BioHydrogen and BioMethane production through two stages AD: A European State-of-Art

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Keywords: biohythane, biohydrogen, anaerobic digestion, biomethane.

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Abstract

According to the "*United Nations* in the *Emission Gap Report 2021"*, the global CO_2 emissions are above 40 $GtCO_2$/year. In order to reduce the greenhouses gas emission, the European Commission (EC) adopted different environmental strategies in the last years. In 2016, the EC published the *Clean Energy for All European Package* (CEoAEP). A part of the CEoAEP is dedicated to *Renewable Energy Directive* (RED II), which set the aim to extend the guarantee of renewable source origin not only for electricity, but also for gases, in particular for hydrogen and methane. In addition to this, *Gas for Climate consortium*, a group of 10 leading European gas transport companies and two renewable gas industry associations, demanded to the EC to recast RED II with a binding of 11% renewable gas target (8% biomethane and 3% green hydrogen). In 2019, the final elements of the CEoAEP were adopted. This set of legislations aims to implement the goals of the *Energy Union strategy*, that is based on facilitate the transition away from fossil fuels toward cleaner energy. That strategy models the EU's framework, and it is composed by 5 essential pillars: energy security, the internal energy market, energy efficiency, decarbonisation, research and innovation. More recently, in December 2019, the EC announced The Green Deal, which contains a series of proposals to achieve at least a 55% reduction in *greenhouse gas* (GHG) emissions by 2030 compared to 1990 levels (Jens et al., 2021). In light of the objective set out in The Green Deal, the EC proposes hydrogen as a clean fuel to achieve this milestone.

Hydrogen is largely adopted in different industrial sectors, in particular in refineries and chemicals production (Pawelec et al., 2020). In 2018, total hydrogen demand was estimated at 8.3 Mt (Pawelec et al., 2020). Over 90% of all hydrogen production plants uses fossil fuels as feedstock (Jens et al.,2021). The most common technology is represented by *steam reforming of natural gas*, also known as *Steam Methane Reforming* (SMR), *Partial Oxidation* (POX) or *AutoThermal Reforming* (ATR). In SMR process, methane and steam react at elevated temperature and pressure to produce a gas stream, which is composed primarily of hydrogen, carbon monoxide and carbon dioxide. POX converts hydrocarbons to hydrogen with oxygen (partially oxidation) at high temperature. ATR uses heat from POX and employs SMR process to increase the hydrogen production resulting in a thermally neutral process, but in lower pressure condition (Holladay et al.,2009).

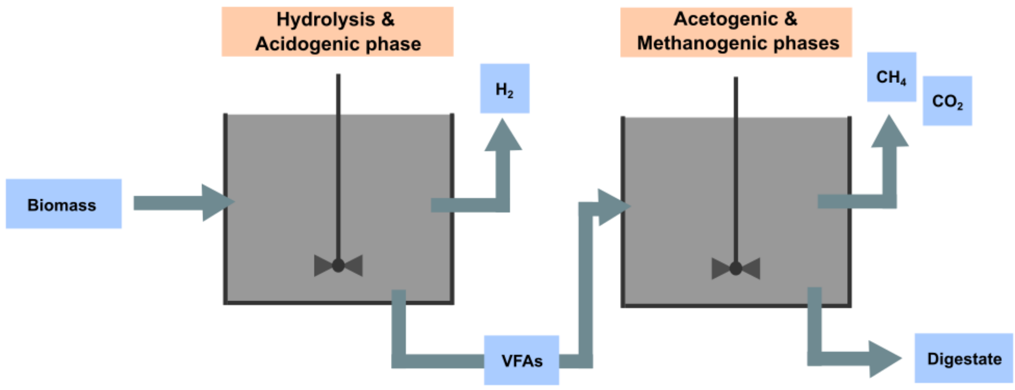
Electrolysis is an alternative process, which is based on electricity's uses to split water in oxygen and hydrogen particles, without GHG emissions. Currently, only the 1.6% of total hydrogen production capacity is produced by electrolysis, principally the electrolysis' plants in action have small scale and use electricity from fossil fuels. To increase this quote and reduce the GHG emissions, several European Countries planned different *Power-to-Hydrogen projects.* These projects are promoted by *International Renewable Energy Agency* (IRENA) and consisting in the development and building of plants able to produce clean hydrogen via water electrolysis, utilizing low carbon or renewable electricity (Pawelec et al., 2020). The use of an electrolyser with direct connection to a renewable energy source could produce clean hydrogen, but it does not ensure a continuous production**.**

Anaerobic digestion (AD), in particular two stages process, is increasing interest in scientific community as a sustainable process to assure hydrogen production with a low impact in carbon emission. Two stages AD process uses organic waste and waste effluents as organic feedstocks. In the first stage reactor, microorganisms hydrolyse organic matter in simpler and smaller compounds, then, during acidogenic phase, biohydrogen and *volatile fatty acids* (VFAs) are produced. At this point, VFAs enter in the second reactor, that includes acetogenic and methanogenic phase. The output of the second reactor is composed by biomethane and carbon dioxide. After an upgrade process, consisting in the carbon dioxide removal from biogas, methane and hydrogen are blended to

obtain biohythane, a methane:hydrogen mixture of 90:10 -70:30% v/v (Bolzonella et al., 2018). Biohythane has better characteristics than natural gas: hydrogen content reduces GHG emissions during combustions and improve the combustion performances, as flammability range and combustion stability. These advantages make biohythane particularly attractive for the automotive sector and for injection in the gas grid. The use of this mixture requires little modifications in storage systems, engines and pipeline systems, compared to the entire redesign, that is required for the use of pure hydrogen.

The blend of hydrogen and methane can be produced also with non-biological processes, as syngas production and methane reforming, however these proceedings have higher impact in GHG emissions (Bolzonella et al., 2018). In recent years, behind to the development of green systems for the production of hydrogen, there is a growing attraction in the conversion of biogas plants to biomethane ones. Considering the high interest in hydrogen, several large-scale initiatives are starting to cover the entire hydrogen value chain, from production, through transport, to consumption. Different projects are already running on hydrogen production in Europe too. Some of them entered as part of the hydrogen-dedicated *Important Project of Common European Interest* (IPCEI) which promotes sustainable economic growth and competitiveness, through the collaboration of the public and private sectors. In particular, *Green Flamingo*, *Green Octopus*, *Green Spider*, *Blue Danube*, *Silver Frog*, *Blue Dolphin*, *Black Horse* and *White Dragon*, are 8 projects that include 43 GW of renewable energy development for green hydrogen production, that would enable CO_2 savings of 37 Mt per year (Pawelec et al., 2020).

This review will aim to provide an overview on biohydrogen, biomethane, biohythane producing plants in Europe. In particular, the attention will be focused on plants with a *Technology Readiness Level* (TRL) greater or equal to 5 (technology validated in relevant environment). Different case studies for hydrogen and methane productions will be considered. One of them is represented by *Biogas Wipptal*, a project aiming to upgrade an existing biogas plant, located in Val di Vizza (Bolzano, Italy), to biomethane plant. In detail, the biomethane is obtained from the removal of CO_2 from biogas derived from the AD of livestock waste. Then, the obtained Biomethane is liquified and converted in a green fuel *(Bio-GNL)*, while the carbonic dioxide is purified and used in beverage industry and as dry ice. Biogas Wipptal project assures the generation of 10.1 millions of kW/h per year of electricity and promises to save 1.2 Kt CO_2 per year.



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