Bioresource Technology 198 (2015) 896–906

Contents lists available at ScienceDirect

Bioresource Technology

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

Review

Anaerobic digestion of microalgal biomass: Challenges, opportunities and research needs

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HIGHLIGHTS

- Microalgae biomass has a huge potential as feedstock for biogas production.
- Novel pretreatments, reactor designs and operation parameters are addressed.
- The microbial community carrying out anaerobic digestion is reviewed.
- Research on intermediate compounds exploitation is discussed.
- Integration of microalgae culture and anaerobic digestion is outlined.

ARTICLE INFO

Article history:
Received 7 September 2015
Received in revised form 21 September 2015
Accepted 22 September 2015
Available online 3 October 2015

Keywords:
Methane
Anaerobic digestion
Microalgae
Carboxylate
Cyanobacteria

ABSTRACT

Integration of anaerobic digestion (AD) with microalgae processes has become a key topic to support economic and environmental development of this resource. Compared with other substrates, microalgae can be produced close to the plant without the need for arable lands and be fully integrated within a biorefinery. As a limiting step, anaerobic hydrolysis appears to be one of the most challenging steps to reach a positive economic balance and to completely exploit the potential of microalgae for biogas and fertilizers production. This review covers recent investigations dealing with microalgae AD and highlights research opportunities and needs to support the development of this resource. Novel approaches to increase hydrolysis rate, the importance of the reactor design and the noteworthiness of the microbial anaerobic community are addressed. Finally, the integration of AD with microalgae processes and the potential of the carboxylate platform for chemicals and biofuels production are reviewed.

1. Introduction

AD is a well-known technology which converts complex organic matter into methane and carbon dioxide. Besides the production of renewable energy, the advantages of AD include the reduction of greenhouse gas emissions, odor and pathogens and the production of a liquid digestate with fertiliser capacity. Four biological processes are involved in anaerobic digestion, namely hydrolysis, acidogenesis, acetogenesis and methanogenesis (Fig. 1). The hydrolysis of complex organic matter (carbohydrates, proteins and lipids) is carried out by extracellular enzymes that are excreted by different bacteria. These hydrolyzed molecules include amino acids, sugars, long chain fatty acids (LCFA) and alcohols. In the following stages, these molecules are converted into volatile fatty acids (VFA), hydrogen and carbon dioxide during acidogenesis and acetogenesis. The degradation of LCFA into acetate and hydrogen is carried out by obligate hydrogen producing acetogenic bacteria. Finally, methanogenesis is carried out by the methanogenic archaea. Archaeas grow very slowly and are less resilient to stress than bacteria. Acetate, hydrogen and carbon dioxide are the main substrates for methanogenic microorganisms, although some species are also able to metabolize formol, methanol or butyrate. Acetoclastic methanogenesis is generally the preferred catabolic pathway, representing 70% of the produced methane. However, the proportion of hydrogenotropic microorganisms becomes higher under stressful conditions (organic loading increase, inhibitors (ammonium or LCFA) accumulation or temperature variations, Carballa et al., 2015).

Methanogenesis is the limiting phase in AD of easily degradable substrates. The slow growth rate of archaea often results in VFA accumulation and a consequent inhibition of methanogenic microorganism's activity. Contrary, when working with particulate

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http://dx.doi.org/10.1016/j.biortech.2015.09.095
0960-8524/

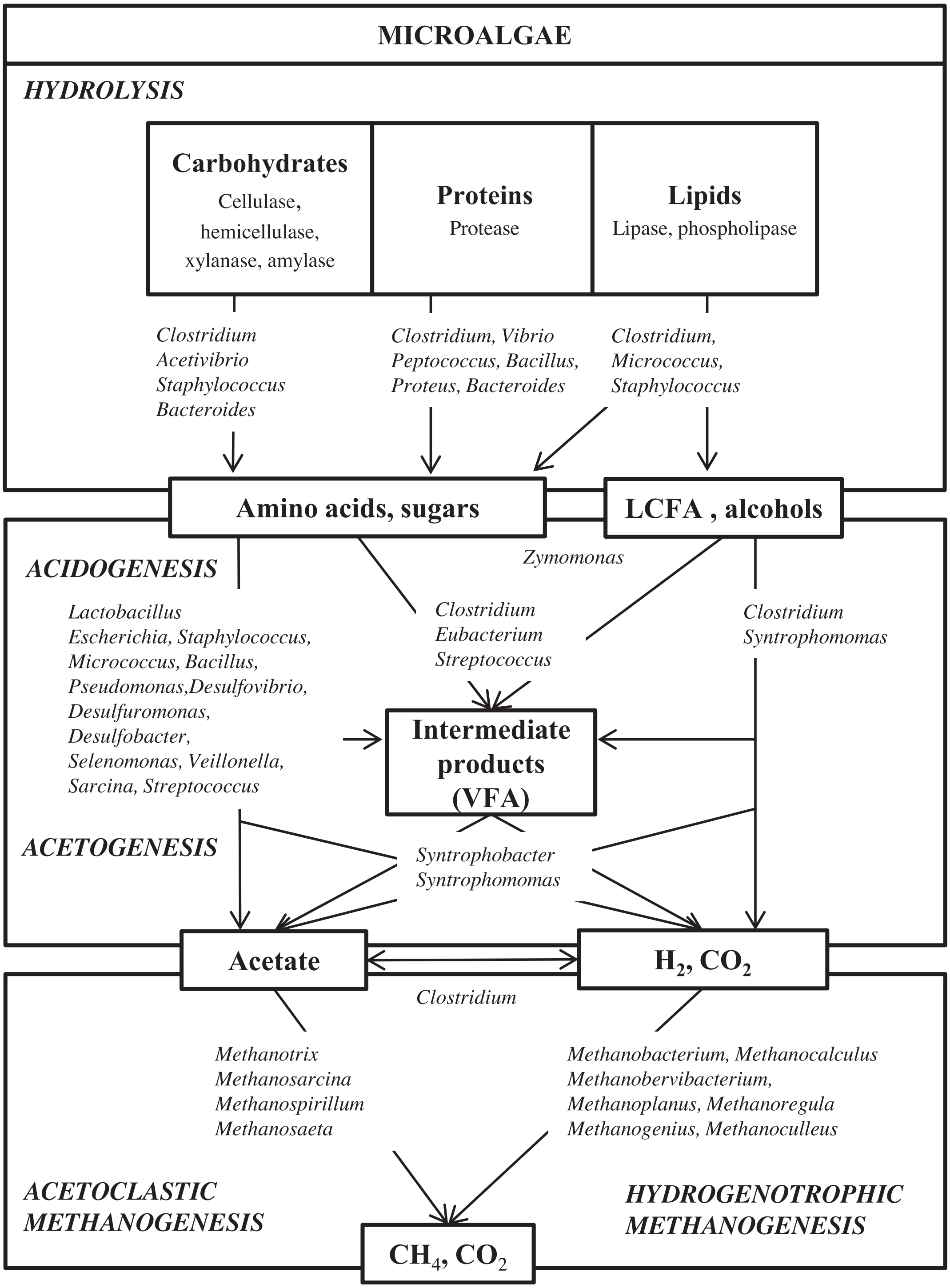

Fig. 1. Anaerobic degradation of microalgae and the respective genera of microorganisms involved in each stage. (Adapted from Stronach et al., 2012 and Gonzalez-Fernandez et al., 2014).

substrates, as microalgae, the hydrolysis phase determines the successful production of methane (González-Fernández et al., 2012).

The economic feasibility of biogas production from microalgae is dependent on the production cost of two technologies, the microalgae cultivation and the anaerobic digestion process. One of the main drawbacks from an environmental point of view for the industrial cultivation of microalgae is the high amount of fertilizer required to perform photosynthesis (Lardon et al., 2009). However, these nutrients can be provided by using nutrient-rich wastewaters as culture broth (Markou, 2012). This strategy would merge both technologies into a biorefinery concept by producing sustainable energy while contributing to wastewater bioremediation. Life cycle assessment (LCA) and net energy ratio (NER) have been used to study the techno-economical parameters of biogas production from microalgae. According to these parameters, the raceway reactor appears to be the most adequate bioreactor to produce microalgae in terms of energy, environmental sustainability and process efficiency (Bohutskyi and Bouwer, 2013). Nevertheless, biogas production feasibility using microalgae as substrates is still not clear and different strategies have been suggested.