Hydrogen and fuel cell research community at UPM: A map of infrastructures for the challenge of developing the whole value chain of the hydrogen economy

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Abstract:
A research community to encompass efforts towards the development of the whole value chain of hydrogen and fuel cells related technologies has been set up at UPM. Such community has as main goal to unite the multidisciplinary expertise of the different engineering schools and faculties of UPM (more than 17 in several technological disciplines) to provide research and innovation services to face the challenge of developing medium and high scale hydrogen-related technologies deployment. Such critical mass of knowledge will be needed to highlight the contribution of high education institutions to the technological development for the energy transition. In this communication, we will show a portfolio of research infrastructures at UPM covering the whole value chain of the hydrogen economy: from production to utilization. The knowledge of available infrastructures is a first step to boost collaboration with other institutions.

Keywords:

Hydrogen; Infrastructures; fuel cells; hydrogen storage; hydrogen transport; hydrogen production.

1. Introduction

The climate crisis, that the anthropogenic activity catalyses, is boosting a systemic transformation towards a more sustainable energy system. The main challenge for such transformation is the deep reduction of greenhouse gases emissions, as to avoid expected catastrophic consequences by limiting global warming of the atmosphere below 2 ºC. In such decarbonization process, that should reach every sector, hydrogen is being considered [1] as one of the relevant technologies contributing in the future to comply with emission reduction targets. The deployment of the hydrogen economy needs the development at high scale of its whole value chain, from high capacity production facilities to their consumption at every sector of the society (industry, services, transport, mobility, residential, ...)., Such value chain includes transport/storage infrastructures, market regulation, and sector coupling. To achieve such targets, a paramount funding support has been activated at the highest level [2] as a clear bet for hydrogen to comply with United Nation Sustainable Development Goals [3,4].

The billion-size funding, that will be allocated at national and international level to develop as fast as possible the hydrogen economy, demands a huge coordination effort between different stakeholders to address efficiently such task. A dialogue between several public research funding agencies (including the EU Research & Innovation Framework Programs), industry, research, academic, professional association, technological platforms and social institutions is required. An example of such dialogue is the Clean Hydrogen Partnership [5], that support the European Commission to organise many of the hydrogen related activities in the framework of the EU Green Deal [2].

A significant contribution of a high education institution, as UPM, implies the adaptation to a research and innovation scheme that goes far beyond the classical submission and execution of low Technological Readiness Projects (TRL) for basic research, demanding a modest amount of economic and material resources. The hydrogen economy needs to successfully implement large projects to produce a high impact into the socio-economic structure of the society. In many projections, hydrogen is expected to manage a very significant amount of the worldwide energy demand. For instance, according to some serious prospections, hydrogen is predicted to manage 5% of the energy demand in 2050 in the order of 240 Mton H_2 [6].

At UPM we have created a research community financed by own resources to tackle the challenge to transfer to our socio-economic environment the added value to contribute to the development of the hydrogen related technologies. One of our commitments is to build the human expertise, that is one of the bottlenecks [7] of the fast development of the hydrogen economy. For such purpose, we have designed a master program as one of our activities. We plan to increase our expertise by a close collaboration with the private sector to support their developments with our contribution to project consortia at national and international level, offering the

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access and utilization of the experimental infrastructures that are available at UPM. Another relevant action to keep our education standards to comply the needs of the productive sector is to be able to contribute to high scale projects.

The first task in relation within UPM was to create an inventory of our current capacities, that has been created by different groups and institutes, to provide a map of infrastructures. Infrastructures has been classified versus the different stages of the hydrogen value chain. Such classification provides a picture of our capabilities at first sight, and allows to identify weaknesses and strengths in our organization at that respect. The classification of our infrastructure has been done attending to the following position into the hydrogen value chain:

- Hydrogen production
- Storage
- Transport
- End uses
- Skills

The current infrastructures for hydrogen research at UPM are the result of our previous research activity in cooperation with industry and research funding agencies. Our commitment is to upgrade such infrastructures to face the challenges of the new projects to come in the field, in which TRL is expected to be much higher. That means that this portfolio of facilities that will be introduced is being updated depending on the requirements of the current and future projects, and the available funding, mostly in the framework of large-scale projects to develop.

2. Hydrogen production

We are working on several methods for production to extract hydrogen from water or hydrocarbons. Regarding the development of electrolysis, we are working at experimental size to test the sensitivity of electrodes with different water composition, not only to test electrodes, but some biological waste treatment. Such activities are in the first stages of development. Additionally, at UPM we are working testing electrodes and membrane configuration to electrolyse seawater (Figure 1) as well as testing of direct methanol fuel cells and electrolysers (Figure 2) at School of Naval Arquitecture and Marine Engineering (ETSIN).

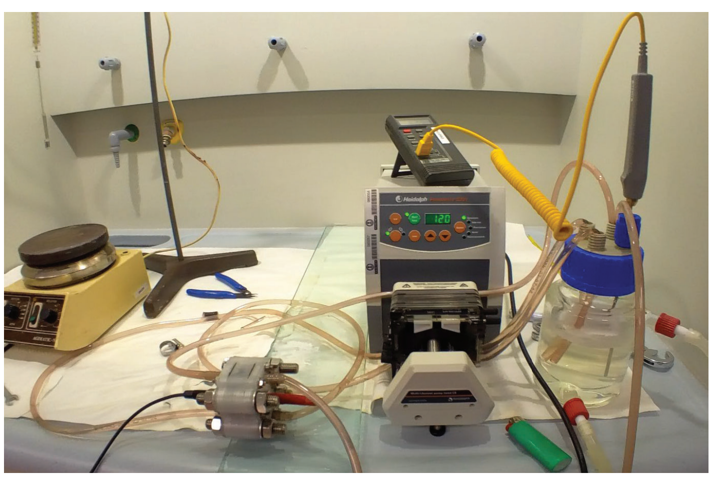

Figure 1: Thermostatic 3d printed alkaline electrolysis cell. Temperature up to 70 °C. Cell used for tests with desalinated seawater as feed

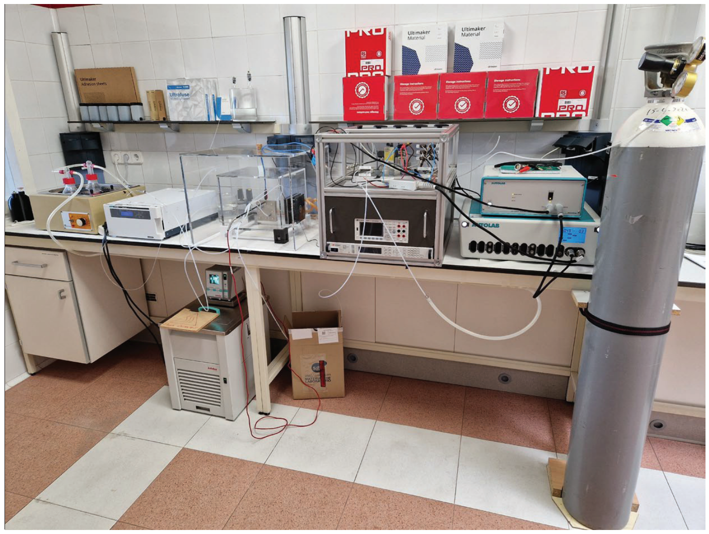

Figure 2: Test bench for direct methanol fuel cell and methanol electrolyser

Regarding Hydrogen integration, it has been installed a demonstration installation in the roof of the School of Engineering and Industrial Design (ETSIDI) consisting of a 260 W PEM electrolyser to produce hydrogen from FV panels located in the roof. In addition, a hydrogen storage system based on metallic hydrides with a capacity of 3 Nm^3 at 6-12 bar is used to manage energy production in combination with a Li-ion battery with a capacity of 2 kWh.

Other capabilities are under development at the School of Industrial Engineering (ETSII), as laboratories for instrumentation testing, or for surface coating that may be applied to the development of materials and temperature or pressure sensors to be integrated in hydrogen production facilities. As an example, we have available sputtering equipment for manufacturing nano-structures for the surface coating of material layers to be used for new electrodes or membranes. A high temperature reactor for methane pyrolysis based on liquid metal technology is also under development, that will constitute a facility for hydrogen production from thermal processes in the future with a capacity of some kW.

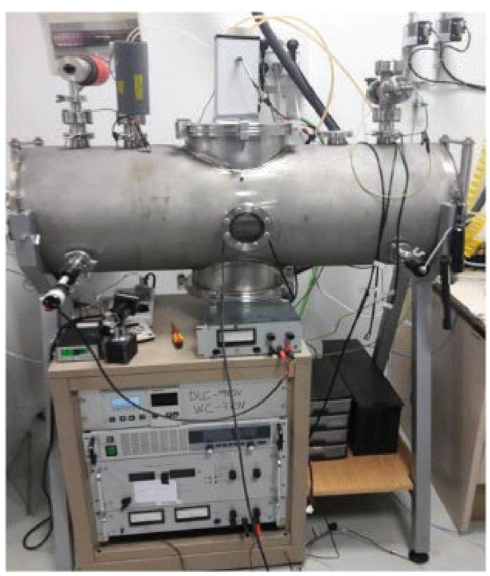

Figure 3: Nano-coating sputtering equipment.

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3. Hydrogen storage

Hydrogen storage is one of the critical technologies for the development of the hydrogen economy. In particular the availability of high capacity hydrogen tanks and reservoirs is of paramount importance for the viability of hydrogen as energy vector. Hydrogen as reserve storage, even for seasonal storage, depends on the possibility to accumulate large volumes and quantities of hydrogen, for instance, into caverns, what is one of the most recognised expertise at the School of Mines and Energy Engineering (ETSIME). For such purpose, we have specific equipment for rock physical analysis to measure rock density (Accupyc II 1340), porous material envelope (Geopyc 1360), gas permeability (Gasperm), currently used in the UNDERGY project. An example of other equipment for measurement of physical rock properties are presented in Figure 4.

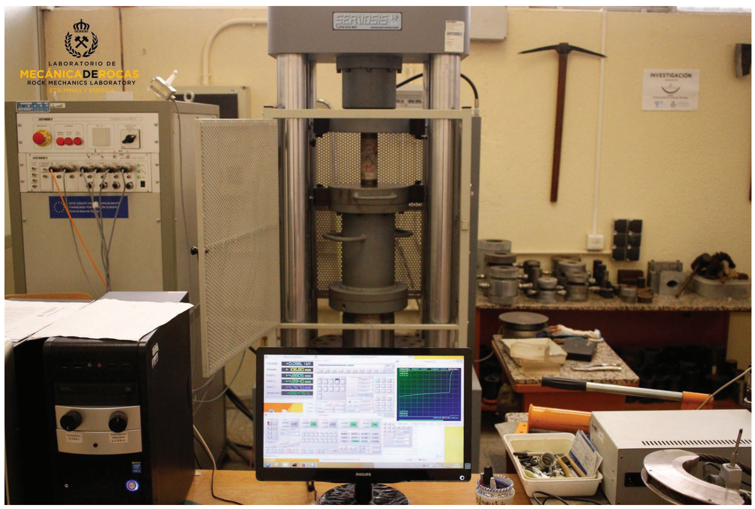

Figure 4: Simple Compressive Strength Measuring Equipment

4. Hydrogen transport

The transport of huge amounts of hydrogen trough dedicated networks, as the existing for oil and natural gas, is on the agenda of many stakeholders related to the hydrogen development and energy supply chain in the European Union and beyond. Research and development in the field of materials, and the effect of high pressure hydrogen in transport ducts are of paramount importance for the technical viability of many projects that are ongoing, The hydrogen corridor proposed [8] by Spain, Portugal and France are the clear example of infrastructure that will need some support in terms of technological development to be safely implemented. At UPM, at the CIME (Centro de de Investigación en Materiales Estructurales/Center for Structural Materials Research) of the School of Civil Engineering (ETSICCP) is available a chamber for high pressure test (up to 100 bar) of structural materials in hydrogen atmospheres, what will be a key information for the choice of structural materials for ducts.

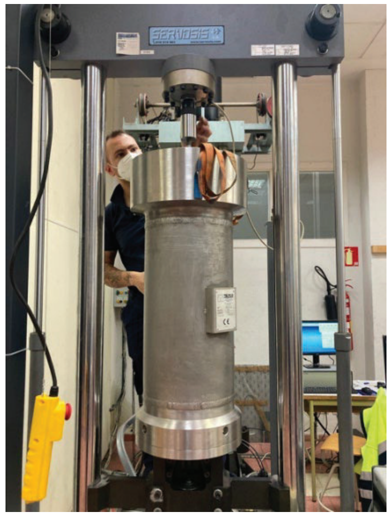

Figure 5: High pressure hydrogen chamber for material testing.

5. Hydrogen end uses

The end use of hydrogen is one of the final steps on its value chain. There are many challenges in this area. One of those challenges is the implementation of hydrogen as energy sources in mobility. That includes, for instance, a test bench for fuel cells operating in hybrid mode for terrestrial vehicle power trains, including Heavy Duty ones. The Test Bench installed at the University Institute of Automobile Research of the UPM (INSIA) can prove Powertrains up to 200 kW and 9600 N.m on each wheel (Figure 6).

Figure 6: Test bench for hybrid power trains.

One of our most important groups, with decades of activity in relation with the development of fuel cells, is PiCOHIMA, of that is currently working in the development of a fuel cell test bench up to a few hundreds of kW (Figure 7), that is expected to be operative at the end of the GreenH2-CM project supported by the Madrid regional government and the Spanish Government trough the “Plan de Recuperación, Transformación y Resiliencia” (PRTR). We have some equipment for evaluating the combustion of gas mixtures, including fraction of H_2, CO_2 and CH_4, that are useful for the characterization of biomass to hydrogen [9,10] conversion and the heating value of the products (Figure 8). Such facility is available at TECMINERGY, a centre depending of the School of Mines and Energy Engineering.

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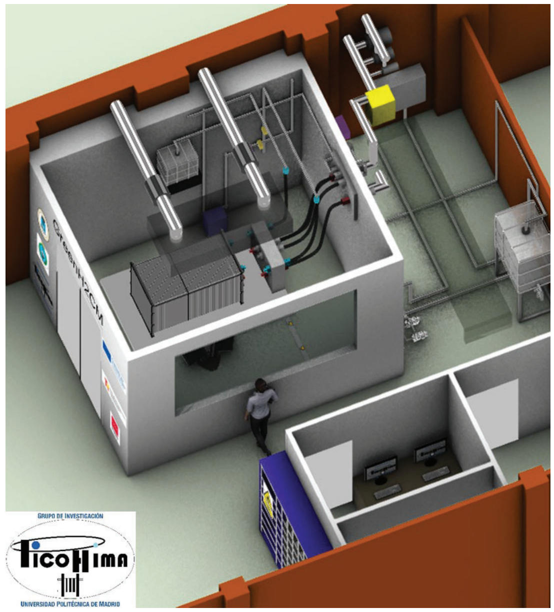

Figure 7: Sketch of the fuel cell test bench under design.

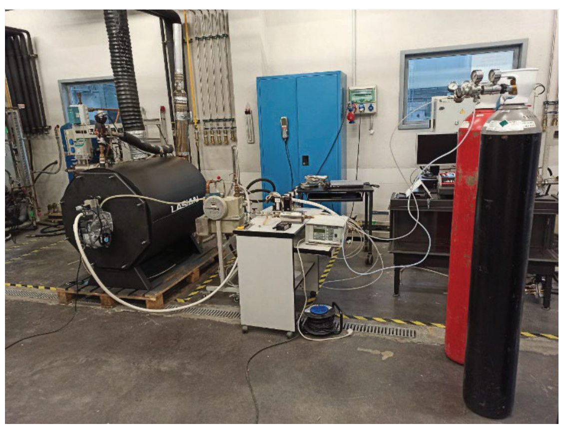

Figure 8: Combustion chamber CO_2 lung (combustion tests of the ternary mixture $CH_4/CO_2/H_2$).

6. Skills

Technology is implemented by people, and the impressive challenge of put into practice the huge projects that are planned to transform the expectations of the hydrogen economy into a reality, demands thousands of skilled people. So many hands will come from fresh young graduates as well as by reskilling of many workers already in related industries. For such purpose, our role as university is to provide tools to allow the access of the Society to the knowledge in order to feed such demand. We have designed a master program [11] of 60 ECTS for the specialization of post-graduated individuals in the whole value chain of the hydrogen economy, from generation to utilization, including regulation and normative as a basic stone for the hydrogen sector.

Conclusion

The hydrogen research and development ecosystem have the societal need to transfer, as fast as possible, knowledge that has been produced for decades into one of the pillars of the energy and productive system.

High education institutions must contribute to the development of high TRL projects in cooperation with industry to transfer such knowledge, as well as for the training of skilled manpower that is needed for such purpose. At UPM we have initiated a process to respond to the needs of a fast implementation of the hydrogen economy in the Society. One of those needs is to gain critical mass and capacity to support large size projects. We have elaborated a first inventory of the existing laboratory infrastructures at UPM to evaluate our own capacity to face such projects. The variety of engineering disciplines at UPM is a strength of the institution to participate in multidisciplinary projects, as required for large scale hydrogen implementation. The expertise at UPM covers the whole value chain of the hydrogen economy. From this first infrastructure inventory, we are trying to upgrade and improve our facilities to face the enormous challenge and contribute to the implementation of a more sustainable society.

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