Microalgae as suppliers of energy?

In view of dwindling oil reserves and ongoing climate change, microalgae are gaining in importance as suppliers of energy. The major advantage of microalgae is that they can be used to produce CO2-neutral fuels without competing with food production. However, despite intensive efforts, the economic production of biofuels from microalgae is not yet possible. This dossier will present and discuss the opportunities and challenges associated with the use of microalgae for energy production.

In principle, microalgae are excellently suited for the sustainable production of energy: just like higher land plants, they are photosynthetic organisms that require CO₂ for the growth and generation of complex biomass. However, they do not need to be cultivated on agricultural areas; they can be grown in closed reactors on arid areas that are unsuitable for agricultural use. Therefore, the production of biofuel from microalgae is not in competition with food production as is the case with currently used first-generation biofuels such as biodiesel produced from rape oil or bioethanol produced from maize. In addition, the cultivation of microalgae in closed reactors only requires limited quantities of water. Marine algal species can also be cultivated in seawater. Moreover, wastewater can be used as a source of inorganic nutrients such as nitrogen or phosphorous. In addition, microalgae are effective users of sunlight since all the cells in a culture carry out photosynthesis, not only the green leaf cells as is the case with higher plants. For these reasons, microalgae generate much higher per area yields than land plants.

Energy carriers produced from microalgae
Microalgae can be used to produce different types of energy carriers, the most important being biogas, biodiesel, bioethanol and hydrogen.

The production of biogas is technically quite simple, as neither complex processing nor multiple preparation steps are necessary. Concentrated and wet algal biomass is homogeneous and, unlike plant biomass, virtually free from lignocellulose, which is difficult to process, and can be directly fermented in a biogas plant. Cultivation and biogas production can be carried out at different sites (decentralised). The biogas consists mainly of methane (energy carrier) and CO\(_2\) and can be used in a block heat and power plant for the production of heat and power or be directly fed into the gas network (as biomethane).

In early 2010, the ETAMAX research project started in Baden-Württemberg. The project involves a large number of research institutions, energy businesses and industrial companies whose objective is to convert algal biomass into biogas and to operate a fleet of gas vehicles with purified car fuel. At present, pilot-scale facilities are being used to further optimise the method.

Oil - biodiesel

In the USA, the production of biodiesel from microalgae is an extremely important issue that receives
a great deal of funding. Depending on the algal species and the cultivation conditions, microalgae can contain up to 50 per cent oil, which can be extracted and further processed into biodiesel by way of transesterification. Energy and petrol companies are extremely interested in the use of microalgae for the production of biodiesel. For example, the American oil company Exxon Mobil and the biotechnology company Synthetic Genomics have invested more than 600 million US$ in a project focusing on the generation of biodiesel from algae. However, there are different opinions – ranging from very optimistic to very sceptical – about the use and benefits of this technology. In February 2010, international experts from different disciplines, including Prof. Posten from the Karlsruhe Institute of Technology, published an evaluation of the potential of microalgal fuels in the renowned journal Nature Biotechnology. The evaluation takes into account both the economic and technical aspects of biofuel production from microalgae.

Economic and technical evaluation of algal biodiesel

The authors of the Nature Biotechnology paper estimate that a maximum of between 100,000 and 150,000 litres oil/hectare/year can be obtained from algal biomass. This calculation is based on a maximal photosynthetic conversion efficiency of 10 per cent, which assumes that cells convert 10 per cent of sunlight into bioenergy. In theory, this means that the global fuel requirements could be covered with microalgae and that there are no general limitations – for example with regard to cultivation areas. The authors have examined industrial feasibility models of microalgal systems in order to identify the key economic drivers. The “base case” model, which integrates current
technology involves the following assumptions: 1) production of microalgal biomass using 500 ha of microalgal production systems; 2) the extraction of oil; 3) the co-production and extraction of a high value product (e.g., beta-carotene); and 4) the sale of the remaining biomass as feedstuff (e.g., as substitute for fishmeal). The second model, which the authors call “projected case” represents the biofuel industry at maturity and does not include the co-production of high value products. The authors concluded that economically viable microalgal biofuel production systems will become possible, under the assumption that the construction costs of reactors remain low (< 150,000 US$ per hectare) and that high enough biomass yields (> 50 g algae per square metre and day) can be obtained. It does not seem unrealistic to assume that these figures will be achieved over the next few years. However, the authors find it difficult to say how long it will actually take before the first economically viable facility is in operation. It is important to note that several external factors influence the need for and the viability of such systems, including oil price evolution and the introduction of more stringent CO2 emission targets and carbon trading schemes.

Biohydrogen from microalgae

Another interesting possibility for reducing our dependence on fossil fuels is the production of environmentally friendly hydrogen using the green algae Chlamydomonas reinhardtii. When there is sufficient sunlight and nutrient deficiency, which reduces the growth of the algae, Chlamydomonas algae switch from the production of oxygen, as in normal photosynthesis, to the production of hydrogen. The advantage of using Chlamydomonas algae for the production of hydrogen is that the separation of gas is far easier than the extraction of oil. However, general difficulties include the low quantities of hydrogen produced, and the fact that hydrogen synthesis stops upon contact with oxygen because the key enzyme in the process – a hydrogenase – is oxygen-sensitive. For these reasons, the production of hydrogen is currently only possible under strict laboratory conditions.
Broad research and development projects, including all steps from molecular biology investigations to the final production reaction, are under way. However, there is still a long way to go before the large-scale application of microalgae becomes possible.

Starch is another important source of energy that can be produced by microalgae. Starch can be converted into ethanol. However, these processes are also at an early stage of development.

R&D activities

The major challenge is the development of reactor technologies that are cheaper and generate higher biomass yields than currently used reactors. Another prerequisite before microalgae can be used for the production of energy is a considerable reduction in the cost of the energy required for the cultivation of algae (e.g., for mixing the algae). Reducing these costs is the only way to achieve a net energy production. These key issues are currently being intensively investigated by Prof. Posten’s team at the Karlsruhe Institute of Technology.

Besides the progress made in process technology, progress also needs to be made in the fields of biology and molecular biology: the process is expected to be greatly optimised through the selection of suitable algal species from a total of around 40,000 known algal species, as well as through the cultivation of specific strains, the physiological characterisation and the development of efficient selection and expression systems. The third major area where improvements can be expected is the downstream process, i.e. the cost-effective and reliable processing of the product.

Conclusion
The photobioreactor with LED lights was developed by Prof. Posten’s team at the KIT in Karlsruhe and is designed to model different natural light influences and deduce information for more efficient light management.

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Microalgae can be used for the specific generation of energy carriers. However, the operation of economically viable production facilities depends on the optimisation of the processes involved, both with regard to process engineering as well as algal biology. It would appear that in the near future, algae will mainly be used in two areas: the production of high value products and the energetic use of residual algal biomass. Prof. Posten makes it clear that the generation of high-value products must not be seen as a kind of subsidy for the energetic use of algae, but rather as an important end in itself. The ability to synthesise a broad range of different products with high value creation potential for the food supplement, cosmetics, medicines and fine chemicals sectors, is one of the major strengths of microalgae.

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