Can pond scum save us from fossil fuels?

By Jo Seltzer, special to the Beacon
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"How do you milk algae for their oil? Tiny milkmaids with very tiny tweezers."

Dr. Richard Sayre, head of the Enterprise Biofuels Insitute at the Danforth Plant Biology Center has a whole comedy shtick to ease the listener into the serious topic of algae's oil eventually becoming a major source of transportation and other fuels. His laboratory has devised a system to extract the oil (up to 50% of their weight) from algae without damaging them, so that the same organism can replenish its oil droplets again and again.

Richard Sayre
Photo courtesy of Danforth Plant Science Center

As the country scrambles to find economical substitutes for fossil fuels, the algae most of us think of as "pond scum" have emerged as a potentially major source of raw materials. And when it comes to research on these one-celled organisms, St. Louis has become a key center for basic research. Last year, both of the Department of Energy's main grants for algae research were granted to St. Louis institutions; $15 million went to the Danforth Center, and $20 million to Washington University.

In addition, $44 million in 'stimulus' funds plus an additional $16 million from industry is being used to establish the National Alliance for Advanced Biofuels and Bioproducts (NAABB), a consortium of 24 companies, universities and national laboratories whose goal is to make fuel and other bioproducts from algae commercially viable as quickly as possible. The Danforth Center heads the consortium, with Sayre as lead scientist and Dr. Jose Olivares as executive director. The aim is to explore different approaches to solving problems, and then to develop the most promising ones. For example, 'milking algae' by the process to be described later in this article will be evaluated against other approaches to growing algae and harvesting their oil.

Algae in and out of favor

The U.S Department of Energy began to explore biodiesel from algae during the Carter administration, and continued the program until the mid-1990's. By then, not only was fossil oil relatively inexpensive—and Carter era gasoline shortages a distant memory—but ethanol came to the forefront of alternative energy efforts. However, production of ethanol from corn uses lots of energy, and also lots of fertilizer to grow the corn, making it an expensive petroleum substitute. Furthermore, using food crops for anything but food has proven to be politically unpopular.

Re-enter algae.   By current conservative estimates, an acre devoted to growing algae and grinding them up for their oil would yield 2000-4000 gallons per year. That yield is at least 50 times higher than oil from an acre of soybeans. Non-farm acreage equivalent to 2-5% of land currently under cultivation could satisfy the country's need for diesel.

Algae's pluses and minuses

Growing algae requires sunshine, water, and carbon dioxide, as well as some inorganic nutrients that must be supplied as fertilizer.

- The water need not be fresh. Many algae species can grow in brackish (salty) water. Some companies are experimenting with growing algae in wastewater.
- The carbon dioxide can come from the air, but the algae will grow faster with more carbon dioxide. Some have proposed that algae growing facilities be placed near coal-fueled power plants, so that the flue gasses can be bubbled through the ponds.

Until very recently, however, oil from algae (or any vegetable oil, for that matter) seemed limited in its uses. It could be converted to biodiesel, and used in the same vehicles that use diesel from petroleum. But most of the transportation in the United States uses more volatile fuels than diesel: jet fuel is 10-20% volatile hydrocarbons, and gasoline is about 50% volatile hydrocarbons.

Breakthrough in oil technology

Within the past 18 months, at least three companies have independently learned to convert vegetable oil to jet fuel and gasoline. This development is a deal-maker. It ensures that new infrastructure will not be needed to use biofuels. A whole new infrastructure would be needed to fuel electric or hydrogen powered engines. But an engine that runs on fossil-based gasoline will be able to run equally well on biofuel-based gasoline, and could be fueled at the same gas stations.

According to Greg Deluga of General Electric Global Research, the challenge in using vegetable oil for transportation fuel is in processing to make it interchangeable with petroleum fuels. He has succeeded in turning soy, coconut, camellina, palm and algae oil into jet fuel. GE Aviation has used that fuel in a 50% mixture in test flights with Continental airlines. The jet fuel must meet exacting specification in terms of staying liquid at very cold temperatures, stability at high temperatures, flash point, heat of combustion, and density. The jet engine must operate exactly the same on biofuel as on fossil fuel. Furthermore the product must be "fungible" or interchangeable so that it can be shipped in the same pipelines and pumped by the same apparatus; if the market is better for biofuel one week, and fossil fuel the next, both can be handled by the same infrastructure.

Already 100% renewable jet fuel has been used in test flight situations. The University North Dakota's Energy and Environmental Research Center has used their jet fuel from seed crop oils in a rocket flight. Tom Erickson, Associate Director of Research at that institution, says that "Now the long-term challenge is getting sufficient quality and quantity of algal oil."

How algae are 'milked'

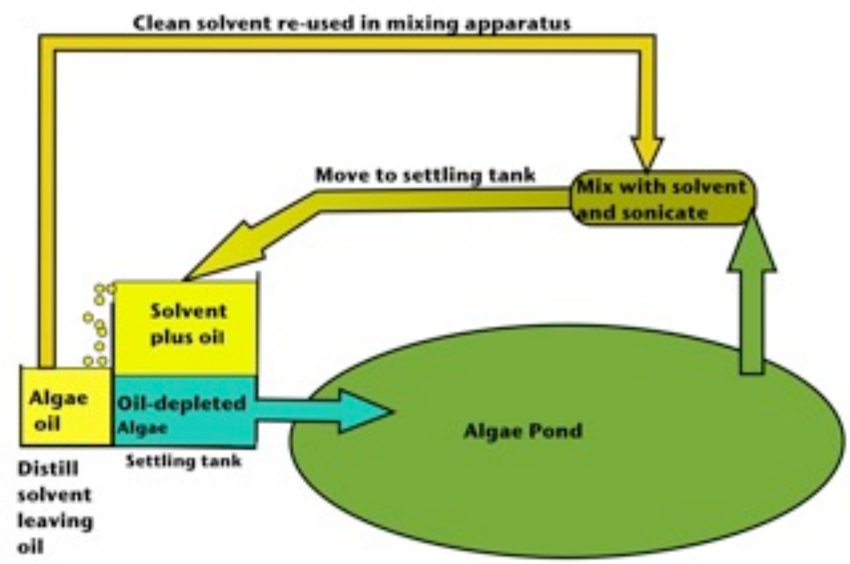
Richard Sayre is convinced that his technique for "milking" the algae of their oil will be an economically feasible way of producing quantities of algal oil sufficient for large scale refining.

The basic principle is that simple hydrocarbon solvent chains can extract the oil from algae without killing them. When algae are intensely mixed with these solvents, the solvents apparently enter the cells and cause lesions in the membrane-coated lipid (oil) vesicles inside. The algal oil then leaves the cell with the solvent, creating an oil phase that floats on top of the water phase that contains the living 'milked' algae.

The algae will grow in shallow (about 1/4 inch) open ponds made with plastic sheeting laid over the ground. The ponds must be shallow to allow maximum penetration of sunlight. The algae will need inorganic fertilizer with some micronutrients. Feeding them some sugar will maximize oil production—the old principle of extra calories being converted to fat.

- In the first generations, the algae used will be naturally-occurring species, selected for their oil production in the ponds, just as Guernsey cows are dairy farmed because they are good milk producers.

In a continuous flow process, algae will be piped through an extraction chamber where they will be mixed with the solvent and subjected to vigorous mixing that may involve gentle agitation with ultrasonic sound waves . From the extraction chamber, the mixture will move to a settling basin, where oil and solvent will rise to the top. The 'milked' algae at the bottom will be pumped back to the pond, where they will start to make more oil.



Solvent and oil will be separated by distillation, and the solvent recycled. Only 0.002% of the solvent is lost at each step.

In this system, once the algae have grown to a useful density, they can continue to produce oil for extraction for at least two months. They don't need to be harvested, and they don't need to be pressed like olives for their oil.

Sayre is chief technology officer for Phycal, a start-up company that uses milking algae as its business model. In its pilot plant with 4000 gallon ponds, they have been able to generate twice as much biomass per unit time, and 40% more oil per unit time than comparable plants that use harvest and press technology. They estimate energy savings to be at least 30%.

In the research laboratories at the Danforth Center, engineers like Jason Kwiatkoski ask questions like "What is the best concentration of algae to have in the extraction apparatus? How long should the algae stay in contact with the solvent? Is sonication the best way to mix the algae with the solvent, and if so for how long?"

Basic research continues. Molecular biologists ask questions like "Will this gene boost oil production? "How can we make these algae use the sunlight more efficiently for photosynthesis?" Phycal is building a facility for bioengineering algae on the BRDG Park behind the Danforth Center.

Backyard Biofuels

There are thousands of algae species, many of which have not been classified. A new project led by Cindy Encarnacion of the St. Louis Science Center, and Matthew Stevens at the Danforth center will soon begin to discover what new species are growing in local ponds and fish tanks.

Beginning in May, participants can come to the Science Center and get a collection sheet and a collection tube. Their specimens will be cultured and identified at the Science Center, and then sent to the Danforth campus where oil content will be measured. Findings from each collection kit will be posted on a special web site.

"We want to connect the public to a real science research project—something that is of economic and scientific importance, " says Encarnation.

The future?

The biofuels industry is still in its infancy. If algae are to be a major starting material for renewable fuel they will need to be grown faster or denser or oilier—or all three.

Nevertheless, two years ago, algae oil cost about $100 per gallon. One month ago, the Department of Defense announced that two pilot projects had produced algal oil for $2 a gallon, roughly the same price as a barrel of crude petroleum. Large scale refining to make jet fuel would add another $3 per gallon. At these prices, algal oil as carbon-neutral biofuel begins to look like it may eventually compete with petroleum.

Of course, going from pilot project to commercial production demands time and research. Many pilot projects cannot be scaled up economically or reliably. But it is conceivable that within the next ten or fifteen years, some farmers will be using their less productive acreage for a new crop—pond scum.