coal resources and the preponderance of coal-based power generation, the use of microalgae for CO_2 mitigation for Kentucky based coal-fired power plants is an attractive option. A conceptual schematic of such a process can be seen in Figure 1.

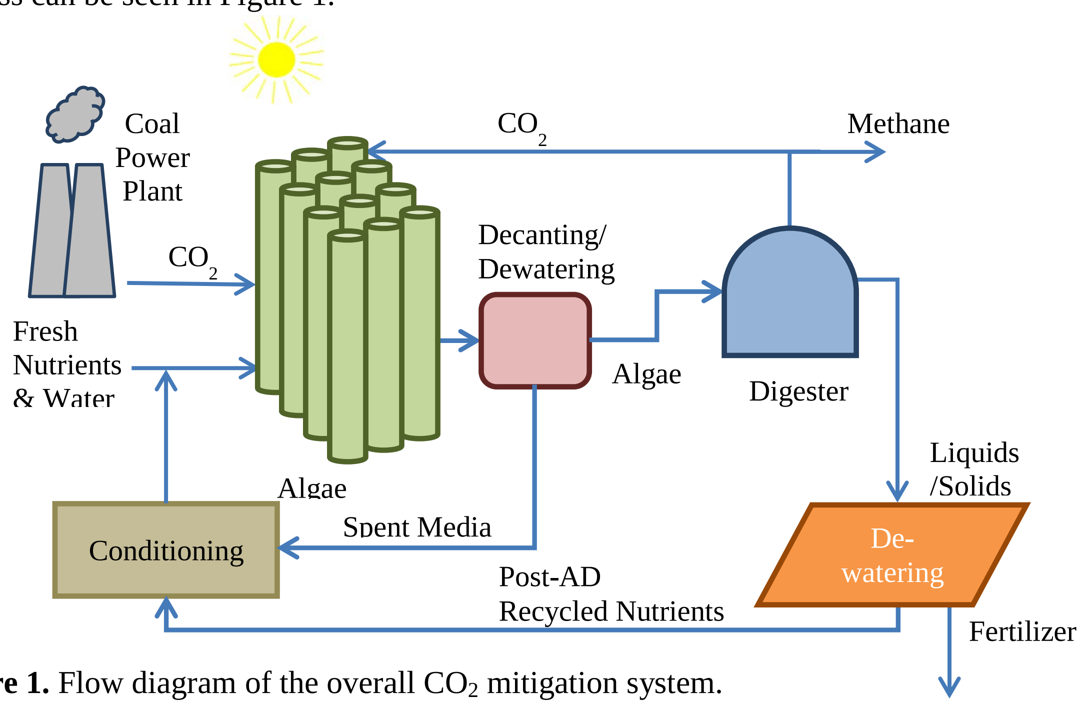

Figure 1. Flow diagram of the overall CO_2 mitigation system.

This factsheet explains the organization of the project and the research that is currently being done (through 2012), all focused on showing that algae based CO_2 mitigation is a viable option.

Current Research and Development Project at UK

Given the potential of microalgae for mitigating coal-fired power plant emissions, the Commonwealth of Kentucky Department of Energy Development and Independence (KY DEDI) tasked the University of Kentucky (UK) with determining the technical and economic feasibility of algae-based carbon capture in Kentucky. The current UK-led project ("Development of an Algae-Based System for CO_2 Mitigation from Coal-Fired Power Plants") is focused on the design, construction, and demonstration of an algae-based CO_2 mitigation process suitable for use at Kentucky power plants. The project is a collaboration between the Center for Applied Energy Research (CAER) and the Biosystems and Agricultural Engineering (BAE) Department.

The overall goal of this project is to design a process capable of utilizing the flue gas through operation of a continuous microalgae culture (selected for its ability to flourish in the relevant conditions), harvesting a sustainable quantity of the algae, and converting harvested algae into a value-added product (e.g., fuel for co-firing, bio-oil for conversion to biodiesel, bio-gas, or a nutritional additive for animal feed). The unique nature of this concept is designing the cultivation and processing system to suit the CO_2 source, as opposed to allowing the cultivation system to dictate the source which has been the general direction of most comparable studies. Efforts have resulted in the development of a rational closed-loop photobioreactor coupled with a low-energy biomass recovery strategy using auto-flocculation and sedimentation. A pair of photobioreactors (~5500 liter each), shown in Figure 2, is currently operating within the greenhouse facility on the campus of the Center for Applied Energy Research at the University of Kentucky.

Figure 2: Example of photobioreactor developed at CAER.

Although a functional and economically relevant small-scale photobioreactor system has been successfully developed, a significant set of challenges remains. Ongoing research focuses on resolving these challenges before the development of a large-scale coal-fired power plant applicable process can be undertaken.

Increasing the Cultivation Volume: Another set of challenges is related to the need to understand phenomena that occur as processes are scaled up. It is well known that progressing from the small laboratory scale (~0.1-1 L) through to the medium development scale (<1000 L) is rife with issues that only occur at certain culture scales and not at others. These issues are frequently operational in nature owing to the continuous cultivation, harvest, and maintenance of the larger scale cultures.

Long Term Growth Studies: A further complicating factor is the need to perform long term growth studies at scale to determine system phenomena related to seasonal culture variations as well as the long term accumulation of undesirable compounds (either produced by an organism in culture or as a result of the flue-gas stream).

Harvesting and Dewatering: During the migration of CO_2, large amounts of biomass will be generated. The algae product solution will be fairly dilute, such that large amounts of water will need to be removed before the biomass product can be converted into value-added products or disposed. Studies are underway to determine the best way to dewater the algae into a thick slurry using flocculants, which are chemicals that can cause the algae cells to clump together and fall out of solution.

Integration with the Coal-Fired Power Plant: The final challenge is the integration of the refined process into an operational coal-fired power plant to produce real-time data derived for incorporation into our existing low-level technical and economic model.

In addition to the pilot scale photobioreactor systems, algae research in Biosystems and Agricultural Engineering focuses on the development of seed culture and small lab scale photobioreactors (Figure 3). At this scale, work on several critical factors for algae production is accomplished.

Figure 3. Small lab scale flask experiments in the department of biosystems and agricultural engineering.

Strain selection: Every algal strain behaves differently. Some prefer common atmospheric conditions, where others strive in high heat or salinity environments. In this study, freshwater strains are being investigated that can tolerate the high carbon dioxide levels and heat from flue gas. Besides carbon dioxide, the algal strain must hold up to pollutants in the flue gas such as SO_x and NO_x. *Chlorella vulgaris* and *Scenedesmus Actus* are two well-studied and robust strains suitable for either condition.

Media optimization: Media contains nutrients algae need to grow. Media optimization improves the doubling time, optimize cell mass, and possibly lower media cost. In the cultivation of *Chlorella vulgaris,* replacing the nitrogen source from potassium nitrite to urea, media cost is lowered without affecting growth.

Temperature: Temperature is an important factor for growing algae. It can affect the growth rate, composition, and the conversion rates of algae. Each alga has a cool range where it will not grow very fast, an optimum range where it will have the highest growth rate and a warm range where growth will be inhibited or die. In this study, the optimum temperature of algae is being investigated with the hope that heat from flue gas can be used.

Flue Gas Toxicity Studies: There are several contaminates in flue gas that have the potential to affect the growth of algae. Studies are being conducted to determine the toxicity levels of sulphuric acid (the same contaminate that causes acid rain) and ash (which contains heavy metals).

Nutrient Recycling Strategies: A portion of nutrients remain in the waste stream after algal harvest. Flocculation is one method of clumping algae into masses for easy separation. A small amount of flocculent can be used without significantly altering the media or affecting the algae. Studies are underway to determine what levels of flocculate are safe to use, such that the media remaining after algae removal can be recycled back into the algae cultivation process, thereby lowering system costs and improving efficiency.

Anaerobic Digestion of Algae: After using algae to recycle CO_2, a quantity of algal waste remains that requires disposal. Anaerobic digestion is a means of diverting this waste that might otherwise be incinerated or dumped into the sewer system. Anaerobic digestion has been shown to convert approximately 50% of the algal mass to another energy source. A byproduct of the digestion process is methane gas, which can be used as a source of heat or to produce electricity. Numerous variables are being studied to determine maximum effectiveness of the anaerobic digestion process.

Media Water Sources: The algae growth media obviously requires water. The type of water used can affect the growth of the algae and have an environmental impact. Several water sources are being considered that could be readily available near a coal-fired power plant: river water, cooling pipe water, ash pond water, pond water, and city water. Using a natural source of water such as the river or recycled water would help decrease environmental impact and media costs of the bioreactor system.

Demonstration in the Field

The research team is currently constructing an even larger scale system that will be installed on site at a coal-fired power plant. An artistic rendering of a larger scale installation is shown in Figure 4.

Figure 4. Artistic rendering of a large scale alga CO_2 mitigation system.

For more information about the status of the project see http://www.bae.uky.edu/biofuels/algae/ or http://www.caer.uky.edu/biofuels/.

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