AEN-116

UK UNIVERSITY OF KENTUCKY College of Agriculture

Algae-Based CO_2 Mitigation for Coal-Fired Power Plants

Czarena Crofcheck, Tabitha Graham, and Michael Montross, Biosystems and Agricultural Engineering

Introduction

As the world's population swells and the needs of developing countries increase, the world's overall energy usage also continues to rise. Recent international legislation emphasizes the effects of climate change and the crucial need to find a way to decrease the greenhouse gas (GHG) emissions being released into the environment. Consequently, power plants have an increased urgency to find a viable way to decrease their GHG emissions. This issue has prominent implications for Kentucky due to our economy's dependence upon coal production.

In Kentucky, coal is used to generate 93 percent of the electricity used, and the resulting CO_2 emissions are of concern. To address this problem, researchers are investigating ways to capture CO_2 to reduce carbon dioxide released into the environment. Researchers at the University of Kentucky are working on algae-cultivation systems to mitigate CO_2 emissions, specifically from coal-fired power plants. This publication provides an overview of the reasons for elevated CO_2 levels, the options for reducing CO_2 emissions, and the many benefits of using algae.

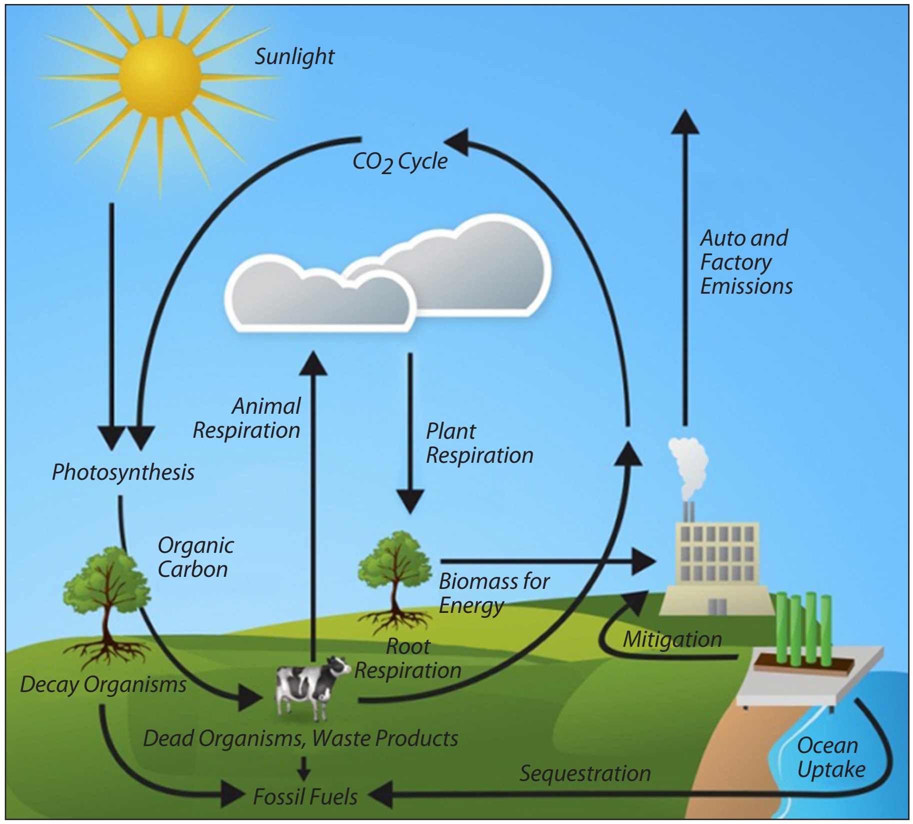

Figure 1. Carbon cycle in our environment.

Carbon Cycle

Carbon is an essential element to life and our environment. The carbon cycle includes the processes of photosynthesis and cellular respiration. Photosynthesis is the biological act of plants and phytoplankton taking up CO_2 from the atmosphere; cellular respiration is the release of CO_2 into the environment by animals. Ideally, the discharge of cellular respiration would equal the CO_2 need for photosynthesis. However, with the addition of CO_2 released when burning fossil fuels, it continues to escalate in the atmosphere beyond the capacity of the natural carbon cycle of photosynthesis and cellular respiration.

Carbon Dioxide Emissions

According to the EPA, in 2008 the United States emitted 6.1 billion tons of equivalent CO_2 through the combustion of fossil fuels with 37.3 percent of those emissions resulting from the combustion of coal. Coal accounts for such a large percentage of these emissions in part because it has the highest amount of carbon per unit of energy, more than petroleum or natural gas. In the fight to reduce greenhouse gas emissions, CO_2 emissions are the main target. Lower CO_2 emissions can be achieved through decreased demands for fossil fuels and through carbon sequestration (storage) and mitigation. Many alternatives to fossil fuels are being developed and used, including solar energy, wind energy, hydroelectric, geothermal, and biofuels such as biodiesel and ethanol. Each has advantages and disadvantages, and usage is often dependent on global location and locally available resources. The production of biofuels continues to be more expensive than utilizing fossil fuels, but the increased environmental benefits have helped increase demand and production. However, while we continue to burn fossil fuels to meet our energy demands, we hope to find ways to decrease the overall CO_2 emissions, helping to balance the carbon cycle.

Sequestration and Mitigation

Sequestration refers to the complete removal of CO_2 from the carbon cycle, typically done by burying CO_2 generated from power plants in deep, underground reservoirs. Carbon mitigation refers to a process of reducing CO_2 emissions to the atmosphere by fixing it into biomass where it still remains part of the carbon cycle. As a part of the carbon cycle, CO_2 is removed from the atmosphere by photosynthetic plants; hence, plants could be used as a CO_2 mitigation strategy.

Current CO_2 Removal

Carbon dioxide is currently removed by chemically reacting it with an absorbent that produces a solid that can be more easily disposed. This process is also referred to as "scrubbing" because it removes CO_2 after it is created but before it is released into the atmosphere. An advantage to this type of recovery is that it can be performed under the temperature and pressure conditions associated with flue gas. Despite these advantages, chemical reaction–based CO_2 mitigation is often an unattractive option because it is energy-consuming, costly, and still has some disposal problems (both the captured CO_2 and the absorbents must be disposed).

Biological mitigation has become a more attractive CO_2 option because biomass is generated through photosynthetic reactions, and the biomass contains energy that can be used later. This biomass energy can also help decrease the demand for fossil fuels, which in turn would decrease the amount of CO_2 emissions.

Why Algae?

Microalgae are being explored as a possibility for biological CO_2 mitigation because many microalgae species can grow under harsh conditions and require few nutrients for growth. This ability allows microalgae to be cultivated in areas that are currently unsuitable for agricultural purposes, which means that they are not competing with current agricultural crops for arable land. Terrestrial plants are extremely inefficient at converting solar energy to biomass energy and are estimated to use less than 0.5 percent of the solar energy received. In comparison, microalgae are estimated to be 10 to 20 percent efficient at converting solar energy into biomass energy. In addition, they are able to fix more CO_2 during photosynthetic growth because of their high efficiencies and growth rates, which makes them more effective at removing CO_2 from the atmosphere and an attractive option for biological CO_2 mitigation. A major difference between sequestration and biological mitigation is that the CO_2 fixed during biological mitigation is not permanently removed from the atmosphere—rather, the biofuel. Therefore, no additional CO_2 is created, and energy is generated in a sustainable method through CO_2 recycling. In a region where coal-fired power plants are common, using microalgae for CO_2 mitigation from flue gas would help reduce GHG emissions without requiring the elimination of these power plants.

The use of microalgae-based bio-mitigation suffers from a range of challenges, primarily related to system complexity and scale-up issues that are driven more by economic constraints than technical issues. 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 climate, political and economic constraints, and the geographical location of most coal-fired power plants are included, the development of a rationale for microalgal carbon capture is even more urgent. Combining these considerations with the abundance of native coal resources and the wide-scale use of coal-based power generation, the use of microalgae for CO_2 mitigation for Kentucky-based coal-fired power plants is an attractive option.

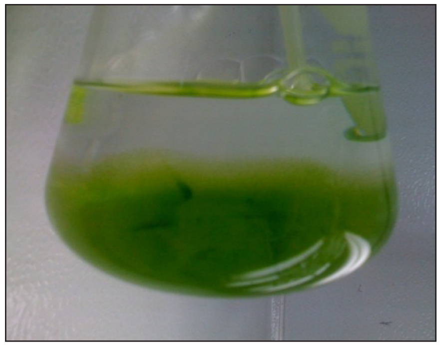

Figure 2. Scenedesmus actus is a potential for mitigation of CO_2 emissions in flue gas.

Figure 3. The overall CO_2 mitigation system.

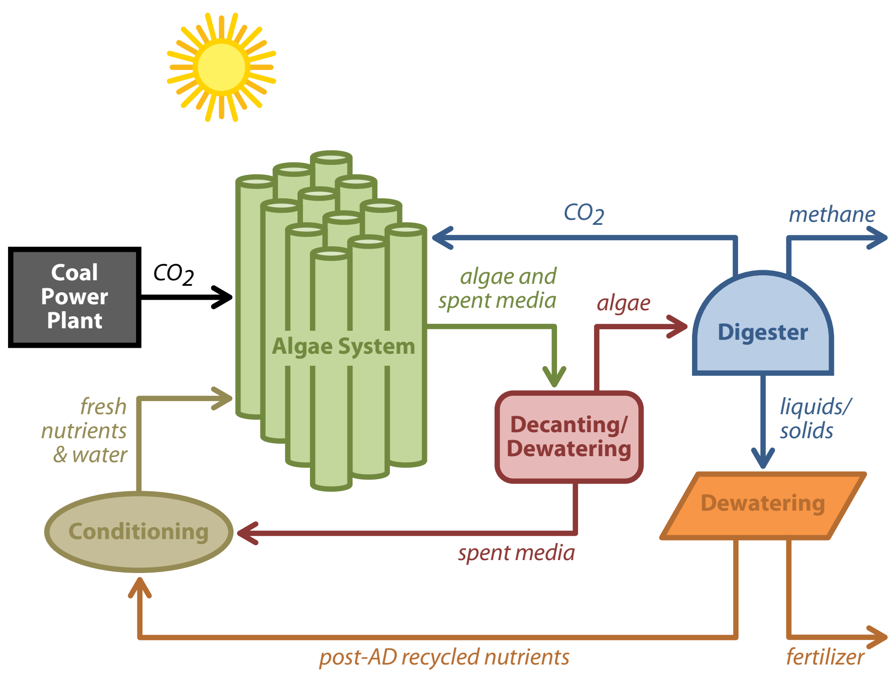

Figure 4. The pilot scale unit located at the Center for Applied Energy Research at the University of Kentucky.

References

Campbell, A.C., and Reece, J.B. (2005). Biology. 7th Edition. San Francisco: Pearson.

Kumar, A., Ergas, S., Yuan, X., Sahu, A., Zhang, Q., Dewulf, J., Malcata, F. X., van Langenhove, H. (2010). Enhanced CO_2 fixation and biofuel production via microalgae: recent developments and future directions. Trends in Biotechnology 28(7): 371-380.

Li, Y., M. Horsman, N. Wu, C. Q. Lan, and N. Dubois-Calero (2008). Biofuels from Microalgae. Biotechnology Progress 24(4): 815-820.

Mata, T. M.; Martins, A. A.; Caetano, N. S. (2010). Microalgae for biodiesel production and other applications. Renewable & Sustainable Energy Reviews 14(1): 217-232.

U.S. EPA (2010). U.S. Greenhouse Gas Inventory Report. 430-R-10-006. Washington, D.C.: Environmental Protection Agency. Available at: http://www.epa.gov/climatechange/emissions/index.html. Accessed 15 January 2011.

Issued 1-2013