Future applications of hydrogen production and CO_2 capture for energy storage

M. Bailera[1], L.M. Romeo[1*], S. Espatolero[1] and P. Lisbona[2]

[1]*Research Centre for Energy Resources and Consumption (CIRCE), Universidad de Zaragoza, CIRCE Building, Campus Río Ebro, Mariano Esquillor Gómez, 15, 50018 Zaragoza, Spain*

[2]*Escuela Universitaria de Ingenierías Agrarias de Soria, Universidad de Valladolid, Campus Universitario Duques de Soria, 42004 Soria, Spain*

(*) luismi@unizar.es

The constant increase of electricity production from renewable energy sources has brought to light the necessity of deploying energy storage systems. The management of excess power generated by renewable sources is one of the future challenges for developing a sustainable power industry. Power-to-gas (PtG) has been proposed as one of the promising technologies to overcome these problems.

PtG converts electricity in synthetic natural gas through the methanation of hydrogen produced by electrolysis. This technology increases the application of hydrogen as energy vector, and it makes the most of carbon emissions to produce a "CO_2 neutral" natural gas and increase electric and gas network flexibility for the energy supply.

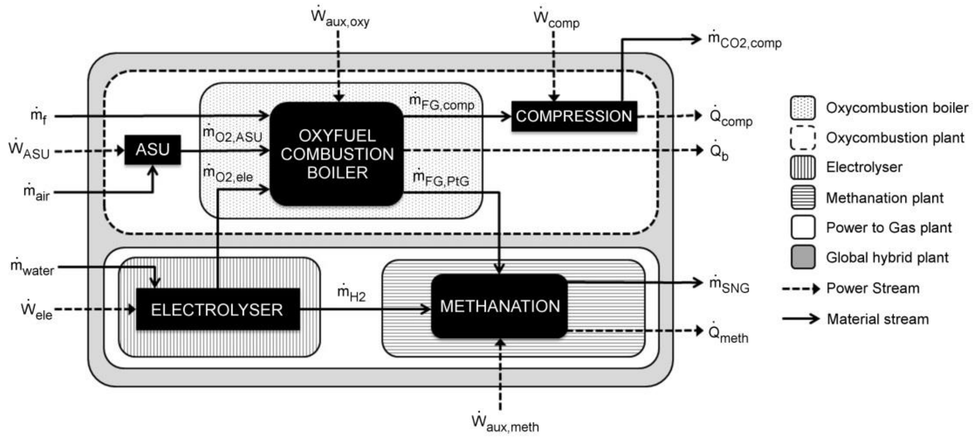

Figure 1. Scheme of the hybrid Power to Gas-Biomass oxyfuel boiler system.

In order to take advantage of the oxygen generated by electrolysis, it is proposed the integration of oxyfuel combustion (O_2/CO_2 as comburent) that provides thermal energy and generates flue gases mainly composed by CO_2 (Figure 1). CO_2 is introduced together with hydrogen in a methanation reactor to produce natural gas. If biomass is used as fuel and hydrogen is generated from wind/solar energy, a CO_2 neutral gas is produced.

The key variable in this system is the size ratio ξ_{oxy}, which relates the energy contained in the hydrogen produced by electrolysis and the useful thermal output of the oxyfuel boiler. This work presents the energy balances of the integrated system (oxyfuel biomass boiler plus hydrogen production with electrolyser) and the influence of the size ratio in the design and application of the system.

$$\xi_{oxy} = \frac{LHV_{H2} \cdot \dot{m}_{H2}}{\dot{Q}_b} \left[\frac{kW_{H2}}{kW_t}\right]$$

Operation ranges of the hybrid system

Depending on the value of the size ratio between boiler and electrolyser, ξ_{oxy}, different strategies of operation may be followed in the PtG–oxycombustion hybridized plant: (i) for a given value, ξ_{ASU}, enough oxygen is produced in the electrolysers to completely fed the oxyfuel boiler and therefore the air separation unit (ASU) becomes unnecessary; and (ii) for ξ_{CO2}, the flue gas flow produced in the oxyfuel combustion is completely reused and converted to SNG thanks to the hydrogen generated (Figure 2).

Furthermore, the use of biomass in the boiler, instead of coal, allows reducing the size ratio requirement for avoiding the need of ASU, ξ_{ASU}, since oxygen content in biomass is much greater. In addition, given the smaller C:H ratio in biomass than in coal, which limits the amount of carbon dioxide generated in the boiler per kWt, the value of ξ_{CO2} to convert entirely the flue gas is also reduced.

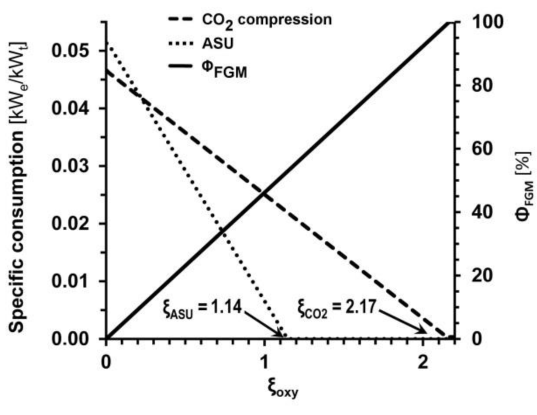

Figure 2. Specific consumptions [kW_e/kW_t] and methanised flue gas [%] vs ξ_{oxy}

Potential applications

The final application of the PtG–oxy plant will define the adequate operation point, the required equipment and its suitability. Five generic scales for the concept, based on literature, are analyzed to determine its technical and economic feasibility: households, district heating (DH), industry, biomass power plants, and co-firing (Table 1).

Small scale installations (households and DH) are not compelled to capture their emissions since the amount of produced CO_2 will not be large enough. Thus, an operation point around ξ_{ASU} would be recommended. In medium and large scale facilities, such as industrial applications or power plants, avoiding greenhouse gas emissions might be mandatory and economically interesting. However, these applications could be operated in a wider range between ξ_{ASU} and ξ_{CO2} without restrictions given the neutrality in CO_2 emissions of biomass combustion. Contrary, co-firing facilities cannot take advantage of biomass neutral emissions, and they will be compelled to capture their carbon dioxide. Therefore, a range next to ξ_{CO2} would be the most suitable operation for those applications.

Application	Boiler (MW)	ξ_{oxy}	Electrolyser (MW)	SNG (MW)	Technical feasibility	Economic feasibility
Households	0.01	$\xi_{ASU} - 1.15 \cdot \xi_{ASU}$	0.02	0.01	✓	-
District heating	2	$\xi_{ASU} - 1.15 \cdot \xi_{ASU}$	3.4 – 3.9	1.7 – 2.0	✓	✓
Industry	20	$\xi_{ASU} - \xi_{CO2}$	33.5 – 63.7	16.8 – 31.9	✓	✓
Power plant	200	$\xi_{ASU} - \xi_{CO2}$	335 – 637	168 – 319	-	✓
Co-firing	1000	$0.8 \cdot \xi_{CO2} - \xi_{CO2}$	2549 – 3186	1275 – 1593	-	✓

Table 1. Generic applications and characteristics for PtG-biomass oxycombustion hybrid systems at different scales.

The technical feasibility is determined by the state of the art of the electrolysis technology. Nowadays, electrolysers are commercially available from a few kWe up to 2 MWe [1]. Therefore, industry is the largest suitable application, by combining up to 30 units of 2 MWe size electrolysers. The following scale, power plants and co-firing, are prohibitive since they would require more than 160 electrolysers. Moreover, the economic feasibility is assessed as a function of the SNG output capacity. Operational costs are strongly attenuated from productions of 2 MW onwards [2], so household applications are unfordable. In conclusion, under current conditions only district heating and industry applications seem to be technically and economically feasible for PtG–biomass oxycombustion hybrid plants.

Heat integration

The overall efficiency of the system, $\eta_{PtG+Oxy}$, accounts for the chemical energy contained in the synthetic methane and the available heats from the boiler, methanation (exothermic reaction) and compression.

$$\eta_{PtG+Oxy} = \frac{LHV_{SNG}\dot{m}_{SNG} + \dot{Q}_b + \Sigma_i \dot{Q}_{m,i} + \Sigma_i \dot{Q}_{c,i}}{LHV_f \dot{m}_f + \dot{W}_{ASU} + \dot{W}_{ele} + \dot{W}_{comp} + \dot{W}_{aux}}$$

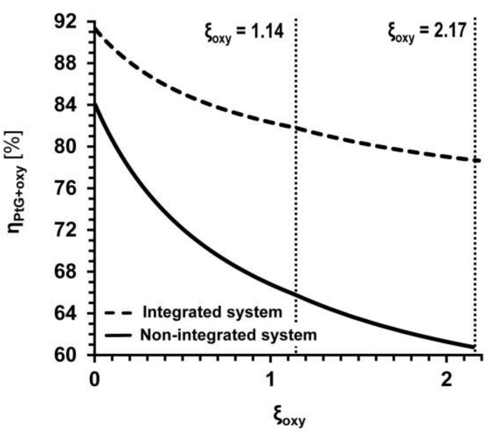

Figure 3. Hybrid plant efficiency vs ξ_{oxy}

Figure 3 illustrates the comparison between the global efficiency of a non-integrated system and a system where complete use of the available heat is accomplished. The rest of possibilities, i.e. the partial use of the available heat due to exchanger temperature limitations, will be intermediate curves. It is worthy to note that the system without Power to Gas (ξ_{oxy} = 0) still observes an improvement in the global efficiency, since the heat from the CO_2 compression train could be potentially integrated.

As the share of PtG increases in the hybrid plant, overall efficiency decreases since Power to Gas presents a more limited performance than the oxyfuel boiler. However, the fall in efficiency is partially buffered thanks to the utilization of the waste energy from different sources, mainly methanation heat.

References

[1] S. Sharma, S.K. Ghosal, Renew. Sust. Ener. Rev. **43** (2015) 1151-1158.
[2] L. Grond, P. Schulze, J. Holstein, Systems analyses power to gas – deliverable 1: technology review, Final Report – Project TKIG01038, KEMA Nederland B.V., 2013.