Preface

Sarina J. Ergas · N. Peter van der Steen

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This special issue focuses on recent advances in culturing, harvesting and processing microalgae for biofuel production. Algae have very high biomass and lipid productivities and can be used to produce a wide range of fuels (e.g. biodiesel, ethanol, methane), value-added chemicals and materials (e.g. animal feeds, polymers). Major mass and energy flows for a hypothetical full-scale algal biorefinery are shown in Fig. 1. The challenge presented in this issue is to achieve this level of process integration in an economically and environmentally sustainable manner. As discussed in the overview by Makareviciene et al. (2013), a major advantage of algal biofuel technology is that, unlike other biofuel crops such as corn bioethanol or rapeseed oil, algae can be grown on marginal land and so does not compete with food crops for arable land. In addition, carbon dioxide from waste gases and nutrients from municipal, industrial and agricultural sources can be used as algal growth substrates. This has the potential to reduce the cost,

environmental discharges and energy requirements for algae production, but poses an additional challenge of simultaneously achieving high growth rates, intracellular storage product production and pollutant removal efficiencies.

The design principles to achieve these goals in photo-bioreactors are based on light availability, transfer of mass and heat, and culture growth conditions. Fernández and Molina (2012) review the different design approaches used today and identify the most promising concepts for the future, as well as adequate control strategies and potential for scale-up of different technologies. The larger the scale of the reactor, the more difficult it is to achieve culture conditions required by algae, thus diminishing the process yield. Raceway reactors are widely used at commercial scale because of their low energy consumption and capital investment, though they are deficient in mass transfer, temperature control and cannot be used for pure cultures. Closed photobioreactors allow better control, that leads to higher production, but at a cost of complexity and higher costs. In spite of this, closed reactors, such as flat panels and tubular reactors, are the only option for producing sensitive and highly valuable strains used in the production of foods, feeds and fine chemicals.

A crucial factor for outdoor production is temperature control (Ras et al. 2013), since algae growth is highest at the species-dependent, optimal temperature. Growth rate increases more or less linearly with temperatures below the optimal temperature, but

S. J. Ergas
Department of Civil and Environmental Engineering,
University of South Florida, 4202 East Fowler Ave.,
Tampa, FL 33620, USA
e-mail: sergas@usf.edu

N. P. van der Steen (✉)
Core Group Pollution Prevention and Resource Recovery,
UNESCO-IHE Institute for Water Education, PO Box
3015, 2601 DA Delft, The Netherlands
e-mail: p.vandersteen@unesco-ihe.org

Fig. 1 Systems level view of an algal biorefinery showing major mass and energy flows

decreases rapidly when temperatures surpass the optimal temperature. The latter effect has often been disregarded in the growth models reported in literature. Integrated modeling of water temperature and algae growth is therefore suggested to describe growth in outdoor production facilities. The energy requirements for cooling may thus be assessed and compared with energetic content of the biofuel produced in the same reactor.

Milledge and Heaven (2012) provide a review of current methods for thickening, dewatering and drying microalgae. The small cell size, negative surface charge and low biomass concentrations usually achieved in microalgae cultivation systems lead to significant challenges in downstream processing of algal suspensions, and it has been estimated that harvesting can account for 20–50 % of the total cost of algal biofuel production. Sedimentation and floatation are the most promising and energy efficient technologies used for algae harvesting, but normally require the use of coagulants to destabilize and aggregate algal cells. A number of different coagulants have been investigated with algae, including multivalent metal salts, cationic polymers, chitosan, starch and electro-coagulation. The high energy inputs required for filtration and centrifugation have been major obstacles

to the use of these technologies for dewatering microalgae, and the authors report that the estimated energy requirements for centrifugation could be four times the energy available in the algal biodiesel. As drying further increases capital, operations and maintenance costs, the authors suggest that energy extraction methods should be selected that do not require drying.

Although a large body of research has been carried out on strain selection and culturing technologies, less research has been done on the conversion of microalgae lipids to biodiesel. Hidalgo et al. (2013) discuss advances in direct transesterification of microalgae biomass for biodiesel production. A major advantage of this approach is that it can be used on wet biomass. The authors discuss the bottlenecks involved in obtaining biodiesel from algae via conventional transesterification of lipids, most notably the high energy requirements for biomass drying and cell disruption. Biodiesel production from microalgae is normally performed in two stages. Lipid extraction can be carried out using solvents, supercritical fluids, microwaves, ultrasound or heat reflux methods. Transesterification of the extracted lipids for biodiesel production can then be carried out using homogenous, heterogeneous or enzymatic catalysis. In contrast, in

direct transesterification lipid extraction and transesterification are carried out in a single step, with a direct reaction of the biomass to produce biodiesel. The approach has the potential to reduce both equipment requirements and energy costs. The authors review the most important parameters influencing the process, including alcohol/lipid ratio, catalyst dosage, reaction time, temperature, co-solvent use, and biomass water content. The need for more research into novel technologies to improve direct transesterification, such as using microwave and ultrasound energy to accelerate cell disruption and reduce reaction times are also discussed.

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