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In the path for creating Research-to-business new opportunities on green hydrogen between Italy and Brazil

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HIGHLIGHTS

- Climate protection is possible by intensifying research cooperation on green hydrogen.
- Italy has many enterprises showing interest in creating business in Brazil.
- Brazil is interested in attracting resources for research and development from the EU.

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ABSTRACT

On September 22, 2021, 5 experts from Brazil and 5 from Italy discussed the future of research-to-business (R2B) cooperation between Italy and Brazil on green hydrogen (H_2) and related technologies. The workshop discussed some priorities of the Brazilian policies and elucidated the strengths and the weaknesses of the biggest economy among the Latin American countries. Because of its territorial and underground resources its social and economic activities, Brazil offers an excellent basin for supporting an H_2-based economy. A well-established connection between Brazilian Universities and EU research organisations already exists in up-to-date research activities and frameworks for grants programmes. Nevertheless, Brazil has some difficulties creating new economies through the industrialisation of research achievements. On the other hand, Italy has a long tradition of creating and exporting technologies because its enterprises are generally prone to creating new business.

In this communication, we reported the argued discussions between Brazilian and Italian players on green hydrogen that discussed how to improve the technological interaction between the two countries. This meeting discussed the entire value chain for green hydrogen, from the production to the end-user, and included distribution and commercialisation of green H_2 and related technologies.

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Background

Climate changes require commitments at each level of society, starting with the governmental policies, industrial stakeholders and well practices of all the people. At the governmental level, it is particularly harsh the challenge for maintaining the average temperature incremental as close as 1.5 °C by 2050 according to the COP21 agreement of Paris established in 2015 [1–3]. During the COP26 held in Glasgow in 2021, the leader of each participating country declared their challenges by balancing the paramount request of a safe environment and their sovereign economic aspirations [4–6]. With the "Nationally Determined Contributions" (i.e. NDCs), the leaders agreed to develop their economy based on carbon-neutral technologies [7–11]. In this scenario, the richest countries have to increase the support to the emerging countries with new technologies and financial aid (cit. "the duty to fulfil the pledge of providing 100 billion dollars annually from developed to developing countries was also reaffirmed" [12]). To achieve this ambitious target, the use of hydrogen as an energy vector and related technologies seems to be one of the most promising available approaches [13,14].

We have assisted in hydrogen's "colouring" in recent years, although hydrogen is a colourless gas and remains the most efficient and climate-neutral energy source as scientists know. Currently, giving a "colour" to the hydrogen gas is widely used in the marketing context to define how H_2 is produced [15]. Therefore, "brown" refers to H_2 produced by the reforming of coal [16]; "Grey" is H_2 produced through the reforming of fossil fuels with CO_2 released in the atmosphere [17]; "Blue H_2 "refers to the reforming of natural gas coupled to capture of CO_2 [18]; "Turquoise H_2 "comes from the pyrolisis of methane and formation of solid carbon [19]; "Yellow H_2" is referred to the electrolysis of H_2O by using electricity produced by renewable- and fossil-based fuels [20]. Moreover, "white" is H_2 achieved as a secondary product [13]; "Violet H_2 " (sometimes also referred to as red or pink H_2) is referred to H_2 achieved by the electrolysis of H_2O assisted by nuclear energy [21]; "Green H_2" is produced by the electrolysis of H_2O assisted by pure renewable power [22–24]. Currently, many countries' outlook includes discussing "nuclear energy yes" or "nuclear energy no". In addition, around 79 Mtons/year of H_2 produced worldwide today comes from natural gas and coal, becoming responsible for more than 900 Mtons/year CO_2 emitted in the atmosphere, almost similar to the emissions of Indonesia and the UK combined [25]. But, with the belief that "what goes around comes around", we focused this workshop on hydrogen that can be produced from a neutral-carbon route ("green H_2") as the most effective solution for current targets also based on Italy and Brazil's technological and scientific competencies and on the economic commitments that a different technology would require.

Brazil produces its inner electrical energy in prevalence from renewable sources and includes an average value of 65% from hydropower, 9% from biomasses, 9% from wind and 2% from solar [26–28]. Based on this scenario, energy storage as green H_2 is recommended [15]. On the other side of the world, Italy is one of the most recognised countries offering manufacturing, high-tech industries and energy distribution providers [29].

Therefore, the Italy-Brazil R2B workshop faced the entire value chain for green H_2 production and use, aiming to create a task force based on these two countries. With a specific focus on coupling conventional and advanced technologies (generally referred to as technologies hybridisation [30]), the meeting faced the most recent research achievements and the most reasonable technological approaches and policies for supporting the transition towards an environmental lowest impact society based on the carbon-neutral economy.

The research activity on materials and processes

The electrolysis of water is widely accepted as the most effective technology for producing pure H_2 [31]. Although a well-established technology based on alkaline liquid electrolytes already exists, many research activities focus on finding more affordable conditions for producing H_2 with the highest efficiency, lowest degradation, and increased compactness [24,32,33]. On the other hand, the current most efficient method to convert the chemical energy of H_2 to power requires fuel cells, which are devices with promising efficiency, as higher as 50% [34,35]. The two above technological solutions are similar in terms of materials and assemblies. Therefore, most efforts aim to study compact devices operating reversibly (i.e. electrolyser and fuel cell) [36,37]. A compact device that could store energy through water electrolysis and generate power when required could be used for most domestic and industrial applications. Since 2001, Research Groups from Italy and Brazil have jointly worked to improve these devices through national and/or international cooperation projects [38,39]. Currently, Prof. Ticianelli from the U. of Sao Paulo is one of the most active scientists involved in bilateral frameworks with Italian institutions. Prof. Ticianelli reported that the conventional electrocatalysts used in reversible electrochemical devices are based on platinum, which is currently considered a critical and no-cost effective raw material. In line with these constrain, as illustrated in Fig. 1, the current research on the hydrogen evolution reaction for water electrolysis demonstrated that the molybdenum carbide-based electrocatalysts (i.e. Mo_2C) could replace the Pt in alkaline and acidic media [40,41]. For the oxygen electrode, the Fe-Nx/C electrocatalyst represents an acceptable cheap material in acidic media, whereas it shows significantly better electrochemical behaviour when compared to Pt in alkaline conditions [42].

Moreover, much attention is required regarding the solid membranes type. For quasi ambient temperature operation, proton and hydroxide ions based membranes are commercialised. However, if the acidic membranes have already achieved considerable endurance stability, the same is still an issue for the alkaline membrane [33,43].

The technological initiatives in Italy

According to EU priorities, hydrogen was identified as an important energy vector for decarbonising industries' activities. Therefore, in July 2020, the EU's strategy favoured the use of H_2 in all energy sectors [44]. From now up to 2030, the

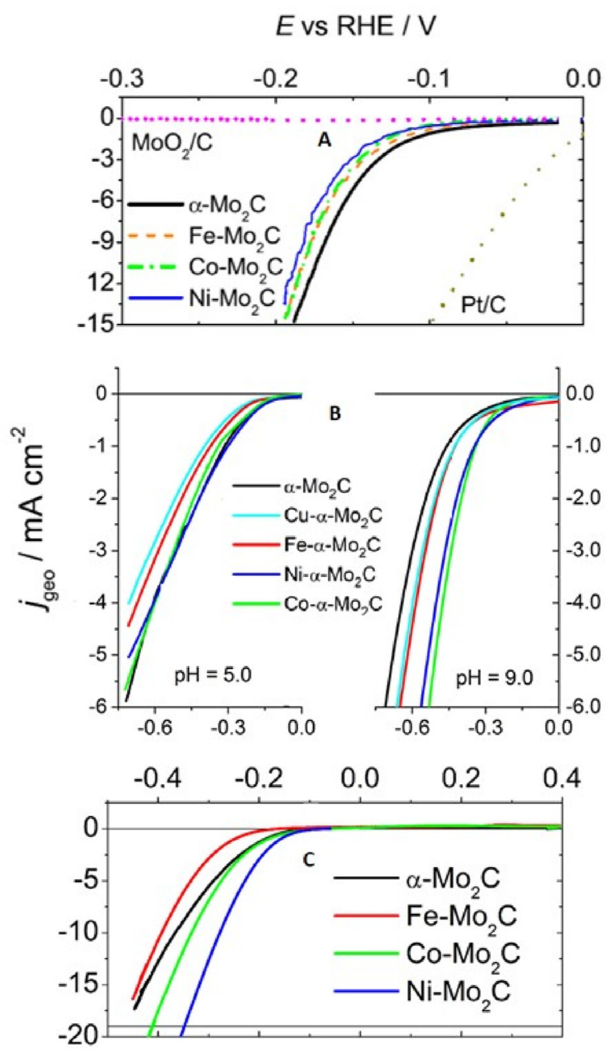

Fig. 1 – Polarization curves for the hydrogen evolution reaction on different Molybdenum Carbide-based catalysts in aqueous solutions at several pHs: (A) 0.1; (B) left 5.5, right 9.0; (C) 13. Adapted from Refs. [40,41,43].

installation of 40 GW of electrolyser loaded with renewable energy is expected to produce 10 million tonnes of green hydrogen and approach the price of grey H_2 of 1.5 €/kg. In December 2019, the Italian Ministry of Economic Development estimated to mobilise investment up to 10 billion euros to adopt the inner Energy and Climate National Plan by promoting the installation of 5 GW of electrolysis capacity by 2030 [45].

With an eye on the opportunities for research grants, EU supported the hydrogen and fuel cell sector, through Fuel Cell and Hydrogen Joint Undertaking (FCH-JU), a public-private partnership. From 2007 to 2020, this organisation supported projects for 135 M€ on H_2 produced through electrolysers [46]. In this framework, Italy participated in over 160 projects with 120 beneficiaries and 321 researchers, recognising 107 M€ of funding support from FCH-JU and coordinated projects for a total budget of 48 M€ (Fig. 2).

At the national level, in Italy, the research on H_2 is supported by the Fund for Research on the Electrical System (e.g. RdS) financed by the Ministry for the Economic Development (MiSE) [47,48]. This research program is economically sustained by gaining a part of the electricity tariff and the last triannual programme (2019–2021) mainly focuses on the storage of non-programmable renewable energy sources (RES) through Power-to-Gas technologies. Currently, 5 projects for 8.5 M€ are running on this topic financed by the resources from the supplement cost applied on the electricity. Viviana Cigolotti from the Italian National Agency for New Technologies (ENEA), reported that Italy planned to invest around 10 billion euros in H_2 technologies by 2030. Half of this investment will come from EU funds and private investments. To enhance the green hydrogen production, Italy sets a capacity of 5 GW of electrolysis, which is enough for the 2% of the national energy demand and sufficient for reducing the emission of 8 million tons of CO_2 in the atmosphere [49]. Viviana Cigolotti also said that the Italian stakeholders on H_2 are working together with political leaders to workstreams for enabling the following 6 key sectors (i) H_2 production concerning creating incentives to green H_2; (ii) H_2 logistic and distribution concerning mainly the review and harmonising the legal aspect; (iii) H_2 storage for creating the conditions for its social acceptance; (iv) mobility based on H_2 to enhance the number of infrastructures and reduce the costs; (v) easy access to the authorisation procedures for industrial, commercial, and residential users; (vi) energy sector working on the injection of H_2 to the gas grid. In Italy, ENEA plays a leadership role in creating conditions for a virtuous circular system around green H_2 and between the demand and offer of research and industry. The trends and perspectives of Italian research projects on H_2 are strongly connected to the relapses of (i) the Mission Innovation IC8, (ii) the Recovery and Resilience fund, and (iii) Clean Hydrogen Partnership and EU Clean Hydrogen Alliance. As a stakeholder, ENEA is the primary beneficiary of Mission Innovation IC8 for creating the first hydrogen demo valley in Italy with a funding of 16 M€ and including technologies such as 200 kW of the P–V system, solid oxide fuel cell stack (e.g. 3 kW) and electrolyser stack (e.g. 100 kW), reversible solid oxide cells (e.g. 40 kW), alkaline and PEM electrolysers (e.g. 200 kW), storage systems (e.g. 500 kg of H_2). Furthermore, ENEA supports MiSE in preparing the Italian project portfolio for the first Important Project of CommonEuropean Interest on H_2 (e.g. IPCEI) and coordinates the European Energy Research Alliance (EERA) Joint Programme on Fuel Cells and Hydrogen.

Hydrogen energy in the brazilian context

The Brazilian ministerial programmes on hydrogen energy started in 2002 with the Fuel Cell Brazillian Programme (Ministry of Science, Technology and Innovation) followed by the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) in 2003, albeit some pioneering studies on this topic were conducted starting from 1977 by Gonzalez [50] and in 1985 realised the first 1 kW fuel cell stack based on PEM cells [51]. The Ministry of Mines and Energy created the first roadmap for hydrogen energy (in 2005). This roadmap was further intensified in recent years [52]. In 2021, Brazil threw the basis for a new national hydrogen program on technology

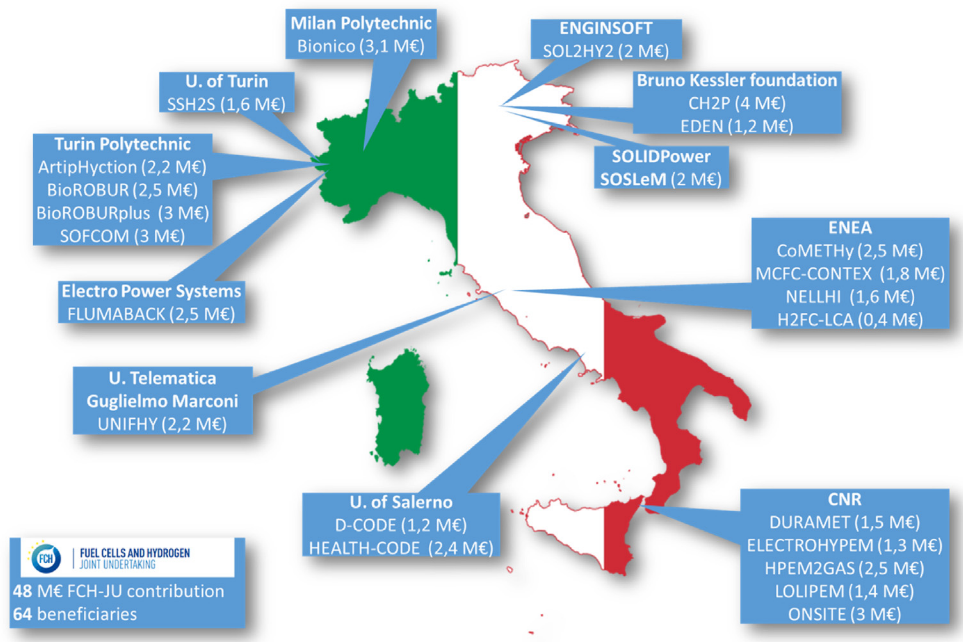

Fig. 2 – Distribution of economic resources coming from FCH-JU organisation through projects coordinated by Italian partners.

development, human resources formation at different levels, energy planning regulation codes and standards, and a special effort on market stimulation and international cooperation. Such delay compared to the more developed countries was mainly due to the economic nature of Brazilian territory. Like many other countries in the world, Brazil is an agri-industrial country, and this aspect relegates the initiatives and investments to marginal. For example, some sectors like mining extraction, cement and steel industries are currently considered refractory to a step-change favouring H_2 and related technologies. Prof P.E. Valadão de Miranda (President of Brazilian Hydrogen Association - ABH_2) discussed the potentialities in Brazil for green hydrogen production. Brazil has a reputation for being a more renewable country than the average globally. Its value is around 45%, whereas the average in the rest of the world is 14% of renewable-based energy production [53]. In particular, the primary source is related to hydroelectric power and the entire Brazilian territory is provided from this resource by an interconnected grid. However, hydropower is not the only renewable resource available in Brazil. In Brazil's northeast and southern regions, a significant amount of energy is produced by wind energy, and the energy storage through hydrogen production may become promising to stabilise the characteristic intermittency of this renewable source. The electrolysis of water could be the way for this requirement. In addition, solar energy farms, mainly in the northern region, and geothermal energy and natural H_2 available in specific country sites are further opportunities for green H_2 production. Nowadays, most of the H_2 currently produced in Brazil comes from the steam reforming of natural gas used in the fertilising and petrochemical industries. By looking only at the natural gas availability, a strategy adopted from Brazil consisted in the modeling how to monetise natural gas remaining resources by means of enhanced oil recovery technology [54]. According to this strategy, Blue H_2 production would reach in 2050 tenfold of the current total H_2 production capacity in Brazil. This perspective can be helpful to pave the way for hydrogen energy technologies adoption during the energy transition period. The current biggest project concerning green H_2 in Brazil is to create an H_2 hub in Ceará state producing and exporting 900,000 tons/year of H_2 with an electrical capacity installed of 5 GW and an investment of 5.4 billion dollars [55]. Another project connected with green hydrogen is the plant installed in Rio de Janeiro producing 250,000 tons/year of green ammonia [56,57]. However, one of the most exciting resources for producing green H_2 in Brazil is probably represented by the biomasses resources, particularly biogas, bioethanol and biowastes, which, coupled with advanced reforming catalysts and reactors, could enhance the capacity of green H_2 production in this country [58–60].

Technologies for the production and use of green H_2

Most of the technological issue for the production and use of H_2 depends on the type of devices to be coupled to the renewable source. Therefore, we discussed the opportunity coming from a new generation of fuel cells and electrolysers. As a specialist of SOLIDPower, Dr Dario Montinaro highlighted the current manufacturing activities concerning solid oxide fuel cells (SOFCs) and solid oxide electrolysis cells (SOECs) [61]. With a production capability of 50 MW per year, SOLIDPower is a leader company in this field, with its main headquarter stably located in Italy. The production of their devices is highly automatised and include (i) a preparation area where the pastes and inks are formulated, (ii) a transformation area where the cells are manufactured and assembled in stacks, and (iii) a firing area where the cells are sintered, and stacks are conditioned, and quality checked. Two main classes of devices are available in the commerce and consist of the model BG-15 of 1.5 kW, having an electrical efficiency of 57% for residential applications, and the model BG-60 for a power generation of 6 kW with an electrical efficiency of 60% and applications in small commercials, data centres and hotels. SOLIDPower has a portfolio of more than 1900 units installed in 12 countries and demonstrated 37 million hours of operation, 47 GWh power generated in the fuel cells mode, 15,000 tons of CO_2 saved, guaranteeing a minimum stack life of 7 years. Their biggest device at pre-commerce status corresponds to a large scale module consisting of 4 stacks demonstrated in H_2 and natural gas reformate (e.g. SOFC) for the power generation of 25 KW [62] and as steam electrolyser (e.g. SOEC) for the production of 50 kg/day of H_2 with 74 kW of electrical power at the thermoneutral voltage and with an efficiency of 98% (compared to the LHV of H_2) [63].

As commercial director of the Hytron Brazilian company, Dr Daniel G. Lopes shed light on their technological devices fabricated in Brazil. Their most advanced solid-state low-temperature electrolyser module (e.g. HyPEM) runs to produce 1000 Nm^3/h of H_2, corresponding to 5 MW installed in a device integrated and autonomous, defined as "turn-key". Nevertheless, the production of H_2 from water electrolysis requires a step of gas drying. Within the portfolio of Hytron, there is the device named HyPSA consisting of 2 beds adsorption dryer module with the capacity of treating 1000 Nm^3/h of H_2 for achieving the 99,9999% of H_2 purity. Since Brazil is the second producer of bioethanol in the world, Hytron is studying the use of this bioresource as a green hydrogen carrier [64]. The potentialities offered by this bioresource are easy transportation, low toxicity, and easy storage. Brazil already has well-established medium-large agro-enterprises, enabling a stable and predictable production [65] which can be exploited for the local production of H_2 close to the user. Owing to these potentialities, Hytron developed a device named HyREF, which converts the bioethanol to green H_2 with a rate of 350 Nm^3/h, pure at 99,9999%. Another step afforded by Hytron is the H_2 storage. In this field, Hytron produces 2 types of compressors based on the diaphragm or hydraulic driven, capable of compressing the H_2 between 200 and 1000 bars [66].

Renewable energy opportunities for the energy sector in Brazil

In the past 20 years, many technological parks around the Brazilian territory have been created to boost decarbonisation using novel and efficient technologies. One of them is the Itaipu Technology Park (PTI, *Parque Tecnológico Itaipu*), located in Foz do Iguaçu, Brazil, at the border between Brazil, Argentina and Paraguay. As reported by the technical director of PTI, Dr Rafael Jose Deitos, the technology park is currently involved in developing technologies for solving local problems but can be replicated on a global scale (Fig. 3). PTI ecosystem has supported the R&D activities, but a business incubators programme, relationships with educational institutions, and tourism promotion at the ITAIPU hydroelectrical power plant are also permanently enrolled. Within PTI, two main research areas on renewable energy are promoted. The first one involves energy reliability and efficiency, which requires a paradigm change based on new business models. In this context, the efforts of PTI consist of moving from the actual model based on just in time power production currently provided from petrochemical, nuclear and majority renewable energy sources (about 70–80%) towards a scenario in which 100% of renewable energy produced by spreading up the solar and wind energy are included in a web of distributed generation system where consumer and producer can become the same identity (e.g. generally named as prosumers). Therefore, PTI is working on improving the reliability of the national distribution electrical grid by developing novel energy storage solutions, including the (i) behind-the-meter battery systems for back–up and peak shaving applications; and (ii) battery energy storage devices for increasing safety and reducing environmental impact, such as salt-based battery technologies developed at PTI (sodium-metal chloride batteries) [67,68]. The second area consists of sustainability and decarbonisation connected to the considerable amount of bioethanol availability in Brazil and the production potential of green H_2 from renewable energy sources (hydro, wind, solar and biomass) [69]. This decentralised provision of green hydrogen is potentially applied in local industries, such as hard-to-abate industrial sectors; the mobility sector (trains, trucks, aeroplanes and ships); and chemical feedstocks production in agribusiness. Lastly, the green H_2 seems to be a valuable business model for Brazilian decarbonisation and the ongoing world energy transitions. PTI is currently fostering technology and market development along Brazil's green hydrogen value chain by involving all relevant actors (e.g. regulators, manufacturers, potential off-takers, research institutions, project developers, etc.) and providing technical solutions with strategic solutions evaluation. For instance, demonstrative energy systems are installed inside PTI, such as the alkaline electrolyser (50 kW), fuel cell device (6 kW), hydrogen storage system and public lights powered by green H_2 fed fuel cells.

Green H_2 as a complement to electrification

With its 3.7 GW installed and 74 million retail customers, Enel Green Power has the leading position as the world's most significant private player in renewable energies. In charge of its role, Enel Green Power has set the reduction of greenhouse gas emissions by 2030 at the target of 80% per kWh vs 2017, and it plans to complete full decarbonisation by 2050. Based on its vision for the future, the Enel Green Power group believes that electrification offers the cheapest and simplest route to decarbonise large portions of total final energy uses and the H_2 is best used as a complement to electrification in order to accelerate the decarbonisation of hard-to abate-sectors as the heavy industries and the aviation. In light of this strategic approach, the Enel Green Power group declared as "the H_2 needs to be renewable and generated by 100% of renewable power through electrolysis because also that produced through the gas treatment and coupled carbon capture

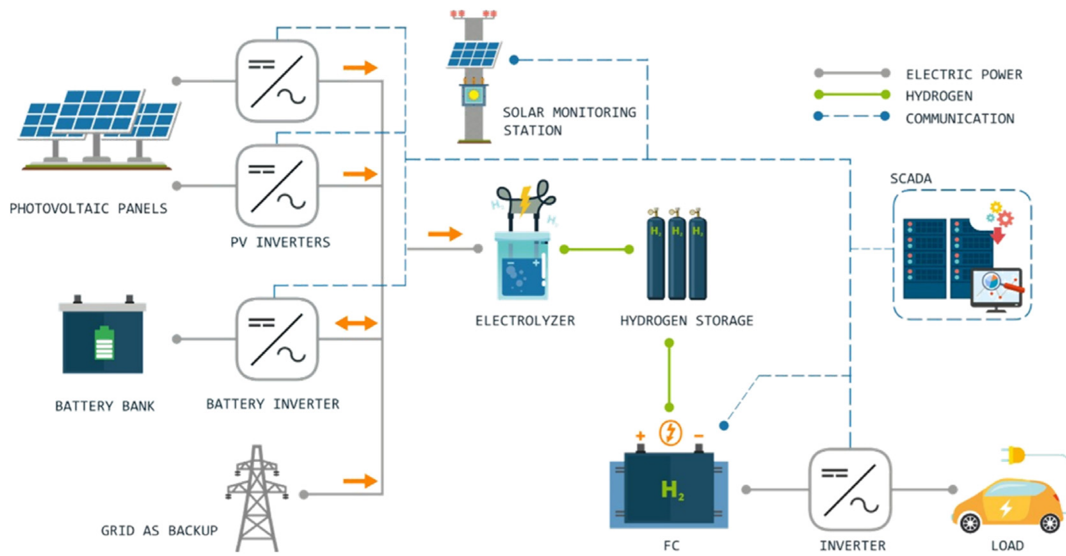

Fig. 3 – Scheme of the advanced devices installed at PTI.

and storage technology can not be considered as a carbon-free approach". Grey hydrogen is a highly carbon-intensive process method, and blue hydrogen requires complex and expensive facilities. Dr Sandra Barba (the delegate of Enel Green Power) declared that meeting the target for 2030 requires competitive costs of green H_2 compared to blue or grey H_2. Nevertheless, the lowering of the cost of the electrolyser and the levelized cost of electricity (LCOE) for renewable-based power generation should be assessed. To accomplish this mission, in 2020, the Enel group created a business unit dedicated to the implementation of green H_2 plants. There is an official Enel position concerning the use of green H_2, which was assessed during the R2B workshop. The Enel Green Power group delegate declared that direct electrification is preferable in the transport, building, and industry sector. In contrast, the green H_2 can replace in the medium period and only in specific applications in the transport sector, especially those for long distances (i.e. long haul ship, train running where the direct electrification is not possible or not competitive, aviation) and in the industry contexts where specific requirements for health and safety are required. Within this official position, it was declared that the preferred approach consists of the stand-alone configuration [70–75], which requires the use of a national electric grid coupled with renewable power sources (i.e. solar, hydropower, and wind generators) to load the electrolysers for producing H_2.

Perspectives of green H_2 economy in Brazil

Long term commitment to R&D research centres (e.g. PTI) and start-ups (e.g. Hytron) on themes related to H_2 is not new in Brazil. In 2002, the Ministry of Science, Technology and Innovation (MCTI) launched the first programme on fuel cells. In 2005 Ministry of Mines and Energy (MME) published the roadmap for realising a hydrogen economy in Brazil [52,76,77]. In 2010 the MCTI published a programme related to subsidies for the competitiveness of hydrogen energy, and in 2018, the Plan for science technology and innovation for renewable energy and biofuels [78,79]. In 2021, the commitment from Brazil government on H_2 and related technology was reinforced by the National Council for Energy Policy (CNPE) adopting two resolutions (e.g. n. 2 of February 10, 2021, and n. 6 of April 20, 2021) which gave the guidelines for energy R&D and Innovation on many energetic related technologies including H_2, and furthermore sustained the National Hydrogen Programme (PNH_2) [52]. The PNH_2 was explicitly designed to mobilise public and private sectors, academia and international cooperations to accelerate the development of a comprehensive and competitive hydrogen market. Within the PNH_2 programme, 6 strategic axes were set concerning: the Strengthening Technological Bases, Training and Capacity Building, Energy planning, Legal and Regulatory framework, Market growth and competitiveness, and International Cooperation. Currently, H_2 and related technologies are included within the National Energy Plan (PNE), which has set a time horizon for the year 2050, as reported by the Director of Economic-Energy and Environmental Studies at the Energy Research Office (EPE), Dr Giovani Vitória Machado. The main challenges of this Plan consisted of defining a legal framework and regulations for the use, transportation and storage of H_2. In particular, it was recommended the establishment of collaborations with international partners in hydrogen projects and market development [69]. At the beginning of 2021, EPE released the technical note on H_2, which set challenges and opportunities consisting of technologies, competitiveness, carbon footprint, and market potentialities. In support of renewable and low carbon H_2 production, other Brazilian organisations are getting funding for research and development. There are the Brazilian Development Bank (BNDES), the Funding Authority for Studies and Projects (FINEP), SANTANDER and BRADESCO banks, Bank of Brazil, and Brazil Green Finance Initiative, among the others. 2021 was an excellent year for announcements on strategies and plans concerning H_2, and green ammonia, Raizen (JV Cosan-Shell) announced a 5-years deal with Yara to sell biomethane

(20,000 m^3/d) for hydrogen and green ammonia production [80,81]. Neoenergia (Iberdrola Group) and the State of Ceará signed a MoU to implement an urban mobility project using public transport vehicles powered by green H_2 [82,83]. Unigel (a fertiliser producer) announced a green ammonia unit in its plants in Camaçari (State of Bahia) by the end of 2022 (Unigel, 2021) [84] The Enterprize Energy and the State of Rio Grande do Norte signed a MoU to produce green hydrogen and green ammonia from wind energy (Brazilcham, 2021) [85]. Fortescue and Açu Port (In the State of Rio de Janeiro) signed a MoU to develop green ammonia projects consisting of a plant 300 MW producing 250 kton/y of green ammonia (Argus, 2021) [86].

The State of Ceará has stipulated MoU with various organisations to realise projects devoted to green H_2. It is the case of the agreement with Energix, Pecém Port, consisting of the development of a plant for 600kton/y of green H_2 with an investment of 5.4 billion US dollars [55]. With Qair, Pecém Port agreed to develop a plant of 540 MW and an investment of 3.8 billion US dollars (Argus, 2021) [86]. With White Martins (Linde/Praxair), they signed an agreement to facilitate the creation of a Green Hydrogen Hub at the Pecém Port (White Martins, 2021) [87]. Furthermore, the State of Pernambuco has signed two MoU on green H_2 projects. One is that Qair and the Suape Port will create a plant of 540 MW with an investment of 3.8 billion US dollars (Argus, 2021) [86]. The other with Neoenergia to develop a green H_2 pilot plant in Suape Port (Neoenergia, 2021) [88]. Therefore, in the light of these multiple agreements with international partners, strategies and renewable power availability, Brazil is working to become one of the most exciting key players in green H_2.

Conclusions

Solving global problems such as reducing greenhouse gas emissions requires actions at different levels. However, it is the solution to local problems that scientists should prioritise. It is a fact that by solving local problems, scientists can help find global solutions. The Italy-Brazil workshop was an excellent opportunity to disseminate the respective advancements of the two countries concerning the production, use, projects, strategies, public and private programmes related to green H_2 in which the scientist can operate fruitfully. The energy transition process is already happening, and the involved delegates agreed that stronger bilateral relations are desirable.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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