Microalgal applications in bioindustry

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Microalgae are microscopic plants inhabiting the world's oceans and other aquatic environments. They are critical for the health of the planet, being responsible for at least half of the global primary productivity. Like other photosynthetic (autotrophs) organisms, microalgae capture solar radiation and convert it to chemical energy as biomass, forming the basis of aquatic food webs, fixing carbon dioxide and producing oxygen as part of the process. Other microalgae (heterotrophs) can utilise organic compounds for growth.

As single-celled packages of bioactive molecules that can be cultured to produce high levels of biomass, microalgae are a renewable resource with a wide range of applications in bioindustry. Their use is established in the human nutraceutical industry with 'super foods' such as *Spirulina* from the cyanobacterium (blue green alga) *Arthrospira platensis* (Figure 1). Intense interest surrounds the development of microalgae as a source of biofuels, and in the mitigation of CO_2 and other greenhouse gases (GHG). Other bioactive compounds, as well as genes from microalgae, offer new opportunities for bioindustry.

Historically, microalgae have been used in human nutrition, e.g. *Arthrospira (Spirulina)* in Central America and Africa, and they are essential live feeds in aquaculture. For over 50 years there has been interest in cultivating or culturing microalgae to use their inherent biochemical properties. These applications include aquaculture feeds, nutraceuticals, high-value biochemicals, biomass production as part of wastewater treatment, and, more recently, the capture of CO_2 and power plant flue gases for GHG abatement.

Nonetheless, internationally, the number of commercial operations using microalgae remains limited. Only a handful of microalgal species of the tens of thousands of species that exist globally have been developed commercially [1]. Cognis [2], in its Australian operation, is the largest global producer of natural betacarotene and other products from the green alga *Dunaliella salina* which is grown in hypersaline open ponds in Western Australia and South Australia. Major producers of *Spirulina* products for the nutraceutical market are Earthrise [3] and Cyanotech [4]. The latter company, along with others such as Mera Pharmaceuticals [5], have also focussed on high-value nutraceuticals from *Haematococcus,* a source of the potent antioxidant carotenoid pigment astaxanthin.

Microalgae can be rich in lipids and were explored as a source of biofuels by the US National Renewable Energy Laboratory (NREL) after the 1970s oil crisis. The Aquatic Species Programme (ASP) in 1978-1996 studied the feasibility of using algae grown in ponds and CO_2 from coal-fired power plants to produce biodiesel. The NREL review of the programme in 1998 [6] concluded that, while microalgae can offer good oil profiles for biodiesel, the cost of production was a major impediment. With increasing global oil prices and the potential to utilise CO_2-rich flue gases from power plants, this is becoming less of an issue.

The International Network on Biofixation of CO_2 and Greenhouse Gas Abatement [7] found that, in the short-term (5-20 years), the use of microalgae for GHG mitigation and biodiesel production should be combined with applications such as wastewater treatments to provide an economic nutrient source for algal growth [8]. In the mid-term (10-20 years), the practice should be combined with production of high-value co-products. Stand-alone dedicated biofuel production is considered a long-term (20+ years) prospect. Australian industry is starting to embrace the production of biofuels from microalgae. For example, the Victor Smorgon Group has licensed microalgal production technology from GreenFuels [9] with the aim of using flue gas as a CO_2 source for algal growth [10].

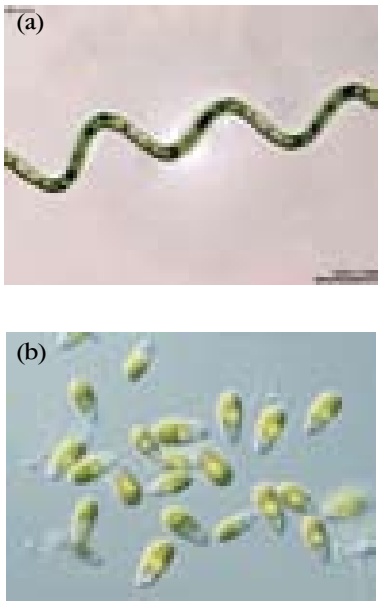

Figure 1. Microalgae cultivated for the human nutraceutical market (a) *Arthrospira* (Spirulina) *platensis* (b) *Dunaliella*.

One focus for the CSIRO Food Futures National Research Flagship is omega-3 long chain polyunsaturated fatty acids (LC-PUFA) that have an impressive range of human health benefits. Global supply of omega-3 LC-PUFA is primarily from fish oil (fish obtain omega-3 LC-PUFA in their diet from microalgae as part of the marine food chain). Due to increasing demand and static or declining fisheries this supply is unsustainable into the future. The Flagship's omega-3 research aims to introduce the microalgal omega-3 pathway into crop plants, thus ensuring a sustainable source of omega-3 LC-PUFA [11]. Early success has been demonstrated with the production of DHA in the model plant *Arabidopsis* [12].

Heterotrophic microorganisms can be grown efficiently and economically using fermentation technologies. Intelligent strain selection and culture condition manipulation can result in a high oil content product. Martek BioSciences [13] have developed high omega-3 LC-PUFA products such as life's DHA™ from the high docosahexaenoic acid (DHA) producers: the dinoflagellate *Crypthecodinium cohnii* and results using thraustochytrids.

Microalgae are essential first foods for many larval and juvenile aquaculture animals. Since the mid 1980s, the CSIRO Microalgae Supply Service [14] has provided Australian and international aquaculture industries with high-quality 'starter cultures'. Reed Mariculture [15] is an example of a company that offers a range of products including marine microalgae concentrates (e.g. Instant Algae®). The potential of microalgae as additives for formulated feeds is relatively undeveloped, although there have been encouraging results on thraustochytrids [16].

Strain selection is a key issue to developing new microalgal applications. Untapped biodiversity is held in microalgal culture collections. The CSIRO Collection of Living Microalgae [17] is a living bank of microalgal biodiversity isolated from the tropics to Antarctica (Figure 2). This is the only culture collection in the southern hemisphere holding a wide biodiversity and is one of two major collections in the Asia Pacific region. CSIRO research since the 1960s has shown Australian microalgal strains to have unique chemical, molecular and physiological characteristics. The CSIRO Wealth from Ocean National Research Flagship has recently screened the Collection for exopolysaccharides (EPS), large carbohydrate polymers, with potential for bioinspired adhesives for medical and other applications, with encouraging early results [18].

Figure 2. Cultured microalgae highlighting the pigment characteristics of different algal classes.

Figure 3. Column reactor [20].

A key challenge in microalgae production is the development of cost-effective production technologies tailored to particular applications. Many types of bioreactors have been developed in the past 40 years [19] (Figure 3), but few have been commercialised. Design strategies have sought to optimise light and nutrition and prevent the build up of excess oxygen and other waste products. Utilisation of flue gases from power plants as part of production adds another dimension. Technologies such as Green Fuels [9] have been developed with this intention. While less efficient, there is support for low technology ponds, with Von Harmelen and Oonk [8] considering low technology the preferred short-term approach to microalgae for GHG abatement and production of biofuels and other products. Realising the full potential of microalgae in bioindustry may require multiple approaches – both low and high technology growth systems – and multiple applications including co-production of target compounds.

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