Milking diatoms – a new route to sustainable energy

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As the world is moving towards cleaner and more sustainable energy alternatives, biofuels have gained a lot of importance, mainly because they are 'carbon neutral'. The carbon released by burning biofuels is only that which plants had previously absorbed from the atmosphere, thus making the net change in carbon content of the atmosphere zero. Many plants such as *Jatropha*, *Camelina*, maize, soybean, oil palm and algae, and fungi such as *Clonostachys rosea* f. *rosea* have been examined over the years as possible sources of biofuels as coal, petroleum and other fossil fuels are fast getting depleted. But, these 'sources' of fuel would require a lot of investment in terms of land, irrigation, fertilizers, protection against pests and pathogens, transport, etc. Other challenges include efficient conversion of polysaccharides like cellulose in these plants to fuels like ethanol and neutralizing the effect that cultivation of such plants may have on land, agriculture and food prices.

Recently, a novel technique to use diatoms (a kind of unicellular algae belonging to the algal class Bacillariophyceae) as a sustainable source of energy has been proposed by a team of scientists from India and Canada, comprising T. V. Ramachandra, D. M. Mahapatra and B. Karthick of the Energy and Wetlands Research Group, Centre for Ecological Sciences (CES), Indian Institute of Science (IISc), and Richard Gordon of the University of Manitoba, Canada. They have proposed ways of harvesting oil from diatoms using biochemical engineering, and also have introduced the design of a solar panel containing genetically modified diatoms that would actively secrete oil products, so that one can directly 'milk' gasoline from the solar panel on a regular basis[1]. A remarkable aspect of this approach is that it addresses two burning issues – global warming (and consequent climate change) and fuel oil crisis. Diatoms are responsible for about one-fifth of the photosynthesis carried out on earth, and, like other primary producers, sequester carbon. They are estimated to fix at least 30% of the global carbon dioxide. Under culture conditions, algal populations can double in size in a few hours, and are more effective absorbers of carbon than higher plants.

For many years now, researchers from all over the world are trying to use various algae – from cyanobacteria to sea weeds – as potential sources of different forms of renewable energy, including methanol, ethanol and hydrogen. In the 1950s, researchers proposed cultivation of algae in wastewater in order to produce methane gas. In 1978, the Aquatic Species Program, a research effort under the Biofuels Program initiated by the US Department of Energy, studied the possibility of using algae to produce hydrogen, and later, in the 1980s, started focusing on their use in the production of transportation fuel, particularly biodiesel[2]. Scientists at National Aeronautics and Space Administration (NASA), USA, have recently proposed a method of using offshore plastic membranous bags filled with sewage for cultivating algae. The algae fix carbon dioxide as they grow and also clean up the sewage water. They can then be used to extract oil[3]. Scientists at Newcastle University, UK and Pennsylvania State University are examining the potential of phytoplanktons (*Chlorella*) and macroalgae (*Ulva*) in bioelectricity production[4]. Efforts are being made in China to use microalgae as carbon sequestering agents in coal fields. Carbon from gasified coal is fed to algae grown in bioreactors near the coal fields, and oil that is produced by them can be harvested every day. Much time, thought and money have been spent on identifying efficient strains of algae for production of energy, and also for developing ever improving systems for optimal cultivation of algae – from open pond systems, that were used in the beginning, to closed algal bioreactors that are used widely today. But extraction of oil from algae is expensive and would require energy input. This is a major drawback in efforts to use algae as well as other plants as sources of renewable energy. The concept developed by T. V. Ramachandra *et al*. using diatoms seeks to address this issue.

Diatoms (Figure 1) are unicellular algae that probably lived in the Triassic period, perhaps as early as 250 million years ago (according to molecular-clock based estimates)[5]. However the earliest well-preserved diatom fossils come from the early Jurassic period, about 190 million years ago[6]. They can live in a wide variety of habitats ranging from oceans and fresh water bodies to deserts and even clouds[7]. Of the 200,000 species of diatoms that exist worldwide, a number of marine forms and a few inland forms have been studied. They produce oil intracellularly as reserve food material during the vegetative period of growth. The oil also helps the diatoms keep afloat in water while waiting for the return of favourable conditions to multiply.

Diatoms with the help of their oil glands produce neutral lipids that are lipid-fuel precursors. Theoretical calculations based on the photosynthetic ability and growth potential of diatoms have shown that diatoms can yield more than 30,000 litres of oil per hectare per annum. Traditionally used crops for the production of biofuels such as oilseeds have an oil content of lesser than 5% of their total mass. Diatoms can yield 100–200 times as much oil as soybean, 10–200 times more than oil seeds and 7–31 times more than oil palm, which is considered as the next best source of oil[1].

Much work has already been done on diatoms as sources of oil. As early as the 1940s, dry weight oil content of about 70–85% was reported in diatoms. Scientists have also found out that diatoms produce more oil (double or even triple the amount produced normally) under stress conditions such as lower nitrogen or silica content in the growth media. Additionally, studies have been made on determining the lipid constituents of diatom oil[1]. A communication entitled ‘Milking diatoms for sustainable energy’, which is to be published in *Industrial and Engineering Chemistry Research*, states, ‘Based on experimental correlations between fluorescence microspectrometry and crude oils of known gross chemical composition (i.e. saturates, aromatics and resinasphaltenes), the ‘pure’ diatom oil contains an estimated 60–70% saturates. The diatom oils are likely to be rich in fatty acids, which during early diagenesis, reportedly transform into condensed lipids[1]’.

Most of the petroleum that we have today has originated from fossilized diatoms. A small fraction of the diatom biomass sinks to the bottom of the oceans and is preserved over millennia to form petroleum reserves. However, Ramachandra and his group have worked out a concept which ‘cuts down’ the time required to produce oil from diatoms from ‘millions of years to daily’. They have suggested a way in which diatoms can be made to work like mammalian glands, so that one can ‘milk’ oil from them continuously for long periods of time. The diatoms will be designed such that they secrete the oil that they produce rather than store it, so that they need not be destroyed to obtain oil, and a continuous supply of oil is ensured. ‘Milking’ diatoms would serve to do away with the cumbersome process of extraction of oil from them.

The team has also proposed the design of a solar panel based on the structure of an angiosperm leaf – the epidermis, the outermost layer of the leaf, would be the solar panel; the inner tissues of the leaf, such as the palisade and spongy tissues that are responsible for much of the carbon fixation and photosynthesis, will be the photosynthetic diatoms (Figure 2). Conditions for optimum production of oil will be provided. Additionally, they have also suggested genetic manipulation of diatoms so that they produce gasoline directly instead of ‘crude oil’ from which gasoline must then be obtained. In other words, they have envisioned a ‘solar panel that converts photons to gasoline rather than electricity or heat’[1].

There is, however, much work to be done before ‘milking diatoms’ becomes a reality. The concept, according to Ramachandra, was benefited by the access they had to the pioneering work of H. P. Gandhi, is now ready, but the technology needs to be developed. The first step is to culture various diatoms and identify species that have higher oil content, and those that have a faster growth in low cost growth media. Also required are diatoms that would be thermophilic (they must be able to survive high temperature conditions of the solar panel), able to survive in the hydrocarbon mixture that they would exocytose, and have a highly efficient photosynthetic capacity. The second step is the design of the solar panel and genetic modification of the diatoms to get a system that would give a continuous supply of oil. Ramachandra *et al.* have also suggested the engineering of an angiosperm leaf with a symbiotic association with diatoms – the diatoms can replace the photosynthetic mesophyll tissue of the leaf while the leaf helps in gaseous exchange and also

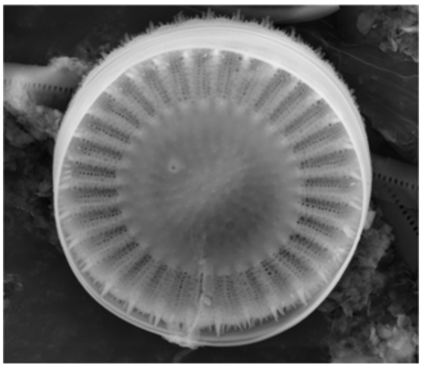

Figure 1. An electron micrograph of a diatom. Courtesy: Karthick, B., Energy and Wetlands Research Group, CES, IISc. Image taken at SEM facilities at INI, IISc, Bangalore.

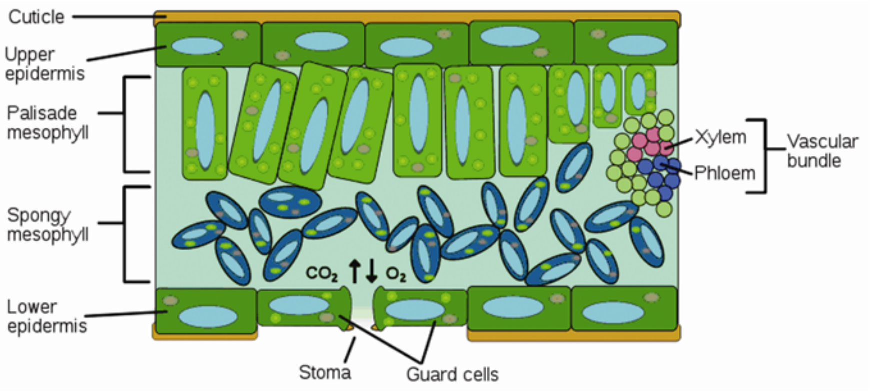

Figure 2. The anatomy of an angiosperm leaf – the inspiration for the design of the diatom solar panel. Source: http://commons.wikimedia.org/wiki/File:Leaf_anatomy.svg

provides a humid environment for the growth of diatoms. Another step is the genetic engineering of diatoms to make them produce gasoline directly so that the secretion can be used without further processing and modification. These various 'steps' may take a number of years, or may even happen simultaneously through collaboration.

The advantages that such a technology would have are immense. First, food crops need not share arable land and water with fuel crops. Much lesser land and time are required to culture diatoms when compared to crops for biofuels. Secondly, food prices will not be affected as crop plants will not be used for fuel production. Energy and money spent on extraction of oil from algae will also be saved, as the diatoms will be made to secrete the oil that they produce. Another important advantage is that diatoms will also serve as sequestering agents for the carbon that is emitted due to burning of fuels. Additionally, since the diatoms will be producing gasoline that is chemically similar to the fuel that we are already using, we can continue to use the automobiles and other machines that we have. The only difference would be that they will be running on a much more environment friendly, renewable source of energy.

According to Ramachandra, diatom fuels can completely replace fossil fuels as long as certain conditions, such as 'the availability of funds and participation of youngsters', are met. However, a number of challenges lie ahead. One is the competition that fossil fuels offer. As Ramachandra says, 'Because fossil fuel based products are established technology, people have already subsidized it'. Even if production of enough oil from sustainable sources such as diatoms becomes a reality, much thought, effort and persuasion may be required to make the general public shift from using fossil fuels to using biofuels. Things may turn out the other way too. 'The switch to an alternative energy source may occur as rapidly as the switch from the horse to the automobile and, thus, may not take another generation.'[1]

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1. Ramachandra, T. V. *et al.*, *Ind. Eng. Chem. Res.*, 2 June 2009; doi:10.1021/ie900044j.
2. Sheehan, J. *et al.*, A look back at the US Department of Energy's Aquatic Species Program – biodiesel from algae, National Renewable Energy Laboratory, US Department of Energy, 1998; http://www1.eere.energy.gov/biomass/pdfs/biodiesel_from_algae.pdf
3. http://earthobservatory.nasa.gov/Newsroom/-view.php?id=38430
4. http://www3.interscience.wiley.com/journal/-122301433/abstract
5. Sorhannus, U., *Mar. Micropaleontol.*, 2007, **65**, 1–12.
6. Sims, P. A., Mann, D. G. and Medlin, L. K., *Phycologia*, 2006, **45**, 361–402.
7. Bassam, N. El., In *Energy Plant Species: Their Use and Impact on Environment and Development*, James and James, Science Publishers Ltd, 2005, pp. 284–287.

ACKNOWLEDGEMENTS. I thank Dr T. V. Ramachandra for providing the pre-print version of 'Milking Diatoms for Sustainable Energy', which is scheduled to appear in *Industrial and Engineering Chemistry Research* in October 2009 and for allowing me to interview him for this article. I also thank to Mr B. Karthick for the diatom photograph. I am grateful to both of them for their extremely valuable comments on the initial draft of this manuscript.

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