Producing biofuels from microalgae

Algae Under Stress

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The global demand for energy continues to grow while non-renewable energy resources are rapidly running out and their exploitation is damaging the environment and Earth's climate. As such, there has been growing interest in scientific circles and among the public in reducing our reliance on fossil fuels and gradually replacing them with renewable sources such as biofuels

One potential material for the production of biofuels is the biomass of unicellular green algae, known as microalgae. Scientists believe that their high yield may render them a potential replacement for fossil fuels. Cultivating microalgae has a smaller impact on the environment and food production than generating other types of biomass. Another advantage of microalgae is their ability to assimilate high volumes of CO_2 (between 1.65kg and 1.83kg CO_2 per kilo of generated biomass), and the option of using CO_2 generated by combustion engines in their cultivation.

Before microalgae can be used to obtain energy, the biomass must first be converted by thermochemical, biochemical, or chemical processes, or by direct combustion. They can be used to obtain biofuels including biodiesel, bioethanol, and biomethanol, or processed photobioreactors to generate biohydrogen.

Less nitrogen, more oil

The organisms known as "microalgae" comprise a highly diverse group inhabiting almost all of the Earth's ecosystems. They include both eukaryotes (organisms which have a cellular nucleus) and prokaryotes (without a nucleus - these latter more properly known as "cyanobacteria"), and various species may be autotrophic (generating nutrients by photosynthesis), heterotrophic (using organic carbon for growth), or mixotrophic (relying on a mixture of the two sources). Depending on their type of metabolism, microalgae require sources of carbon, mineral compounds, and light. Heterotrophic species are able to grow in the dark, using organic compounds as their carbon source. Mixotrophic species also photosynthesize inorganic carbon (CO_2). The volume of obtained biomass and lipids is higher for heterotrophic growth than that generated under autotrophic conditions. However, heterotrophic cultures can easily be infected by organic sources of carbon present in their environment; this can present a problem, in particular in the production of biomass on a large scale.

The main advantage of unicellular algae is their fast proliferation. Under optimal conditions, their biomass can double over the course of a day, or - for certain species - just a few hours. The rate of proliferation is mainly driven by characteristics specific to each species, as well as by the availability of nutrients and carbon dioxide, and physical and chemical factors such as temperature, intensity of photosynthetically-active radiation, and the ratio of periods of light and darkness during each 24-hour cycle. Defining optimal growth conditions for each species is a key element in the development of biomass for energy production. Since microalgae exhibit metabolic plasticity, adjusting culture conditions can improve yield and reduce costs of the biomass conversion process. These issues are being studied at the PAS Institute of Agrophysics in Lublin.

The ability to accumulate lipids in cells - which means they can be used in the production of oil - is an important feature of microalgae. However, under optimal growth conditions, many species produce fatty acids that are unsuitable in the production of biofuels. The algae need to be exposed to stress (such as limited nutrients, especially nitrogen) to alter their metabolism; this triggers a shift towards the biosynthesis and accumulation of triglycerides, which can constitute up to 80% of the total lipid content in the cell and are a suitable substrate in the production of biofuels.

The key stage is the selection of the most appropriate species or strain. Important factors are growth rate, volume and quality of fatty acids produced, competition with other microalgae or bacteria, and resistance to mechanical stress. Biofuels are generated using freshwater algae including *Scenedesmus sp., Chlorella sp.* and *Spirogyra sp.*, and seawater algae such as *Synechccocus sp.* and *Dunaliella sp.* Currently, microalgae of the *Chlorella* genus appear to be the most suitable for the production of biofuels due to their high lipid content and yield.

Leaving the laboratory

So far, using microalgae solely for the production of biofuels has been shown to be cost-ineffective. As such, it is worth considering using this biomass for other purposes, such as developing pharmaceuticals and nutraceuticals, and demoting energy generation. However, we still do not have fully-tested technologies for manufacturing on a greater than laboratory scale, therefore developing new solutions remains the greatest challenge.

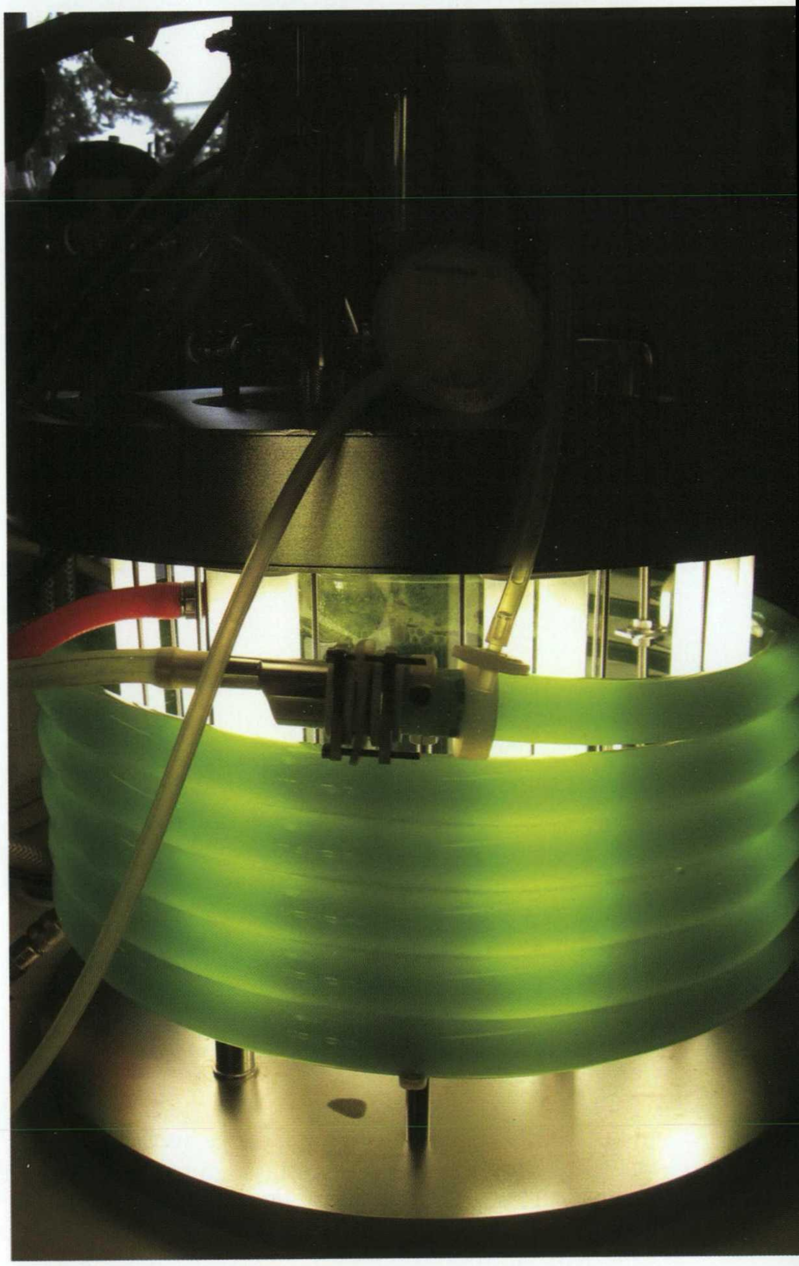
One of the key issues is the high cultivation costs, driven in part by the price of nutrients. One possible replacement could be effluent (wastewater), a cheap source of nitrogen, phosphorus and water. Utilizing such waste also makes biomass production a more environmentally-friendly process.

The second issue is the cultivation method. Microalgae require an aquatic environment: either open natural or artificial ponds, or closed photobioreactors. Cultivation in open systems is cheaper and technologically more straightforward, although it also has several disadvantages: it produces a low yield, generates high evaporation levels, cultivation parameters are difficult to control, and the systems are open to infection by other microorganisms. Using photobioreactors, we are able to obtain higher yields and density of biomass under precisely-controlled conditions including light levels. Although such cultivation entails higher costs, it is more effective overall.

At the Laboratory of Renewable Energy and Biomass Technologies at the PAS Institute of Agrophysics in Lublin, we are conducting the project "Development of physiological and technical guidelines for the production of algae for energy generation", led by Prof. Jerzy Tys and financed by the Ministry of Science and Higher Education. We have constructed a 250-liter photobioreactor, comprising a cultivation module and a control module for adjusting the culture conditions. We have also fitted it with LED lights and a chamber for thermal or UV light sterilization. Sterilization of the equipment and nutrients is essential for maintaining a monoculture of algae throughout the cultivation process. By connecting the photobioreactor directly to a centrifuge, we are able to run the culture continuously: when the biomass reaches a specific density, it is immediately diverted into the centrifuge. The culture is maintained in constant motion using a peristaltic pump, while the temperature is kept constant with a heating mat.

Our hope is that the solutions we have developed for our photobioreactor will enable us to optimize cultivation conditions and eventually produce microalgae biomass on an industrial scale. ■

Grzegorz Paul



Culture tank of a laboratory photobioreactor

Further reading:

Kwietniewska E., Tys J., Krzemińska I., Kozieł W. (2012). Microalgae - cultivation and application as a source of biomass: a review. *Acta Agrophysica Monographiae, 2,* 1-108