An algae-based fuel

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In the context of climactic changes and of soaring prices for a barrel of petroleum, biofuels are now being presented as a renewable energy alternative. Presently, research is being done on microscopic algae which are particularly rich in oils and whose yield per hectare is considerably higher than that of sunflower or rapeseed. At the industrial level, bioreactors which use micro-algae to trap CO2 and NOx are in active development in the United States.

The Mayas and the Aztecs of present-day Mexico used micro-algae as a dietary supplement. In the Nahuatil language, micro-algae, which are naturally very rich in protein, were called "tecuitlatl." Today, it could be the case that micro-algae, this time rich in lipids, may prove to be an alternative to petroleum. The National Renewable Energy Laboratory (NREL) and the Department of Energy (DOE) are working to produce a commercial-grade fuel from these triglyceride-rich micro-algae. NREL, located in Golden, Colorado, is an ensemble of laboratories researching the development of fuels.

The interest in microscopic algae

Some species of algae are so rich in oil that it accounts for over 50% of their mass. NREL has selected approximately 300 species of algae, as varied as the diatoms (genera Amphora, Cymbella, Nitzschia, etc.) and green algae (genera Chlorella in particular). These samples are stored at the Marine Bioproducts Engineering Center (MarBEC), where they are put at the disposition of researchers from around the world. Both fresh-water and salt-water algae, particularly rich in oils, were selected. Molecular biology technology is used to optimize the production of algae lipids, as well as their photosynthetic yield. Other species, capable of synthesizing hydrogen, are also the object of research.

[caption with image of sunflower]
The production of traditional biofuels requires expansive land surfaces for cultivation. Terrestrial biofuels come traditionally from two sources: oil, produced from sunflower or rapeseed, and alcohol, produced from the fermentation of sugars from beets, wheat, or corn.

The production of these biofuels necessitates the use of large tracts of land. According to Jean Marc Jancovici, an engineer specializing in greenhouse gas emissions, it would require a sunflower field 118% the size of France to replace the 50Mtep of petroleum consumed each year by the French for their transportation needs (104% of the size of France for rapeseed, 120% for beet, 2700% for wheat).

The diatoms' world

Diatoms, or Bacillariophytes, are unicellular, microscopic algae. They are identifiable by the form of their silicon skeleton. Their size varies from 5 micrometers to 5 millimeters. These organisms are widespread in salt water, where they constitute the largest portion of phytoplankton biomass, but they are also found in freshwater. There exist approximately 100,000 known species around the world. More than 400 new specimens are described each year. Certain species are particularly rich in oils.

These microscopic algae use a photosynthetic process similar to that of higher-developed plants. They are veritable miniature biochemical factories, capable of regulating CO_2, just like terrestrial plants, thanks to the enzyme Rubisco (Ribulose 1.5 carboxylic biphosphate). The Calvin cycle yield serves as starting point for the biosynthesis of sugars and lipids. The enzyme carboxylic acetylcoenzyme A (ACCase) plays a key role, notably with the diatoms, in the synthesis of triglycerides or triacylglycerols (TAGs), molecules sought for fuel production. NREL researchers were the first to demonstrate the existence of that enzyme in diatoms. In diatoms, a lack of silicon leads to an augmentation in lipid synthesis, in concert with the genetic activity of ACCase. This gene has been isolated and cloned in the hopes of augmenting its expression and thus the production of oil. When a nitrogen stress is applied to green algae, the same results ensue. Other enzymes promoting the biosynthesis of triglycerides are the object of intense research.

There are no better captors of the sun's rays than these microscopic photosynthesizing organisms. And they grow fast: it's possible to complete an entire harvest in a few days, which is not the case with rapeseed or wheat. Their automated cultivation, in large basins or bioreactors, is easy. Experiments have taken place in Hawaii, California, and New Mexico. The open-air farm in Roswell, New Mexico, has a surface area of $1000m^2$. Other factors, such as the influence of pH or differences in daily and nightly temperature, are being studied to increase the productivity of these algae. Elsewhere, the Japanese government has launched a research program to investigate the development of reactors which would use fiber optic cables, which would reduce the surface area necessary for their production and ensure better protection against contamination.

The yield from these algae is clearly superior to that of terrestrial plants such as rapeseed because they are unicellular. Their cultivation in a liquid environment allows them better access to resources: water, CO_2, and minerals. It is for this reason that the microscopic algae are capable, according to NREL scientists (John Sheehan, et al), "of synthesizing 30 times more oil per hectare than the terrestrial plants used for the fabrication of biofuels." We speak here of the rendering per hectare because the important factor in their cultivation is not the volume of the basin where they are grown, but the surface exposed to the sun. Productivity is measured in terms of biomass (kg of algae or oil) per day and by surface unit. Thus, comparisons with terrestrial plants are possible. Professor Michael Briggs at the University of New Hampshire estimates that the cultivation of these algae over a surface of 38,500 km^2, if situated in a zone of high sun-exposure such as the Sonora Desert, would make it possible to replace the totality of petroleum consumed in the United States. Interest in this biotechnology is therefore immense. Arid zones are ideal for the cultivation of algae because sun exposure is optimal while human activity is virtually absent. These algae can even be nourished on recycled sources such as pork and poultry refuse, and can play a role in the treatment of waste water.

Algae and men

In fact NASA was the first to become interested micro-algae, in the framework of space missions. NREL's work on algae began in the 1970s in the context of the American oil shortage, which had been predicted since 1956 by geophysicist King Hubbert. It then became apparent to the American government that it was indispensable to search for foreign oil or to develop other fuels. Work on algae began to take off in 1980s but had to be cut 16 years later due to budget cuts. Recently, work on algae has begun anew, in response to skyrocketing petroleum prices which have created market conditions making algae-based diesel a competitive alternative. In 1998, a barrel of petroleum sold for $13; today the price can exceed $50 per barrel. If the production of algal biodiesel has not already been widespread at an industrial scale, it's simply on account of concerns about profitability and competition. In 1982, it was estimated by Benemann that the cost of production for a barrel of algal biodiesel was, on average, $94 (the hypothetical base was $61 and hypothetical high was $127, depending on the mode of production). According to Michael Briggs: "The operating costs, including power consumption, labor, chemicals, and fixed capital costs (taxes, maintenance, insurance, depreciation, and return on investment) worked out to $12,000 per hectare. That would equate to $46.2 billion per year for all the algae farms, to yield all the oil feedstock necessary for the entire country. Compare that to the $100 - $150 billion the US spends each year just on purchasing crude oil from foreign countries, with all of that money leaving the US economy." Scientists at NREL think that these new fuels will become competitive by 2010.

Seventy percent of the oil extracted from algae is done by pressing them. The use of an organic solvent increases the extraction level to reach 99%, but at a higher cost. "All oil extraction can be effected by a simple cold press – by pressing, or chemically, or by a combination of the two methods," according to Prof. Briggs. Given its relatively high viscosity, the virgin vegetable oil can be used directly in adapted diesel motors. The triglycerides which constitute vegetable oils can equally be transformed into monoesters and into glycerol by a reaction of the trans-esterification with methanol molecules. The smallest molecules of biodiesel thus obtained can then be used as a fuel in compression motors. This biodiesel contains no sulfur; it's non-toxic, and highly biodegradable.

The solution to all our problems?

In order to have an optimal yield, these algae need to have CO2 in large quantities in the basins or bioreactors where they grow. Thus, the basins and bioreactors need to be coupled with traditional thermal power centers producing electricity which produce CO2 at an average tenor of 13% of total flue gas emissions. The CO2 is put in the basins and is assimilated by the algae. It is thus a technology which recycles CO2 while also treating used water. In this sense, it represents an advance in the environmental domain, even if it remains true that CO2 produced by the centers would be released in the atmosphere by the combustion of biodiesel in buses and cars.

Diatoms, which millions of years ago helped create the conditions necessary for the formation of hydrocarbons consumed today, will be useful to us a second time.

GreenFuel Technologies Corporation: when industry turns green

At the industrial level, bioreactors which use micro-algae are in an advanced state of development in the United States. The team around Doctor Isaac Berzin, Chief Technology Officer of the American company GreenFuel Technologies Corporation, based in Cambridge, MA, has developed a bioreactor that reduces NOx and CO2 emissions by trapping them in the algae. This system was tested successfully in an installation at the 20MW *Massachusetts Institute of Technology* (MIT) Cogeneration Plant (*Cogen*) plant. This technological innovation is featured in an exhibit at the *Museum of Science* in Boston, on display since July 2004.

*GreenFue*l's bioreactor is a triangular structure made of polycarbonate tubes between 2 and 3 meters long and 10 to 20 centimeters in diameter. The hypotenuse of the triangle is exposed to the sun while the two other sides are hidden from the sun. World-class mathematicians integrate the speed of the fluid in the tubes with the quantity of light available in order to develop the best performing system settings. The temperature is also of critical importance, but easy to control: in the reactor, the thermal temperature variation is no more than 10C. The gas injected comes from *Cogen* with approximately 13%. CO_2 content. This CO_2 is assimilated by algae which have been chosen according a protocol used by NASA. It is not a question of GMOs [genetically modified organisms], but rather of algae that have habituated to growing conditions. The gas cleaned by the bioreactor exits from the top, while a fraction of the algae is drained daily. The biomass thus obtained can be used to produce biodiesel, bioplastics, or molecules of pharmaceutical interest.

In October 2004, a report from the testing firm *CK Environmental* indicated that during a measuring period of 7 days, the bioreactors reduced nitrogen oxides by 85.9% (+/-2.1%); the bioreactors reduced CO_2 by 82.3% (+/-12.5%) on sunny days, and by 50.1% (+/-6.5%)on overcast or rainy days. The test method used conforms to the standards imposed by the *Environmental Protection Agency* (EPA). Previous systems using algae managed to reduce CO_2 emissions by 5% and NO_x emissions by 70%. The system can be used in latitudes where solar exposure is weak, albeit with relatively reduced efficiency. The calibration phase is still in progress. It is theoretically possible to achieve 90% CO_2 capture, but financial and technological constraints must be taken into account to reach such levels. Nevertheless, this bioreactor already constitutes a considerable technological advance. According to Julianne Zimmerman, of GreenFuel management, "GreenFuel is working to deploy small scale field trials in the US in 2005 and 2006; we aim to commence operation of our first full-scale installations in 2008." For industrialists the world over, reducing greenhouse gas emissions is an environmental and economic challenge, notably in the framework of the application of emissions quotas imposed by the Kyoto Protocol (for signatory countries). Peter Cooper, from *Cogen* management, is enthusiastic: "The system is even more efficient than we had hoped. This new technology, which is able to reduce significantly CO_2 and NO_x emissions, represents an important step in the fight against global warming."