Biotechnology Advances 30 (2012) 1344–1353

Contents lists available at SciVerse ScienceDirect

Biotechnology Advances

journal homepage: www.elsevier.com/locate/biotechadv

Research review paper

Production cost of a real microalgae production plant and strategies to reduce it

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ARTICLE INFO

Available online 14 February 2012

Keywords:
Costs analysis
Microalgae
Tubular photobioreactor
Production cost

ABSTRACT

The cost analysis of a real facility for the production of high value microalgae biomass is presented. The facility is based on ten 3 m^3 tubular photobioreactors operated in continuous mode for 2 years, data of *Scenedesmus almeriensis* productivity but also of nutrients and power consumption from this facility being used. The yield of the facility was close to maximum expected for the location of Almería, the annual production capacity being 3.8 t/year (90 t/ha·year) and the photosynthetic efficiency being 3.6%. The production cost was 69 €/kg. Economic analysis shows that labor and depreciation are the major factors contributing to this cost. Simplification of the technology and scale-up to a production capacity of 200 t/year allows to reduce the production cost up to 12.6 €/kg. Moreover, to reduce the microalgae production cost to approaches the energy or commodities markets it is necessary to reduce the photobioreactor cost (by simplifying its design or materials used), use waste water and flue gases, and reduce the power consumption and labor required for the production step. It can be concluded that although it has been reported that production of biofuels from microalgae is relatively close to being economically feasible, data here reported demonstrated that to achieve it by using the current production technologies, it is necessary to substantially reduce their costs and to operate them near their optimum values.

Contents

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0734-9750/$ – see front matter
doi:10.1016/j.biotechadv.2012.02.005

1. Introduction

Recently microalgae biomass has been proposed as a raw material for the production of energy and other commodities for several reasons such as their high productivity, the possibility of using low quality water including seawater, and the fact that no fertile land is needed (Chisti, 2007, 2008; Gouveia and Oliveira, 2009; Patil, et al., 2008; Wigmosta et al., 2011). However, until now microalgae have been only produced with the purpose of obtaining high value products mainly related to applications for humans (health, cosmetics, nutraceutical and foods) and aquaculture (Borowitzka, 1999; Richmond, 2000). For these applications, the amount of biomass needed is very small compared to the requirements of markets such as energy or commodities. The microalgae biomass market produces only 5 kt/year at production costs of 25000 $/t (Pulz and Gross, 2004). However, to replace only a 5% of the US demand of fuel for transport it is necessary to produce more than 66000 kt/year of oil rich biomass at production costs below 400 $/t (Chisti, 2007). Moreover, to replace all transport fuels in Europe by biodiesel from microalgae, 9.25 million ha (almost the surface area of Portugal) would be needed, assuming a productivity of 40000 l/ha·year (Wijffels and Barbosa, 2010).

Although the potential of microalgae to contribute to the world energy and commodities demand is high, there is a large gap between the current available technology and the one needed to supply the potential world demand. The technology must be scaled-up several orders of magnitude to significantly contribute to the biofuels market, and the biomass production cost must be also reduced. Thus, it is still necessary to solve a large number of bottlenecks related with biological, engineering and economic aspects (Richmond, 2000). Biological and engineering aspects of the problem have been studied in the last century and still are being analyzed. Concerning economic analysis of the problem, due to the lack of existing facilities and including of a defined technology, only approximations can be performed, all of them assuming large uncertainty. Recently, several approximations to this problem have been published (Douskova, et al., 2009; Norsker, et al., 2011; Richardson, et al., 2010; Singh and Gu, 2010; Wigmosta et al., 2011; Wijffels, et al., 2010; Williams and Laurens, 2010). Alternatively, more accurate data can be obtained from the facilities that are now existing.

In the present paper, the cost analysis of a medium-scale plant for the production of microalgae is presented. The validity of the manufacturing process proposed has been tested and it is used here to estimate the costs of production at large scale. Moreover, this analysis can be used to identify the major factors determining the production costs, helping to identify the key technical problems to be solved to achieve economic viability.

2. Materials and methods

2.1. Microorganism and culture conditions

The microalga used was *Scenedesmus almeriensis* (CCAP 276/24, Culture Collection of Algae and Protozoa of the Centre for Hydrology and Ecology, Ambleside, UK). The optimal conditions for the production of this strain have been reported elsewhere (Sánchez et al., 2008a, 2008b). The culture medium used was Mann&Myers (Mann and Myers, 1968) prepared using agricultural fertilizers instead of pure chemicals. The microalga was grown photoautotrophically in tubular photobioreactors aerated to avoid dissolved oxygen accumulation, under pH controlled by on-demand injection of pure CO_2, and temperature below 35 °C. The cultures were operated in continuous mode at a dilution rate of 0.34 1/day.

2.2. Production facility

The microalgal production facility used is located in "Estación Experimental Las Palmerillas", property of Fundación CAJAMAR (Almería, Spain). This facility is similar in design and operation to an industrial plant although it is used for research. The core of the process is a set of ten tubular fence-type photobioreactors built as previously described (Acién Fernández et al., 2001; Alías et al., 2004; Molina, et al., 2001). Each photobioreactor is made of 400 m long tube of 0.09 m diameter, with a bubble column 3.5 m high and 0.4 m diameter for degassing and heat exchange. Diameter of the tube was optimized to maximize the volume of culture per reactor but minimizing yield losses by excessive light path to photosynthesis. The tubes are optimally arranged to maximize the interception of solar radiation. Liquid and gas flow rates entering each photobioreactor are measured using flowmeters; the pH, temperature and dissolved oxygen at the end of the loop are measured using Crison probes (Crison Instruments, Spain), connected to a control-transmitter unit Crison MM44, that sends the information to a PC control unit, allowing a complete monitoring and control of the facility. The simplified flowchart of the production process used is shown in Fig. 1. In addition to photobioreactors, the facility is equipped with all the necessary ancillaries as an RITEC Fertilizer Unit (Almería, Spain) used for the automatic preparation of culture medium from fertilizers and fresh water. The sterilization of the culture medium is performed by filtration/ozonization online. The culture medium is pumped daily to the photobioreactors and the harvest is continuously centrifuged by using a continuous decanter (solid–liquid centrifugation unit, Flotweg, Germany) to obtain sludge with a 15% dry matter content. The biomass sludge is freeze-dried in a Cuddom Freeze-dryer (Blenheim, New Zealand) to obtain dry biomass as final product. Each reactor is bubbled at constant airflow rate of 200 l/min and the pH is controlled by on-demand injection of pure CO_2 at 3 l/min. The temperature of the culture is controlled by passing, when needed as determined by the computer control, cooling water at 1500 l/h through an internal heat exchanger

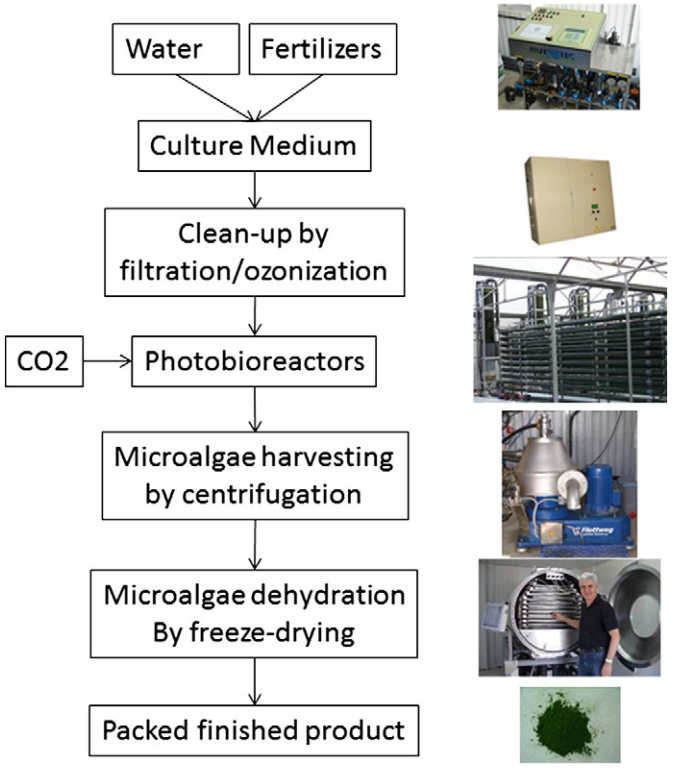

Fig. 1. Schematic block-diagram of the production process used for economic analysis. Culture medium is prepared on-line by a fertirrigation unit of 4 m^3/h capacity. The culture medium is sterilized by filtration up to 1 μm pore size and ozone at doses of 10 g/m^3, previously to be introduced into the photobioreactors on daylight period. Harvest is centrifuged at 9500 rpm at a flow rate of 2 m^3/h, a sludge of 15–20%d.wt. being obtained. The sludge is freeze-dried for 24 h in a equipment with capacity for 80 kg/day of water, dry biomass with humidity lower than 4% being obtained. Finally, the dry biomass is milled till a 300 μm particle size.