Potential of microalgae for sustainable energy production

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Abstract Microalgae have lately been discussed whether they can serve as a renewable energy source in the future. To achieve this goal, bioreactor technology and algae strains must be optimised. The energy input of a process should be minimized to ensure a positive energy balance as basic requirement. In this study a detailed material flow based life cycle model of different processes of algal energy production is created. A special focus is set on the energy input of the reactor system. Cumulative energy demand (CED) and environmental impacts for energy production with microalgae can be determined within the life cycle model. Potential systems of algal energy production can be identified.

1 Introduction

1.1 Microalgae

Bioenergy is gained from various resources, such as residual straw and wood, energy crops or microalgae. Microalgae have some advantages compared to other resources for bioenergy: Algae grow faster than land plants and their uptake of fertilizer is almost 100% efficient [1]. They can be cultivated in closed systems in salt or wastewater – even on non-arable land – which prevents a competition with food production. Algae consume high concentrations of carbon dioxide which can for example be provided from flue-gas [2]. Algal biomass is a form of chemical energy which can be further converted into hydrogen, biodiesel or other liquid or

gaseous fuels. Some algae species can produce hydrogen directly via photolysis or indirectly via photosynthesis and fermentation [3].
At present microalgae are already grown to produce high value chemicals for food and the chemical industry [4]. Previous research suggests that net energy generation from microalgae is negative and not commercially viable so far [5], [6]. The energy input of photobioreactors is too high, and the efficiency of the process chain is too low yet. However, improvements are under way which promise a positive net energy balance.

1.2 Energy from microalgae

There are two main options to improve the net energy balance: by increasing the energy content in the biomass or by decreasing the energy input of the whole system.
On the output side the efficiency of microbiological growth and energy conversion has to be enhanced. A ten percent efficiency to convert the sunlight into chemical energy (photo conversion efficiency, PCE) is possible. At the current state of research PCE of only one to three percent has been achieved [1]. This problem could be solved by intelligent reactor design (providing the optimum light dose for the algae) or genetic engineering. Microalgae are microorganisms and can be engineered genetically more easily than complex land species. It should be ensured, however that GMOs stay in a closed system, to prevent potential harm to the environment.
Decreasing the energy input is possible for any step in the process chain: algae growth, including gassing and mixing, algae harvesting, or subsequent steps such as lipid extraction for biodiesel. An optimal bioreactor for algal energy production should be designed in a way that energy input for mixing and gassing is low whilst a high areal productivity is maintained.

2 Goal and scope

Aim of this study is to find out to what extend the design of a photobioreactor can contribute to improve the energy balance of bioenergy generation with microalgae. The system is analysed from a life cycle perspective and shall derive recommendations for the design of a bioreactor. It shall be identified which parameters influence the energy and environmental balance. The model describes the production of bioenergy with microalgae on one hectare of land. For the identification of weak points, one megajoule energy output produced from the biomass will be the functional unit (FU).

3 Life cycle model

On the basis of a life cycle model, it is possible to evaluate and compare cumulative energy demand (CED), costs, and environmental impacts of a system. Within this model, different parameters - e.g. material selection and design of the bioreactor - can be varied to find out how an optimal process chain could look like.

A life cycle of the production of biogas from microalgae in a photobioreactor was modeled using the software umberto®. Biogas was chosen as an end-product since anaerobic digestion of the biomass requires not many energy-intensive steps of processing – in contrast to for example biodiesel from algae [7].

Materials for the construction of the facilities were taken from the database ecoinvent. Data for harvesting the algae biomass were taken from an existing microfiltration process. Energy consumption of the bioreactor was calculated referring to the reactor design. A flow chart of the modeled process is shown in Figure 1.

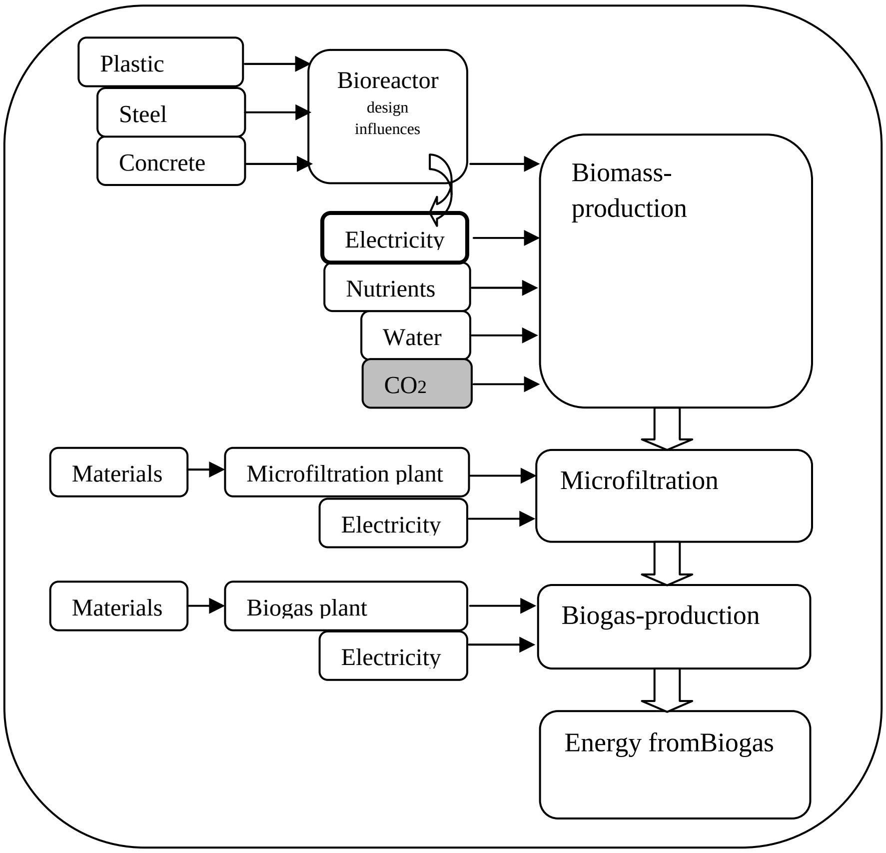

Fig.1: Flow chart and system boundaries of the life cycle model. The bent arrow indicates the influence of the bioreactor design on the energy consumption of the bioenergy-production process.

4 Outlook

4.1 Carbon balance

Energy for carbon dioxide supply will for a preliminary analysis not be included but has to be taken into account. It has to be noted that in an engineered process, microalgae cannot remove carbon dioxide from the atmosphere, but ‘recycle’ emissions from an industrial process. The carbon dioxide which has been consumed during the growth phase will eventually be emitted into the atmosphere; plus potential carbon dioxide from operating processes. In contrast to land plants, microalgae need carbon dioxide in high concentrations [8]. Therefore carbon dioxide sources like flue gas from electricity production, Haber-Bosch synthesis or similar sources are needed for an efficient biomass production.

4.2 Economical aspects

As mentioned above, microalgae can be used to produce a range of energy and non-energy related end products. The costs of the system highly depend on the end-product. Williams *et al.* found that "Despite its obvious benefits, the economics of anaerobic digestion are not promising" [7]. Jorquera *et al.* [9] did a cost analysis of biodiesel from microalgae and found that "no system would be currently competitive with petroleum" although only the costs of pumping were considered in his study and a more detailed analysis would have to incorporate many other cost-inputs. He estimated that microalgae become competitive with fossil fuels when the cost of petroleum rises to US $ 165 per barrel (for the biomass production with a flat plate reactor) at least.

Until now, it seems not possible to gain energy from microalgae in a cost-effective way. However, the idea can be viable when genetical and technical engineering will be successful and fuel prices will be rising [7]. With the developed life cycle model, the necessary steps towards energy production from microalgae will be highlighted.

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