Growing algae for biofuels and biomass – Literature for the basics

David N. Thomas,
Bangor University, U.K. and Finnish Environment Institute, Helsinki, Finland

The price of fossil fuels has driven policy makers to look for alternative sources of energy in a quite extraordinary way over the last decade. At the forefront of much of the news has been the investment by governments and large multinationals into the development of so-called "biofuels". Many plant species produce lipids and once these are extracted, refined and processed they can be used directly or alternatively crops can be utilised to produce ethanol. However, growing commercial crops in the quantities to satisfy sustainable commercial demands requires considerable investment in terms of land and of course fertiliser and infrastructure for cultivating and optimising the growth of the crops.

For several decades there have been many initiatives to investigate the use of microalgae for biofuel production, since they are known to have rapid growth rates, grow to high biomass per unit volume of water and can be easily harvested. This is summarised in a fairly recent non-specialist FAO report by van Iersel & Flaminni (2010). An excellent overview of growing algae on industrial scales is given by Richmond (2004). See also Schenk *et al.* (2008). However, it should be noted that the ideas of growing algae on industrial scales is not a new concept and even in the May 1954 issue of *Mechanix Illustrated* there was an article about growing algae on moon farms to banish starvation!

van Iersel, S. and Flammini, 2010. Algae-based biofuels: applications and co-products. FAO Environmental and Natural Resources Service Series, No. 44. FAO, Rome, Italy.

Richmond, A. (ed.) 2004. Handbook of Microalgal Culture. Blackwell Publishing, Oxford, U.K.

Schenk, P.M., Stephens, E. and Poston, C, 2008. Second Generation Biofuels: High Efficiency Microalgae for Biodiesel Production. Bioenerg. Res. 1, 20–43

However compelling the interest of having a relatively easily cultivatable crop for biofuel (Christi, 2007, Wijffels & Barbosa, 2010), the case for microalgae is still rather dubious and it is worth reading the debate in Reijnders (2008), Christi (2008a,b) and Weyer et al. (2009). It is certainly easy enough to grow algae in bioreactors, but it is frequently the efficiency of the whole process (energy out - energy that needs to be supplied) that is often treated poorly by laboratory based studies and/or pilot industrial plants (Williams & Laurens, 2010; Stephenson et al, 2010: Hulatt & Thomas 2011a, b; Hulatt et al. 2012). Some companies manufacturing and supplying photobioreactors have made claims that their systems can produce extremely large quantities of biomass/ lipid. However, as observed by Tredici (2010), many of these claims are thermodynamically impossible. In fact some of the problem may simply be due to the inefficiency of the photosynthetic process itself (see Melis, 2009 and citations therein). This being said it is clearly possible that strain improvement and the use of advanced molecular tools may change concepts of efficiency of oil production by commercial strains of microalgae (e.g. Kilian et al. 2011).

Chisti, Y. 2007. Biodiesel from microalgae. Biotechnology Advances, 25, 294-306.

Chisti, Y. 2008a. Response to Reijnders: Do biofuels from microalgae beat biofuels from terrestrial plants? Trends. Biotechnol. 26, 351-352.

Chisti, Y. 2008b. Biodiesel from microalgae beats bioethanol. Trends in Biotechnology, 26, 126–131.

Hulatt, C.J. and Thomas, D.N. 2011a. Productivity, carbon dioxide uptake and net energy return of microalgal bubble column photobioreactors. Bioresource Technology, 102, 5775-5787.

Hulatt, C.J. and Thomas, D.N. 2011b. Energy efficiency of an outdoor microalgal photobioreactor sited at mid-temperate latitude. Bioresource Technology, 102, 6687-6695.

Hulatt, C.J., Lakaneimi, A-M., Puhakka, J. & Thomas, D.N. 2012. Energy demands of nitrogen supply in mass cultivation of two commercially important microalgal species, Chlorella vulgaris and Dunaliella tertiolecta. BioEnergy Research, In press.

Kilian, O., Benemann, C.S.E., Niyogi, K.K. and Vick, B. 2011. High-efficiancy homologous recombination in the oil-producing alga Nannochlopsis sp. PNAS, 108, 2165-21269.

Melis, A. 2009. Solar energy conversion efficiencies in photosynthesis: minimizing the chlorophyll antennae to maximize efficiency. Plant Science, 177, 272-280

Reijnders, L. 2008. Do biofuels from microalgae beat biofuels from terrestrial plants? Trends in Biotechnology, 26, 349–350.

Weyer, K.M., Bush, D.R., Darzins, A. and Willson, B.D. 2009. Theoretical Maximum Algal Oil Production. Bioenergy Research, 3, 204-213.

Stephenson, A.L., Kazamia, E., Dennis, J.S., Howes, C.J., Scott, S.A., Smith, A.G. 2010. Life-cycle assessment of potential algal biodiesel production in the United Kingdom: a comparison of raceways and air-lift tubular bioreactors. Energy Fuel, 24, 4062–4077.

Tredici, M. R. 2010. Photobiology of microalgae mass cultures: Understanding the tools for the next green revolution. Biofuels, 1, 143-162

Wijffels, R.H. and Barbosa, M.J. 2010. An outlook on microalgal biofuels. Science, 329, 796-799.

Williams, P. and Laurens, L. 2010. Microalgae as biodiesel and biomass feedstocks: review and analysis of the biochemistry, energetics and economics. Energ. Environ. Sci. 3, 554-590.

Industrial cultivation of microalgae is not just being considered for the biofuel market, but also as a means of sequestering CO2 from power plants and/or bio-remediating inorganic nutrients from waste-water treatment plants (Craggs et al. 2011). In particular, the recent implementation of carbon trading and renewable energy policy means that CO_2 mitigation technologies will play an important role in market economics (Giovanni & Richards, 2010). However, the big unknown is what to do with all the biomass produced by such schemes. If commercial biofuel production is still not widespread commercially viable, there has to be a viable way of utilising the algal product produced. Some of the most rapidly growing areas of research along these lines are looking at the anaerobic digestion of algal material to produce methane or hydrogen (see Carver et al. 2011; Lakaniemi et al. 2011 and citations therein).

Carver, S.M., Hulatt, C.J., Thomas D.N. and Tuovinen, O.H. 2011.Thermophilic, anaerobic co-digestion of microalgal biomass and cellulose for H_2 production. Biodegradation 2011, 22, 805-814

Craggs, R.J., Heubeck, S., Lundquist, T.J. and Benemann, J.R. 2011. Algal biofuels from wastewater treatment high rate algal ponds. Water Science and Technology, 63, 660-665.

Lakaniemi, A.-M., Hulatt, C.J., Thomas, D.N., Tuovinen, O.H. & Puhakka, J. 2011. Biogenic hydrogen and methane production from Chlorella vulgaris and Dunaliella tertiolecta biomass. Biotechnology for Biofuels, 4, 34 doi:10.1186/1754-6834-4-34

Giovanni, E. and Richards, K. 2010. Determinants of the Costs of Carbon Capture and Sequestration for Expanding Electricity Generation Capacity. Energy Policy, 38, 6026–6035.

All of this being said there is a plethora of information on the web, and it is often difficult to sort out the sense from the, at times, quite absurd. There are several resources (including many reports to download presented with a more balanced approach at the non-pofit *Algal Biomass Organisation* (http://www.algalbiomass.org/).