Economics, physics are roadblocks for mass-scale algae biodiesel production, study finds

April 5 2011

Companies looking to engineer an eco-friendly diesel fuel have more red lights in their path. According to Kansas State University researchers, making petroleum diesel completely green would not only bend the laws of physics, it would cost too much green.

"Fossil fuels are limited, and since we can't use more than what Earth offers, a lot of people are looking for alternative fuel sources like algae," said Peter Pfromm, professor of chemical engineering and member of a K-State interdisciplinary team that analyzed oil produced by algae as a source of biodiesel.

Pfromm and K-State researchers Vincent Amanor-Boadu, associate professor of agricultural economics, and Richard Nelson with the Center for Sustainable Energy conducted an in-depth analysis on algae biodiesel production. Their first algae-related nonprofit study, "Sustainability of algae derived biodiesel: A mass balance approach," supplied the cover picture in a recent edition of *Bioresource Technology*, a peer-reviewed journal.

The team applied engineering fundamentals -- mainly a carbon mass balance -- to put sustainability on a scientific footing, Pfromm said. The total mass of Earth never changes, and in order to be sustainable, mass conservation and especially a closed carbon mass balance must be maintained for the algae diesel production and consumption system, he said.

The researchers created a mass flowchart using carbon as a tracer, tracking it through the entire algae diesel system. This checked for use of non-sustainable resources like oil and gas, and made sure the atmosphere wasn't a carbon dioxide dumping ground. Because an algae production facility creates biomass mainly from carbon dioxide, this carbon flow must be balanced out or sustainability doesn't work, Pfromm said.

"The inflow must equal the outflow if we want to be sustainable," he said. "Without this, our production cycle won't last for decades -- or even centuries -- and will instead deplete resources that can't be renewed and degrade our planet."

The first part of the study focused solely on the science and technology of algae biodiesel. It showed that from a purely technical standpoint, producing algae-based biodiesel in a sustainable way works -- but not to the extent needed to eliminate dependence on petroleum diesel. With sustainability the goal, the team found that under the most optimal and optimistic conditions, the amount of algae diesel produced per day was drastically lower than the projected ideal quantities from many algae production concepts.

"We found that phycologists -- algae scientists -- maintain that some popular estimates of producing 200 to 500 grams of algae per square meter of open pond per day weren't feasible because there's simply not enough sunlight coming through the atmosphere to do so," Pfromm said. "Unless we can change the sun, such production is physically impossible -- and the hard numbers prove that. Most economists wouldn't necessarily recognize this as an issue in a business plan because it's dictated by physics, not finances."

The team used a more realistic, yet still optimistic, production number -- 50 grams per square meter per day. They determined it would take 11

square miles of open ponds making 14,000 tons of algae a day to replace 50 million gallons of petroleum diesel per year -- about 0.1 percent of the U.S. annual diesel consumption -- with an eco-friendly algae alternative.

"Algae don't make oil out of the kindness of their hearts. They store energy as oil when they are starved for nitrogen so they can make more algae in the future," Pfromm said. "The end result is the yield isn't that high because we can either stress the algae to produce more oil or let them reproduce very efficiently -- not both."

The team added economics in a follow-up study, which has yet to be published.

"Once money is involved, technological sustainability becomes theoretical because nobody is going to use the technology or science unless there's an incentive," Pfromm said. "For investors and most of the industrial world, the incentive is going to come with a dollar sign. But if it takes 20 years before anyone starts making a buck in profit, no one's going to back it."

Open ponds are the cheapest containment unit in which to grow algae. But as a production facility increases in size, so do the number of ponds it operates -- and a facility close to 11 square miles in size is a steep investment, Pfromm said. Biologically these open ponds are also problematic because they are prone to invasions by algae-eating organisms or microorganisms that can be spread by the wind.

Enclosures like tubes stop the algae-eating organisms and other contamination but have a much higher overhead. Cooling then becomes necessary because sunlight warms the containers and can overheat the algae. A refrigeration unit is too costly, which leaves water spray-cooling the cheapest alternative. Cooling one container isn't a problem, but

cooling half-a-million containers quickly adds up, Pfromm said. These containers also have to be cleaned to avoid buildup, because dirty containers mean limited sunlight and limited production.

Absent government support and incentives, all of the building, maintenance, production and transportation costs are out of pocket for algae production. And with the underlying science heavily restricting production, the team's economical analysis finds finances will stay in the red for quite some time, Pfromm said.

But while market conditions, prices and costs can be changed by tinkering with subsidies, mandates and policies, science ultimately cannot, Pfromm said.

"Right now the fundamentals are the problem. It doesn't matter how well we engineer our production machine, the engine under the hood just isn't that good," Pfromm said. "The best option right now is to invest in fundamental research and design so that the yield can hopefully reach beyond the 50 grams per square meter per day on our most optimistic assumption."

Provided by Kansas State University