AUFWIND: An ambitious German microalgae project for producing third-generation biofuels

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The term ‘microalgae’ has no taxonomic meaning, except that it refers to a spectrum of photosynthesising micro-organisms from Protista and Archaebacteria, including chlorophyta (green algae) and cyanobacteria (blue-green algae). Microalgae have been studied in the laboratory, in mass outdoor cultures and in nature for more than a century. They are grown for a variety of potential applications, which include basic research on photosynthesis, the production of lipids for energy, bioremediation, anti-microbial substances, cheap protein for animal and human nutrition, and the production of various bio-chemicals.[1,2]

Microalgae have several competitive advantages over higher plants, namely higher growth rates, suitability for growing in photobioreactors, and non-reliance on good agriculture soils. Storage products of microalgae generically could be either carbohydrates and/or lipids, with the potential to produce ethanol, diesel, methane and even kerosene from these compounds. However, a major frustration for microalgal biotechnologists has been the realisation of much lower yields than what laboratory measurements suggest should be possible.[3]

The potential of algae as a fuel source is undisputed. It was these photo-autotrophic micro-organisms that were fixing sunlight energy into lipids for millions of years, generating the petroleum reserves that modern human civilisation uses today. However, such reserves are finite, and the challenge is to marry biology with technology to produce economically competitive fuels without harming the environment or compromising our food security. The fundamental ability of microalgae to produce energy-rich biomass from carbon dioxide, nutrients and sunlight, through photosynthesis for biofuels, has led to the concept of ‘third-generation biofuels’.

The key compounds used for bio-diesel and kerosene production are lipids, especially the triacylglycerols (referred to as TAGs). These lipids, once extracted, need to be trans-esterified for biodiesel, and a further ‘cracking’ step is required to produce kerosene. For biofuels, microalgae with high TAG content are required. A number of such algae have been isolated and lipid contents from 20% to 60% have been achieved. An essential step in forcing microalgae to channel energy compounds into lipids is some form of stress. Stressors such as high light, low nitrogen, low phosphorus and high salinity have been used. Limiting nitrogen was the main stressor in the cultures used in our study. This limitation was achieved by transferring exponentially growing cells into a balanced nutrient medium with a known limiting concentration of nitrogen.

The AUFWIND project at the Research Centre Jülich in Jülich, Germany consists of three different commercially available photobioreactor types, constructed adjacent to each other. This enabled us compare three very different pilot-to-commercial-scale systems for biomass and lipid production. The project is undisputedly the first of its kind to address biofuel production from microalgae on such a large scale and in such different systems.

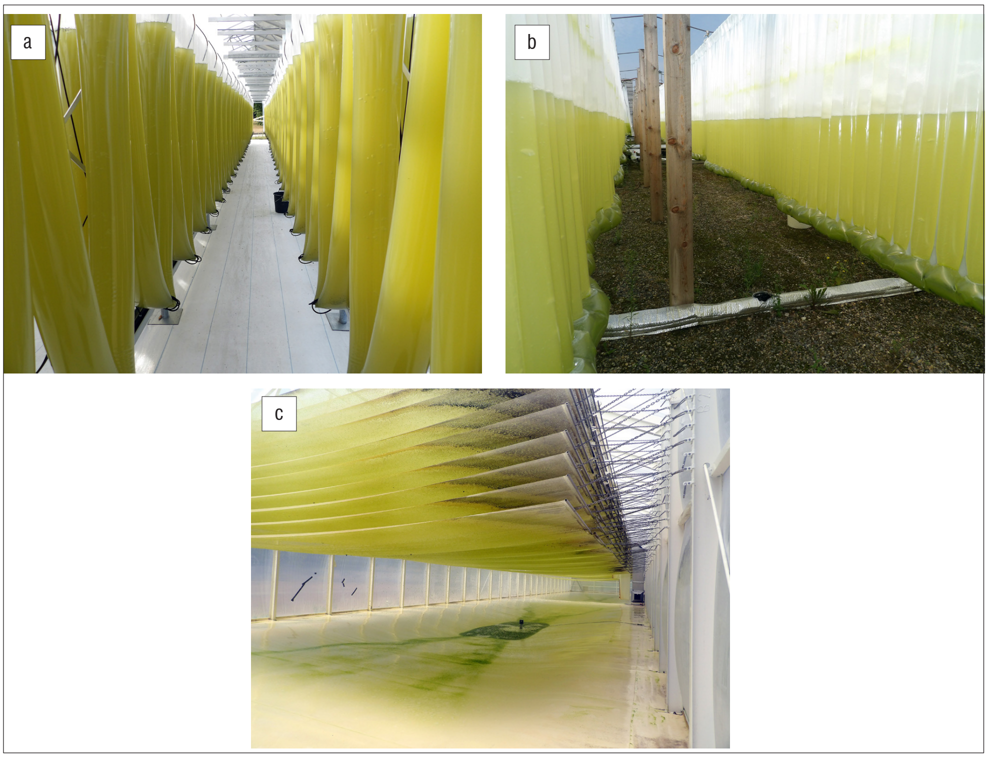

Figure 1: Three photobioreactors at the AUFWIND project. (a) Novagreen photobioreactor, housed in a glasshouse, comprising 1338 V-bags each containing 25 L culture (note the yellow colour, typical of lipid-rich microalgae); (b) the Phytolutions photobioreactor is made up of six sections, each containing up to 10 ‘curtains’ of vertical tubes interconnected with a horizontal tube at the bottom; and (c) stacked horizontal mesh sheets of the IGV system, housed in a plastic-covered greenhouse.

The three photobioreactors are from Novagreen[4] (Figure 1a), Phytolutions GmbH[5] (Figure 1b), and Institüt für Getreideverarbeitung GmbH (IGV)[6] (Figure 1c). Each photobioreactor occupies 500 m^2 of land surface area. The Novagreen system consists of interconnected vertical plastic tubes, each roughly 150 mm in diameter, whereas the Phytolutions system is outdoors and consists of 'curtains' of vertical plastic tubes, each with a diameter of about 90 mm. The most ambitious photobioreactor is from IGV, and consists of horizontally layered nets; the algae are sprayed over the nets and allowed to grow while dripping from one net to the next. All systems received additional carbon dioxide, and an array of environmental and culture parameters were measured continuously.

The green alga *Chlorella vulgaris* (Beijerinck), strain CCALA 256, was used as a growth organism. One of the main tasks was to manipulate growth conditions so that the microalgae converted their stored energy into lipids, and to establish protocols to run the various photobioreactors on a large scale. This was accomplished in just over 2 months of intensive experimentation that resulted in modifications to the designs of the photobioreactors, different microalgal strain selection, and the replacement of the nutrient broth with a so-called balanced one (so that at final yield all the supplied nutrients had been taken up by algae). From the experiments it became evident that the specific growth rate of the algae was constrained by an upper limit that differed for each photobioreactor, but was always approximately linearly proportional to the daily dose of photosynthetically active radiation. Extremely encouraging was the fact that the microalgae could be manipulated on an industrial scale and lipid contents >40% were achieved.

One should have no illusions regarding the technology and economic feasibility of the project. However, with continued research, optimisation, and utilisation of waste resources, it is highly likely that the production of lipids from microalgae for biofuels can become a reality in the near future. An added benefit from the project is the generation of valuable data for large-scale industrial applications.

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