The All-gas process: reaching energy self-sufficiency in small WWTPs

Raul Cano, Ignacio de Godos, Maikel Fernandez, Enrique Lara, Frank Rogalla, Zouhayr Arbib*

FCC Aqualia, Avenida Camino Santiago 40, E 28050 Madrid, Spain. *Zouhayr.Arbib@fcc.es

Abstract:
In the FP7 All-Gas project, the combination of microalgae and anaerobic digestion leads to alternative wastewater treatment for small communities, combining anaerobic pretreatment before feeding the microalgae culture in high rate algae ponds. As the harvested microalgae biomass is digested, the process generates two biogas streams which can be upgraded to obtain biomethane as final biofuel product. This biogas is the major fuel component. CO_2 is separated from the biogas and recycled, together with the carbon of the residual biomass after combustion from local agricultural biomass. The overall process produces more than 100 L of biomethane per cubic meter of treated wastewater, and a net energy of 0.5 kWh th/m^3 wastewater. The construction of a 4 Ha culture surface in a demonstration phase pretends to treat 2500 m^3/day of wastewater from 10,000 eq. inh. This process allows to convert small WWTPs from energy consumers to net producers, creating a new concept of process sustainability based on microalgae.

Keywords: anaerobic digestion; biofuels; energy recovery; microalgae; wastewater

Introduction

Co-financed by the FP 7 programme of the EU Commission, the project "ENERGY 2010.3.4-1: Bio-fuels from algae" intends to demonstrate on large scale the sustainable production of bio-fuels based on low cost microalgae cultures (www.all-gas.eu). The objective of the project is: (1) implement on a 10 ha scale the full process chain; (2) demonstrate sustainable algae culture ponds, integrated with biomass separation; (3) processing for oil and other chemicals extraction, and downstream biofuel production and (4) treat and reuse wastewater for nutrient recovery.

Figure 1 shows the process block diagram where wastewater is pre-treated in anaerobic reactors before microalgae in high rate algae ponds (HRAPs). The biomass harvested from the HRAPs is anaerobically digested, and the biogas from both anaerobic processes can be upgraded to biomethane, which can be used as a biofuel for cars. To maximize biomethane production and avoiding the use of fossil fuels as energy source, additional CO_2 and some heat for digestion is provided by a biomass boiler burning olive pits, instead of using biogas for electricity and heat.

In this work, the energy balances are shown and an energy assessment is performed to evaluate energy self-sufficiency of the process. As well, two scenarios will be compared to study the effect of the first anaerobic pretreatment step in the whole process (Figure 1), as well as the effect of temperature conditions of anaerobic digestion and seasonal variations.

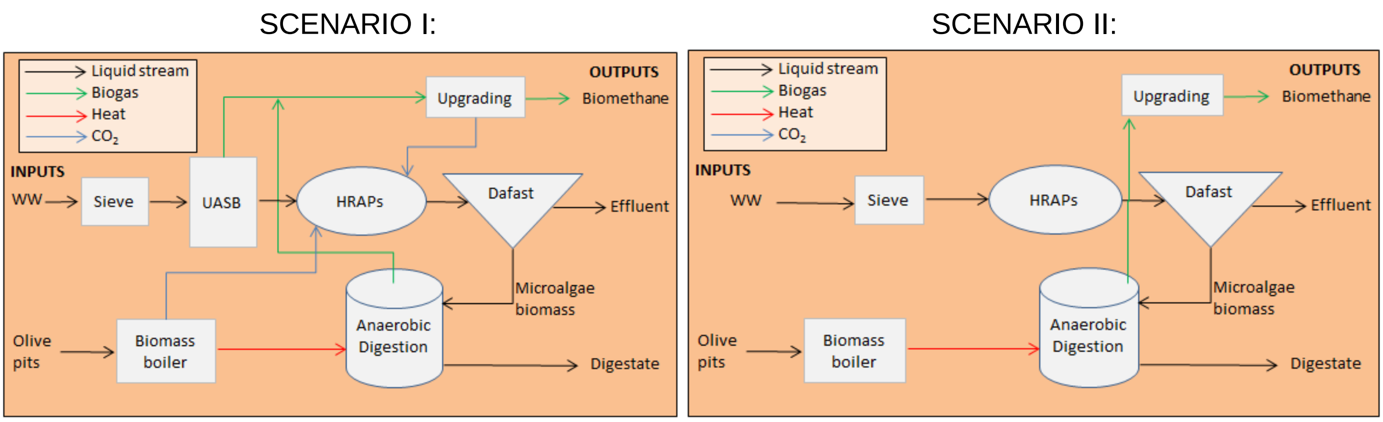

Figure 1. Process flow diagrams of: **SCENARIO I:** With UASB pre-treatment of the raw wastewater; **SCENARIO II:** Without UASB pre-treatment, using screened raw wastewater to feed the raceways.

Material and Methods

The experimental plant is located in 'El Torno' WWTP, Chiclana de la Frontera, Cádiz (Spain). Results presented in this work were obtained in this plant at two different scales: pilot and prototype, composed mainly by: **anaerobic wastewater treatment** before algae culture (three UASB reactors 20 m^3 each of effective volume fed with sieved municipal wastewater) -just included in Scenario I-; **algae pilot (200 m^2) and prototype (1000 m^2) reactors** with HRT between 3 and 7 days; **harvesting plant** to concentrate the biomass up to 4% of total solids with a dissolved air flotation (DAF) unit; **algal biomass digesters** pilot (eight CSTR with 4 L each of effective volume) and prototype (three digesters of 700, 700 and 1500 L) working at 28 days HRT. Mesophilic (35 ºC) and thermophilic conditions (55 ºC) were compared.

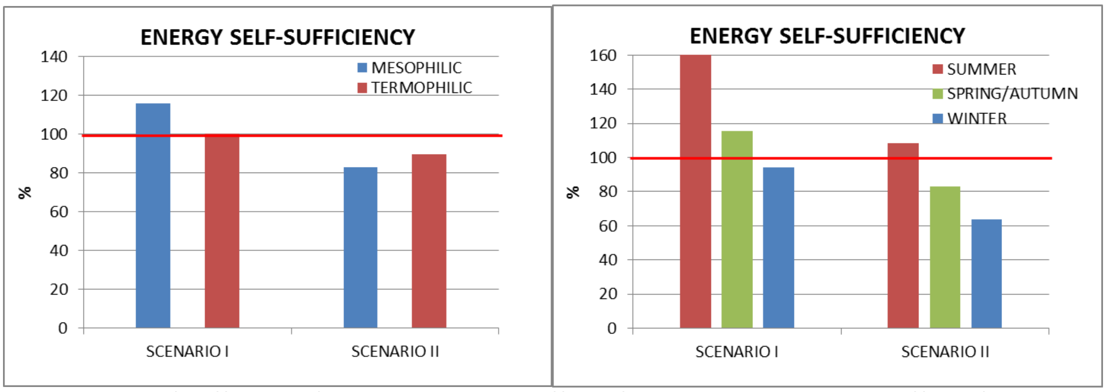

Figure 2. Energy self-sufficiency for each scenario: a) effect of anaerobic conditions; b) effect of seasonal variations

Results and Conclusions

In Figure 2 the final energy balances of the processes can be compared. The higher energy recovery of scenario I is mainly due to the biogas produced in the UASB, average of 69 L of CH_4 per m^3 treated wastewater. In scenario II, a considerably higher production of microalgae can be achieved compared to I: 25 versus 18 g/m^2 d, respectively. This increase in biomass production is mainly due to higher carbon input in the raceways, directly correlated with the amount of organic matter: 590 g COD/m^3 and 198 g COD/m^3 in sieved and digested wastewater, respectively. More biomass production in scenario II generates higher quantity of biogas from anaerobic digester: 58 compared to 37 L CH_4/m^3, also because of higher methane yields. Then, from an energy recovery point of view, scenario I is more interesting since more energy is produced per unit of wastewater treated, leading to a more self-sufficient process in terms of overall energy balance. However, scenario II can be economically more attractive: no need of external supply of CO_2, no UASB reactors, 50% more wastewater flow can be treated with the same microalgae cultivation area.

Thermophilic processes do not offer great energy savings in the process since more energy is often required to heat the digester than the recovered energy in the form of biogas. Therefore only if low cost waste heat is available, it could be an option to maximize biogas output.

Climate conditions play an important role on the process performance and efficiency. In summer conditions, algae productivity in HRAPs increases more than 3 times and HRT decreases around 3-4 days. As well, at this condition, more biogas is obtained from UASBs and from anaerobic digestion since more algae is harvested from HRAPs. Comparing energy balances for summer conditions, full energy self-sufficiency is reached for both scenarios. Scenario I is still the highest energy producer, providing a net energy output of 0.5 kWh th/m^3. Therefore, the process presents an important potential to be implemented in small communities with warm climates where temperatures remain high and constant along the year.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the support of the EU FP7 Programme ENERGY.2010.3.4-1: Biofuels from algae (Grant Agreement no. 268208).