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COMMISSION STAFF WORKING DOCUMENT

Building a European Research Area for clean hydrogen - the role of EU research and innovation investments to deliver on the EU's Hydrogen Strategy

1. INTRODUCTION

The Staff Working Document showcases the role of EU R&I investment in accelerating the green energy transition through hydrogen to reach the EU's European Green Deal ambition of becoming the first climate-neutral continent by 2050.

The Competitiveness Council Conclusions on the new European Research Area of December 2020 recognised the "green" and "digital" twin transition and a resilient recovery as the core directions for translating the "New European Research area (ERA)" into concrete policy and funding actions. The Council called the Commission and interested Member States to carry out an agenda process for a green hydrogen R&I ERA pilot action in 2021. This Staff Working Document also contributes to the green hydrogen pilot launched under the European Research Area, which aims at developing and implementing a common Strategic Research and Innovation agenda for green hydrogen[1] between the Commission and interested Member States.[2][3]

Achieving a climate-neutral EU economy by 2050 calls for the EU to ensure a complete switch from fossil fuels to clean (renewable) energy for all energy uses and a deep decarbonisation of highly emitting industrial sectors such as steel and chemical industries (most notably refinery and fertilizer plants), as well as the transport sector. It is widely recognised that this would require production, distribution, storage and use of clean hydrogen at scale.

To this end, the Commission adopted Communications on the EU Strategy for Energy System Integration[4] and the Hydrogen strategy [5]for a climate-neutral Europe, to put the EU in a leading position to achieve real deployment of the European hydrogen economy. These initiatives set as ambition to install at least 40 GW of hydrogen electrolysers in the EU by 2030 and to scale up clean (renewable)[6] hydrogen production in the EU to 10 million tonnes by the same deadline in order to set the EU on track to deploy renewable hydrogen at large scale in the whole economy including in hard-to-decarbonise sectors towards 2050. They also highlight a persisting need for research and innovation investment in clean hydrogen to become a major contributor to the green transition of the EU's economy.

The 'fit for 55' legislative package also contains various proposals in the energy and transport areas that will further stimulate the hydogen economy[7][8].

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[1] There exist many definitions of variants of hydrogen, among these green hydrogen and renewable hydrogen. In this document the definition of "clean hydrogen" indicated in the European hydrogen strategy is used, which defines "clean" as "renewable".

[2] See the Competitiveness Council conclusions of 1 December 2020 on the revamping of the European Research Area

[3] See also: https://www.bmbf.de/bmbf/shareddocs/kurzmeldungen/en/green-hydrogen-for-a-sustainable-future.html

[4] https://ec.europa.eu/energy/topics/energy-system-integration/eu-strategy-energy-system-integration_en

[5] Short: European hydrogen strategy, https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf

[6] See also footnote 1

[7] Including road and maritime transport and aviation; for road transport, the main objective is to contribute to the climate goals by reducing CO2 emissions from cars and light vehicles, with measures such as the introduction of emissions trading in transport, more stringent CO2 standards, facilitating the development of the necessary hydrogen infrastructure and promoting higher shares of renewable fuels.

EU Research and Innovation Framework Programmes invested more than EUR 1 billion over the period 2008-2021 into developing hydrogen technologies through two successive Fuel Cells and Hydrogen Joint Undertakings. These partnerships leveraged an additional EUR 1 billion for hydrogen technology investment from the private sector. Several Member States have adopted national hydrogen strategies with an ambitious research and innovation component. Still, the latest State of the Energy Union report[9] concludes that, despite the political impetus in clean hydrogen, investments in research and innovation do not yet follow, in particular at national level, the political ambitions. Evidence shows a discrepancy among the EU Member States with a concentration of efforts in some countries such as France, Germany and the Netherlands, and consequently more needs to be done towards mobilising EU activities in the hydrogen sector.

Despite the heterogeneity, Europe is in pole position to be the world leader in clean hydrogen technologies and such leadership can only be maintained, through increased research and innovation (R&I) efforts at both EU and national level, with a strong component on international cooperation.

Hydrogen in a nutshell

Hydrogen's potential to store and carry renewable energy provides a strategic opportunity to accelerate the transition from fossil fuels to renewable energy and therefore to decarbonise the EU economy, as well as providing decarbonised fuels and/or feedstock for hard to abate sectors in industry and transport. Its potential utilisation in various economic activities also offers a solution for standalone regions or for industry or logistic nodes to switch towards a clean and flexible energy at once.

Hydrogen as commodity must be produced from another substance, by separating it from a variety of sources. It is currently used mainly as feedstock for industry, however the most promising future large-scale applications are to store and carry renewable energy, and to fuel various economic sectors, with particular importance for e.g. heavy-duty transport and for energy-intensive industries.

Box 1: Basic information on hydrogen in a nutshell

2. EU HYDROGEN R&I ACHIEVEMENTS

The successive Fuel Cells and Hydrogen Joint Undertakings (FCH JU) under the 7th Framework Programme and under Horizon 2020 played an important role in structuring and mobilising an otherwise fragmented landscape of different sectors and industries. Competing or different, unrelated stakeholders were convinced to work together towards clear objectives and successful mechanisms were developed for fostering continued technological innovation.

During this time, the European hydrogen market has considerably scaled up, creating EU technology leaders in the areas of electrolysers, hydrogen refuelling stations (HRS), and fuel cell buses. These innovative technologies will allow Europe to integrate the use of renewable

[8] Considering Hydrogen refuelling infrastructure, the revised Alternative Fuels Infrastructure Regulation, COM/2021/559 final, will require Member States e.g. to expand charging capacity, and to install charging and fuelling points at regular intervals on major highways.

[9] https://ec.europa.eu/commission/presscorner/detail/en/SPEECH_21_4701

hydrogen in many sectors that up to now were difficult to decarbonise, in particular heavy-duty transport and energy-intensive industries.

Today Europe is a leading producer of **electrolysers** for clean hydrogen production. EUR 150 million of EU R&I investment since 2008 enabled a 200-fold increase of electrolyser capacity to up to 20 MW per electrolyser system today. More efficient and cost effective electrolysers enable upscaling production of large volumes of clean hydrogen. The European Green Deal call, launched under Horizon 2020, will further scale up the electrolyser capacities towards the goal of demonstration and deployment of a 100 MW electrolyser system by 2025.

Figure 1: Overview of increased capacity of electrolyser for hydrogen production in the EU, funded by FCH JU.

Hydrogen fuel cell buses are one of the biggest success stories of the EU's R&I investment in hydrogen. They provide multiple benefits and are popular with the public and transport operators. With zero air pollutant emissions, they contribute to cleaner air in urban areas – positively impacting residents' wellbeing. Their ability to travel up to 400 kilometres without refuelling also makes them a strategic choice for sustainability-seeking city councils.[10] Currently, there are about 390 hydrogen-fuelled buses (and about 2750 hydrogen-fuelled cars and vans) registered and are circulating in Europe. With a growing market, Europe's fleet of hydrogen buses has the potential to expand to over 1 200 by 2025[11], and 600 000 hydrogen fuel cell buses and minibuses may be in service in 2035 worldwide[12].

Thanks to EU R&I investments for hydrogen-powered busses, fuel efficiency has increased three-fold in 15 years and their refuelling time has more than halved.

[10]Around 120 FC buses have been deployed until today through FCH JU and 247 are planned or in development phase. The FCH JU initially co-financed the flagship project Clean Hydrogen in European Cities (CHIC), launched in 2010. The project supported the deployment of 56 fuel cell buses across Europe and Canada to demonstrate how cities can decarbonise public transport. Other FCH JU projects trialling bigger fleets followed – including High V.LO-City, HyTRANSIT and 3EMOTION. More recently, a total of 315 buses have been deployed or planned to be deployed through the JIVE and JIVE 2 projects (including all buses currently under development), bringing the total number of hydrogen buses in Europe to almost 400.

[11] https://www.sustainable-bus.com/fuel-cell-bus/fuel-cell-bus-hydrogen/

[12] https://www.informationtrends.com/global-market-for-hydrogen-fuel-cell-buses-2022/

Powered by hydrogen, Fuel Cell Electric Vehicles FCEVs have short refuelling times and the only tailpipe emission they produce is water. The lack of hydrogen refuelling stations however has discouraged captive fleet operators such as taxi companies from adopting them quicker. The FCH JU worked with industry leaders and municipal authorities to bring hydrogen-fuelled vehicles, such as taxicabs and police vehicles onto Europe's streets.[13] So far, 159 **Hydrogen Refuelling Stations HRS** are deployed in Europe [14], out of which 72 were deployed via FCH JU (mainly via Hydrogen Mobility Europe H2ME and H2ME 2 projects).

The Horizon 2020 European Green Deal call also included a call for **hydrogen green airports and ports**[15] as multimodal hubs for sustainable and smart mobility with an EU R&I investment of EUR 100 million.

Today there are 21 **hydrogen valleys** in the European Union[16] that showcase hydrogen economy locally by bringing together all the elements of hydrogen production, storage, distribution, and end-use in a single space. The FCH JU have supported the development of hydrogen valleys through investments of EUR 35 million[17] and through Project Development Assistance (PDA), which aims at promoting participation of regions, in particular from Eastern Europe, in their projects and activities, and intends to focus especially for next steps on less hydrogen developed regions especially for newer Member States. Developing local and customised approaches within each valley shows a high level of flexibility of hydrogen technology to adjust to the local situation.

[13] Three FCH JU-financed projects have helped promote the adoption of FCEVs in European cities: Zero Emission Fleet vehicles for European Roll-out (ZEFER), Hydrogen Mobility Europe (H2ME) and Hydrogen Mobility Europe 2 (H2ME 2).

[14] https://www.fchobservatory.eu/index.php/observatory/technology-and-market/hydrogen-refueling-stations-availability-system

[15] https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/lc-gd-5-1-2020

[16] https://www.h2v.eu/, 24 are in Europe, two of them are outside the EU, in the UK

[17] Projects BIG HIT, HEAVENN and GREEN HYSLAND.

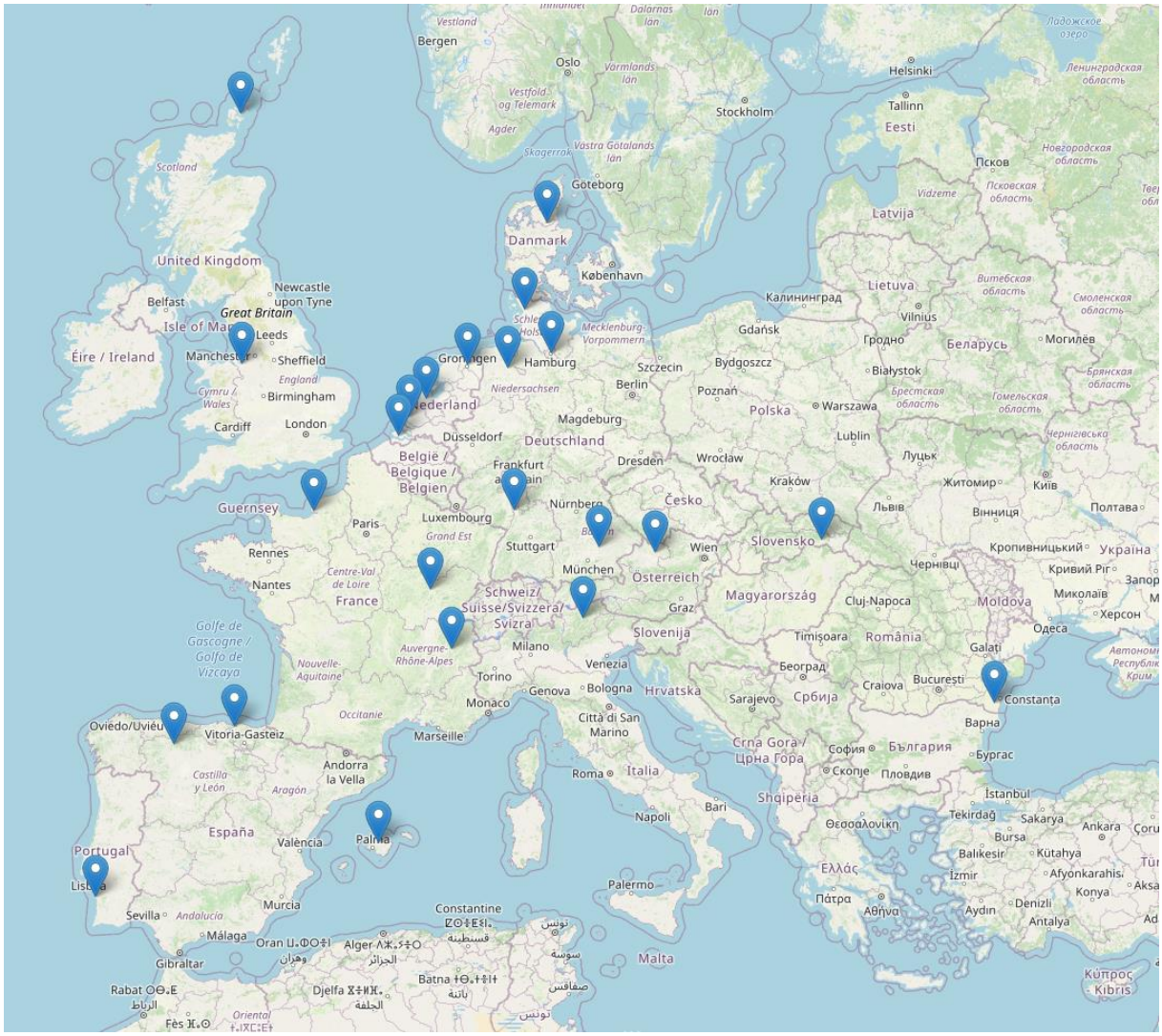

Figure 2: Locations of hydrogen valleys in Europe

For example on the Orkney Islands, clean hydrogen is produced through wind and tidal energy and supplies all energy used on the island, including for ferries.[18] In Groningen, the existing gas network has been revamped to supply clean hydrogen for industry, residential and transport applications.

The hydrogen valley concept is widely replicable and the Hydrogen Valley Platform, established by the FCH JU, is facilitating exchanges of best practices and performing matchmaking services.

[18] Set on the small Scottish archipelago of the Orkney islands, the project is going to demonstrate the possibility of comprehensively relying on hydrogen as a way to maximize the use of their renewable energy resources. Electricity produced from wind and tidal installations is to be converted into hydrogen through two water electrolysers. The hydrogen will act as an energy-storage medium and will be converted back, through fuel cells, into heat and power for buildings as well as into electricity for the operation of vehicles. Various catalytic hydrogen boilers will provide the heating needs for two schools at Shapinsay. A 75 kW fuel cell will supply heat and power for several harbour buildings, a marina and three ferries (when docked) in Kirkwall. And finally, a hydrogen refuelling station also by the Kirkwall harbour will feed 10 hydrogen fuel cell road vehicles.

3. CHALLENGES AND OPPORTUNITIES FOR R&I INVESTMENTS[19]

Hydrogen applications have progressed significantly over the past decade. Today, many hydrogen technologies/applications are ready for market deployment but they remain comparatively more expensive than competitor technologies. Substantial R&I efforts are still needed to **improve the efficiency, cost, durability and manufacturability** of technologies for hydrogen production, distribution and end-use and optimise their market-readiness and scaling up. Scientific advancement will be required to secure cost reductions and efficiency improvements in the production and use of applications at higher Technology Readiness Levels (TRLs). Further R&I activities covering large-scale demonstration projects are vital in proving the feasibility of and potential for using large-scale electrolysers, and large-scale clean hydrogen end-use applications. Additional R&I effort should be also placed on new technologies to produce renewable hydrogen (e.g. photoelectrochemical water splitting) to continue supporting EU leadership.

The production of clean hydrogen relies upon the availability of **abundant and low-cost renewable energy**. The EU has a diversity of sources of renewable energy, and Horizon Europe will continue to support both renewable energy and smart sector integration, especially looking at market uptake and the development of breakthrough technologies for renewable energies. EU R&I activities will support all renewable energy sources, to allow all parts of the EU to make the optimal choice among possible renewable energies, whether hydropower, geothermal, wind, various solar energy, or biomass, adjusting to the specific situation and resources of the regions, implementing the principle of energy efficiency first.

The scope of hydrogen related applications is increasing from its present focus on transport, fuel cells and electrolysers. It is expanding to include the energy sector and industry and is focusing on specific transport applications (maritime, aviation, rail, heavy transport). With the constant emergence of new applications, the supply chain becomes more complex and continuous improvements (new materials, efficiency, reliability, lifetime, cost, interoperability) are still needed for all applications.[20] Electromobility is also expected to concur with the fuel cell and/or hydrogen mobility for passenger and light duty transport.

Currently, few complete value chains for hydrogen, from production to end-use, are operational across the EU. Limited collaboration and knowledge sharing, as well as limited market maturity has thus far prevented from developing the hydrogen ecosystem with **fully integrated hydrogen value chains**.[21] R&I investments are needed to technologically improve and test several hydrogen applications before they can be successfully implemented into larger scale hydrogen value chains.

Regarding the distribution of hydrogen, the development of infrastructure is slow and holding back widespread adoption.[22] Development of the required suitable and safe **infrastructure** for hydrogen transport, storage and distribution will require R&I activities, for example to

[19] For the purpose of this document, the term "R&I investment" is used for both research and development as types of research eligible for support under the R&D&I State aid rules (notably for fundamental research, industrial research and experimental development), but also for additional activities broadly referred to as "research" in a wider sense

[20] Impact Assessment for Clean Hydrogen.

[21] E4tech (www.e4tech.com; 2019).

[22] IEA, the future of hydrogen 2019, page 14.

address the challenges of injection of hydrogen into the gas grid, demonstration of large volume refuelling stations (> 1 tonne of hydrogen per day) and to address issues related to transportation of liquid hydrogen, e.g. by trucks. The development of infrastructures needs significant investment and should therefore be planned in a sound manner across the whole system, to avoid costly stranded assets and duplications (for instance between gaseous and liquid hydrogen infrastructure).

Despite considerable R&I progress in **transport applications**, several challenges remain ahead. There is still a need to examine and prove solutions in the hard to abate sectors like heavy-duty vehicles, trains, shipping and aviation. The competitiveness of hydrogen technologies is dependent on research and innovation breakthroughs, on efficiency of mass production processes for big volumes of transport equipment and components and on the price and availability of hydrogen as a fuel.[23].

Sustainable Finance Taxonomy is also an opportunity in directing future private investments[24]. The EU Taxonomy is recognizing low carbon, including clean hydrogen and related R&I as "sustainable investment".

In view of the growing importance of hydrogen there is a need for a clear market-enabling **regulatory framework** at EU and international level to support the production and use of key clean hydrogen applications at scale both at national and EU level.[25] Moreover, the international dimension of hydrogen deployment and upscaling of production at global level should be pursued. For example, the import of cheap, clean hydrogen from wind and solar energy produced outside of Europe, might become more important in the mid-term, pending on the development of the EU's own capacity and on the guarantee of circularity and zero emission of the whole value chain of clean hydrogen imports to the EU (from production until final use). At the same time, hydrogen can become an enabler of the green transition in partner countries, and Europe is the leading producer of electrolysers for clean hydrogen production. These deployments would depend on the development of reliable international standards, the development of the required infrastructure and technology and on a common emissions accounting methodology.[26] Pre-normative R&I activities continue to be crucial to support these developments, as e.g. pre-normative research done in the JRC on safer use of hydrogen and fuel cells.

Finally further R&I efforts are needed to address various issues of technologically cross-cutting importance, as:

- **Circularity of hydrogen equipment**,
- **Environmental and socio-economic impact** of hydrogen technology,
- **Reducing use and dependence from critical raw materials**,
- **Safety issues along the whole value chain** to build the confidence needed for widespread take-up in society,

[23] Therefore, actions aimed to stimulating a broad rollout of Fuel Cell vehicles around Europe are equally important to research and innovation actions. This is valid in particular for hard to abate sectors, in order to drive the Total Cost of Ownership (TCO) of the Fuel Cell vehicles down. Addressing all of these aspects simultaneously is necessary to allow for hydrogen transport applications to enter mass market.

[24] Support may be given by the European Investment Bank that is committed to continue its support for investments in clean hydrogen, in line with the indications of the EU Taxonomy, which could range from R&D investments to demonstration projects, as well as the building of the necessary infrastructure.

[25] IEA, the future of hydrogen 2019

[26] Impact Assessment for Clean Hydrogen.

- Research on how to increase **public awareness and acceptability**[27] and
- **Development of skills** for industries at all steps of the hydrogen value chain.

Research on social sciences and humanities will be key to understand and analyse, in relation with an assessment of citizens' needs, how to get citizens' engagement on these relatively disruptive hydrogen solutions.

EU R&I investments in the clean hydrogen value chain also make economic and strategic sense: it may lead to create up to 5,4 million **new jobs** in the EU by 2050,[28] and would support the **open strategic autonomy** of the EU for its energy supply, especially for its Member States currently depending strongly on imports. Using locally produced renewable energy to supply clean hydrogen supports reducing critical dependency on fossil fuel imports.

4. FUTURE EU R&I ACTIVITIES TO ACCELERATE THE HYDROGEN ECONOMY

To address the challenges identified above, Cluster 5 "Climate , Energy and Mobility" of Horizon Europe, the new EU R&I Framework Programme, will invest EUR 15 billion during the period 2021- 2027 in clean energy, mobility and climate sciences. This includes EUR 1 billion contribution to the **Clean Hydrogen Joint Undertaking**[29], leveraged with EUR 1 billion contribution from the industry. This partnership will focus on renewable hydrogen production, but also hydrogen transmission, distribution and storage, alongside transport and other end-use technologies. This new Joint Undertaking will also involve stakeholders along the whole value chain, enhancing cooperation between the diverse industry sectors involved. It will mobilise more widely the industry and the research communities, increasing the multiplier effect of R&I for investments.

The new partnership will have a large spectrum of activities. To mention only some, the partnership will for example invest in solutions for offshore wind energy directly producing clean hydrogen, and it will continue to support hydrogen valleys. It will work on connections between hydrogen valleys, thus establishing hydrogen corridors across the EU. Moreover, in order to continue raising the uptake of project results by Member States and Regions, ensuring effective cooperation between different stakeholders and pooling of funding and financing resources across Europe, the Clean Hydrogen Joint Undertaking intends to provide technical assistance e.g. though procurements of services, or through the instrument of "Project Development Assistance for Cities and Regions"[30].

Enhancing R&I at all TRL will be the pre-condition to increasing energy efficiency and reducing cost of the entire hydrogen value chain, through using the whole range of existing

[27] Recent research initiatives focused on the public perception of hydrogen show that public awareness of hydrogen technologies is still relatively limited

[28] See study by the FCH JU: "Hydrogen Roadmap Europe: A sustainable pathway for the European Energy Transition"https://www.fch.europa.eu/news/hydrogen-roadmap-europe-sustainable-pathway-european-energy-transition

[29] The Clean Hydrogen Joint Undertaking (CHU) will build on the work of the Fuel Cells and Hydrogen Joint Undertaking FCH JU.

[30]https://www.fch.europa.eu/news/project-development-assistance-cities-and-regions-summary-report-now-available

instruments, e.g. **Horizon Europe** (notably the European Research Council, European Innovation Council, Horizon Europe clusters) and the **European Institute for Technology and Innovation EIT** (notably its Knowledge and Innovation Community KIC InnoEnergy), and linking this chain with the investment programmes inside of the EU as well as outside (in particular the **Catalyst Fund**[31] and the **Mission Innovation**[32] leveraging capacity).

The Commission is currently refining the assessment, as part of the ongoing revision in the framework of the Fitness Check of State Aid Rules, of the conditions governing the State support for the deployment and use of renewable hydrogen, which could be proposed for allowing national public support (State aids) to hydrogen, under the revised Climate Energy, and Environmental Aid Guidelines (CEEAG)[33] rules.

Research & Development & Innovation State aid support for hydrogen-related research projects (including fundamental research, industrial research and experimental development) has been possible in the past and will continue to be a possibility under the technology-neutral R&D&I Framework and GBER[34], in compliance with the conditions provided therein.

The **IPCEI** (**Important Projects of Common European Interest**) instrument[35], under consideration by Member States, would aim to support large-scale, cross-border hydrogen projects, in the common interest of the European Union.

Investment projects from the industry will benefit from the Hydrogen Alliance structure set up for clean hydrogen. The **Clean Hydrogen Alliance** is developing a high-visibility pipeline of 'bankable' investment projects for the large-scale deployment of hydrogen in Europe and covering the whole hydrogen value chain. This will facilitate coordinated investments between private and public stakeholders across the EU, providing public support where appropriate and crowding in private investment.

To accelerate the clean hydrogen technologies from the R&I phase to market entry and anticipating the upcoming challenge of reducing the impact on planetary resources related to the production of the required industrial equipment, the use of **technology infrastructures**[36] may provide a solution. Technology infrastructures could be used by undertakings to carry out testing and foster upscaling of technology, to advance, through industrial research and experimental development in an industrial environment, towards mass production of hydrogen technology and its production equipment, including assessment of circularity by design and of regulatory conformity. Private stakeholders have already started identifying

[31] Breakthrough Energy Catalyst Programme – Accelerating the Deployment of Clean Technologies https://www.breakthroughenergy.org/scaling-innovation/catalyst

[32] http://mission-innovation.net/.

[33] Public consultation on the revised Climate, Energy, and Environmental Aid Guidelines (CEEAG)

[34] General Block Exemption Regulation GBER

[35] 'Important projects of common European interest' IPCEIs , see https://ec.europa.eu/competition-policy/state-aid/legislation/modernisation/ipcei_en ; in December 2020, 22 EU countries and Norway signed a manifesto to launch IPCEIs in the hydrogen sector, which has not yet been notified to the Commission under the applicable state aid rules. The idea of Member States on setting-up IPCEIs in the hydrogen sector led to a strong response from the industry.

[36] The concept of "technology infrastructures" has been developed in the Commission Staff Working Document on Technology Infrastructures, SWD(2019) 158 https://data.consilium.europa.eu/doc/document/ST-8411-2019-INIT/en/pdf; the revised RDI framework (as per the draft in public consultation) envisages to include provisions on measures to support testing and experimentation infrastructure which are also known as technology infrastructures.

needs for specific topics to initiate this process, which should lead to the development in the EU of a network of flexible testbed facilities, possibly supported by Horizon Europe.

Knowledge management, open data and knowledge transfer are all necessary components to ensure that deployment takes place consistently in different sectors of the economy. Quality, harmonisation and availability of data on hydrogen are core conditions for further developing a hydrogen economy. The governing principle will be to manage research data on hydrogen responsibly, in line with the FAIR[37] principles and with the aim to make these data "as open as possible and as closed as necessary", thus following the open science provisions set for the Horizon Europe programme. Quality, harmonisation and availability of FAIR data on hydrogen are core conditions for further developing a hydrogen economy. The TRUST database[38] set up by the FCH JU and its Fuel Cell and Hydrogen Observatory[39] pave the way for a consistent approach at European level. Building on these successes, the next step for the Clean Hydrogen Joint Undertaking would be the development of an EU Clean Hydrogen Observatory[40] which will need all parts of Horizon Europe delivering results on hydrogen to input systematically the data base, as is already the case for Horizon Europe Cluster 5 "Climate, Energy and Mobility". A further step will see, under the ERA pilot on hydrogen, national research projects to also report to the TRUST database, so that the observatory would gather all EU wide R&I relevant data.

Education and training at all levels to develop a broad skills basis on new hydrogen technologies, as well as curricula on hydrogen in the academia, will be more and more needed and even critical to help the EU industry benefitting from the European R&I on hydrogen and maintain or increase its competitiveness. A European Area on skills for hydrogen technology may be developed within both the ERA pilot on Green Hydrogen and the Pact for Skills[41] and the Erasmus blueprint alliances,[42][43] considering synergies with the European Education Area[44].

In order to support the further development of regulatory measures and international standards, the Clean Hydrogen Joint Undertaking will continue work on **pre-normative research** and will provide support to translate the results into **standards**. The FCH JU already developed a substantial basis for standardisation, supported by Commission services and the "Regulations, Codes and Standards Strategy Coordination group[45] of the Joint Undertaking stakeholders, assisted by the European Commission's Joint Research Centre JRC. Work is performed at international level too, especially by the International Partnership

[37] FAIR data are data that are curated to satisfy the principles of Findability, Accessibility, Interoperability, and Reusability (FAIR principles: www.nature.com/articles/sdata201618).
[38] https://www.fch.europa.eu/projects/knowledge-management
[39] https://www.fchobservatory.eu/
[40] The model of EUON (European Observatory for Nanomaterials can be used for developing this, see https://echa.europa.eu.
[41] https://ec.europa.eu/social/main.jsp?catId=1517&langId=e
[42] https://erasmus-plus.ec.europa.eu/programme-guide/part-b/key-action-2/alliances-innovation
[43] Private stakeholders of the CHJU are already applying to the Pact for placing hydrogen as a specific domain of interest instead covering it through various other ones, to match the new place of hydrogen in the EU energy and industrial policy.
[44] https://ec.europa.eu/education/education-in-the-eu/european-education-area
[45] https://www.fch.europa.eu/page/rcs-strategy-coordination-group

for Hydrogen and Fuel Cells in the Economy IPHE[46], led by the Member States and with participation of third countries and the European Commission.

Pre-normative research activities and research facilities associated with this dimension are also present in the Commission (JRC), e.g. infrastructure for testing fuel cells, electrolysers and hydrogen tanks.

Further activities to support R&I activities on hydrogen are included in the Recovery and Resilience Facility RFF[47] and the Technical Support Instrument (TSI)[48].

5. RENEWED FOCUS ON SYNERGIES

An important element supporting the implementation of the European hydrogen strategy is the reinforcement of synergies among European funding instruments and actions to close the innovation gap in Europe. Synergies are needed to pull together resources, align priorities and ultimately maximise the impact of clean hydrogen R&I investments.

The Single Basic Act establishing the Horizon Europe Joint Undertakings underlines that it is essential that the Clean Hydrogen Joint Undertaking establishes structured collaboration with many other **European partnerships**, notably for end-use.[49] The Clean Hydrogen Joint Undertaking should interact in particular with the European partnerships[50] on zero emission road transport (European Partnership – Towards zero-emission road transport (2ZERO)), on waterborne transport (European Partnership on zero-emission waterborne transport), on railway (European Partnership for transforming Europe's rail system), clean aviation (European Partnership for Clean Aviation), processes for the planet (Processes4Planet – Transforming the European Process Industry for a sustainable society), clean steel (European Partnership for Clean Steel - Low Carbon Steelmaking) and clean energy (European Partnership for Clean Energy Transition).

[46] International Partnership for Hydrogen and Fuel Cells in the Economy (www.iphe.net)

[47] RRP status December 2021; https://ec.europa.eu/info/business-economy-euro/recovery-coronavirus/recovery-and-resilience-facility_en . The Recovery and Resilience Facility, set up to help the EU emerge and stronger from the current crisis, also foresees hydrogen related measures which are included in at least 15 Recovery and Resilience Plans RRPs , for a total amount of EUR 9.3 billion. Measures included in the RRPs mostly focus on the research and innovation stages, illustrating the emergent nature of hydrogen, with projects ranging from demonstration projects to first industrial development.

[48] Regulation (EU) 2021/240 of the European Parliament and of the Council, of 10 February 2021, establishing a Technical Support Instrument. The Technical Support Instrument (TSI) is the EU programme that provides tailor-made technical expertise to the EU Member States to design and implement reforms, including those promoting the role of R&I investments in accelerating the green energy transition through hydrogen. The technical support, for example, involves strengthening of administrative capacity, harmonising the legislative framework, and sharing of relevant best practises.

[49] The Clean Hydrogen Joint Undertaking would be the only partnership focused on addressing hydrogen production technologies. Collaboration with end-use partnerships should in particular focus on demonstrating the technology and co-defining specifications. Recital 58 of the Single Basic Act.

[50] Recital 58 of the Single Basic Act.

An informal Clean Planet Inter-partnership Assembly has been established by the Commission services to support, among other tasks, this cooperation and coordination.[51]

Synergies may lead to operational agreements (that could be for example the conclusion of Memoranda of Understanding[52]), consecutive calls, coordinated calls, joint calls or topping up calls by different European partnerships of Horizon Europe. The Joint Undertakings may also apply to Horizon Europe provisions enabling different types of synergies, such as alternative, cumulative or combined funding and transfer of resources.[53]

Synergies with the **Clean Hydrogen Alliance** will be fostered through a portfolio of EU-funded R&I hydrogen 'champion' projects ready for further deployment (i.e. around TRL 8) suggested by the FCH JU[54] to the Alliance's round tables. Vice versa, the Alliance will provide specific feedback on identified technological barriers and/or risks as well as specific R&I needs, which can be considered in the preparations of the Clean Hydrogen Joint Undertaking Annual Work Programme for 2023/2024.

Companies participating into a potential, forthcoming integrated Important Project of Common European Interest (**IPCEI**), could build[55] on the results of research and innovation projects previously funded through EU R&I Programmes, in particular the Fuel Cell and Hydrogen partnerships when relevant, provided that the ambitious specific research and innovation criteria for participation in an IPCEI would be met and recalling that the applicable state aid rules would not allow support for mass production or commercial activities.

Clean hydrogen represents already a solution for switching to a clean energy in many cities in the EU at all scale (small, medium, large), whether for a specific use (public transportation for instance) or for the choice of cross-sector energy supply (e.g. for industry and for power production). The contribution of clean hydrogen to reaching the objective of at least 100 climate-neutral cities by 2030 of the Horizon Europe **Mission on Climate-neutral and Smart Cities** could be further developed.

In line with Annex IV of Horizon Europe Regulation[56], "Synergies with other Programmes", the Commission services will optimise **synergies between EU R&I activities and other European programmes,** such as the regional programmes (e.g. channelled through the 5 European structural and investment funds, the ESIFs), the ETS Innovation Fund, the

[51] While the task to report to the Governing Board of the Clean Hydrogen Joint Undertaking on the desired synergies between the JU and different hydrogen end-user European partnerships is explicitly mentioned in the Single Basic Act, it is relevant to build on the activities of the Clean Planet Inter-Partnerships Assembly to further widen the reach out to other EU Funds relevant to clean hydrogen deployment. Given the responsibilities attributed to the different bodies of the JU concerning synergies between European Partnerships, and in particular to the Governing Board and the Executive Director, a Sherpa Steering Committee on Synergies regarding clean hydrogen matters is foreseen to be created in order to realise the necessary links between the Inter-Partnership Assembly, as well as other EU Funds, and the Governing Board.

[52] The Clean Hydrogen Joint Undertaking is exploring an agreement with the Zero Emission Waterborne Transport co-programmed partnership.

[53] Recital 14 of the Single Basic Act.

[54] Precisely the FCH JU 2

[55] Without obligation

[56] Regulation (EU) 2021/695 of the European Parliament and of the Council of 28 April 2021 establishing Horizon Europe – the Framework Programme for Research and Innovation, laying down its rules for participation and dissemination, and repealing Regulations (EU) No 1290/2013 and (EU) No 1291/2013, OJ L170, 12.05.2021, p.1.

financing programmes of the EIB, InvestEU and Connecting Europe Facility (CEF). Regarding hydrogen, these programmes are particularly relevant. Calls under the **ETS Innovation Fund** will invite for large-scale demonstration projects of hydrogen solutions and should as much as relevant attract and build on previous EU R&I funded projects in order to maximise the impact of EU R&I support and bridge the valley of death in the innovation process. CEF focuses on building modern EU infrastructure (transport, energy and telecom), deploying innovative solutions on a large scale. Infrastructures represent a specific challenge as a hydrogen economy will have to rely upon a consistent and harmonised network for storage, transport and distribution of hydrogen. Seeing the time for return on investment in infrastructure, it is critical to already foresee the maximum level of interoperability.

To accelerate market uptake and scaling up of hydrogen solutions across the hydrogen value chain[57], the cooperation between the European Commission, the European Investment Bank EIB and the Breakthrough Energy Catalyst fund of Bill Gates may serve as a testbed for creating synergies with international programmes. The "Catalyst Programme"[58] is a pioneering partnership and will start by funding projects across four technologies, among which 'green hydrogen'[59]. EU funding for the partnership will come from Horizon Europe and the Innovation Fund within the framework of InvestEU.

The European Green Hydrogen Acceleration Centre (EGHAC), operated by **EIT InnoEnergy** and supported by Breakthrough Energy, focuses on accelerating industrial projects in hard-to-abate sectors such as steel production. By accelerating innovative companies developing low carbon solutions, InnoEnergy is well-placed to build on results from the FCH JU[60] and the European Partnerships on Clean Hydrogen and Clean Steel - Low Carbon Steelmaking, and scale them towards the market.

The Commission services supported by the Clean Hydrogen Joint Undertaking will actively promote and support additional activities to ensure implementing **the ERA Pilot on green hydrogen**[61], in particular by:

- Developing a common knowledge and data sharing area for hydrogen technologies, market statistics, socio-economic indicators, policy, regulations and financial support;
- Mapping of industry's needs for skills and for re-skilling and upskilling linked to new hydrogen technologies;
- Developing technology infrastructures, helping EU enterprises and especially SMEs to accede quickly to market with promising hydrogen technologies;
- Ensuring consistency in implementation of the Strategic Research and Innovation Agenda of the ERA pilot and the Strategic Research and Innovation Agenda of the Clean Hydrogen Joint Undertaking to ensure that they reinforce each other and can jointly address potential R&I gaps.

[57] A study - commissioned by Commission services - on the mapping of the investor landscape relevant to different types of hydrogen, including a consultation among selected investors is underway. The study will be important to understand investor appetite across the hydrogen value chain and identify regulatory barriers perceived by investors.
[58] https://ec.europa.eu/commission/presscorner/detail/en/ip_21_5586
[59] 'Green hydrogen' term used in the Catalyst fund.
[60] Precisely the FCH JU 2
[61] See Article 78 (2) of the Single Basic Act.

The FCH JU have been supporting the development of **hydrogen valleys** through specific support in their work programmes, project development assistance as well as the establishment of a Hydrogen Valley Platform under the Mission Innovation Challenge 8 initiave, which facilitates exchange of best practices and performs project matchmaking services. The Clean Hydrogen Joint Undertaking will continue to support the development of Hydrogen Valleys for either standalone or isolated regions with a high potential in renewable energy and a currently low interest in hydrogen, or for cross-border Hydrogen Valleys. The European Regional Development Fund (ERDF) has established a European Hydrogen Valleys Partnership, an interregional smart specialisation 3SP Thematic Platform on Hydrogen Valleys, and recently launched interregional partnerships on Hydrogen technologies for carbon-intensive regions. The new Interregional Innovation Investment Instrument (I3) will support partnerships that focus on green transition, including climate neutrality, resource efficiency and circular economy, among other topics. Pilot actions supported previously, including one on hydrogen technologies in carbon-intensive regions, could explore new opportunities provided by the I3 instrument, to continue supporting the development of innovative value chains.[62] In order to accelerate the expansion and connection of hydrogen valleys across the EU, these activities should be further connected and reinforcing each other.

The European **Strategic Energy Technology Plan (SET Plan)** is a key stepping-stone to boost the transition towards a climate neutral energy system through the development of low-carbon technologies in a fast and cost-competitive way. The research pillar of the SET-Plan (the European Energy Research Alliance EERA) operates 18 joint research programmes, including one on Fuel Cells and Hydrogen. The SET Plan is supported by the Horizon Europe co-funded (EU and Member States / Associated Countries) **European Partnership for Clean Energy Transition.** This partnership will boost and accelerate energy transition in all its dimensions and includes system-related aspects of clean hydrogen. The European Green Deal and the European hydrogen strategy offer an opportunity to revamp the SET plan and align its activities with the new policy priorities.

6. GLOBAL R&I ACTIVITIES

The climate crisis is a global challenge requiring a global solution. Further deepening of international collaboration on hydrogen is necessary for accelerating the global green transition. It is also relevant to strengthen the efforts to produce and enable import of clean hydrogen in Europe. This is why the Commission prioritises international R&I cooperation on hydrogen through multilateral initiatives such as Mission Innovation in making clean hydrogen cost competitive with other energy vectors in different industries across production, transportation, storage and end-use. The Commission is focussing in particular for multi-lateral cooperation on industrial countries and emerging economies and on countries in the EU's immediate vicinity as well as Africa and Latin America.[63] Also Eastern countries have a

[62] More generally, additional regional activities in the area of hydrogen are developed by the Committee of the Regions, or through ERRIN, the European Regions Research and Innovation Network, and through the "RIS3 Platform" that assists EU countries and regions to develop, implement and review their Research and Innovation Strategies for Smart Specialisation, as e.g. for the European Hydrogen Valleys partnership.
[63] EU strategy on hydrogen COM(2021) 252 final

high potential for collaboration with the EU and are often already connected to the EU energy systems, being located rather close to the EU.[64]

The **Mission Innovation (MI) Clean Hydrogen Mission** launched in June 2021 at the Mission Innovation Conference, is co-led by the Commission, the United States of America, the United Kingdom, Australia and Chile. It aims at accelerating the building of a global clean hydrogen economy by reducing end-to-end clean hydrogen costs to about EUR 1,8[65] per kg by 2030.

To achieve the goal, Mission members commit to delivering at least a combined 100 large-scale integrated clean Hydrogen Valleys by 2030. These will generate economies of scale, pushing down clean hydrogen costs to catalyse the development of a global clean hydrogen economy. The delivery of different production, storage and transport methods and end-use applications through cohorts of hydrogen valleys with the aim of reaching critical levels of investment and experience will generate cheaper and more efficient supply chains. The Commission will stimulate this by continuous support and knowledge sharing via the hydrogen valley platform. The MI Clean Hydrogen Mission will also stimulate an enabling environment, recognising the importance of other hydrogen related initiatives and the critical role that regulation and international standards play in accelerating and supporting a global clean hydrogen economy.

In order to create such enabling environment at a global level, the Commission, supported by the FCH JU (which will continue in the Clean Hydrogen Joint Undertaking) participates in the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), and in the Clean Energy Ministerial Hydrogen initiative (CEM H2)[66]. Furthermore, synergies with other intergovernmental organisations are possible, as with **EUREKA**[67].

To strengthen EU's **cooperation with other regions, especially within the EU / African Union partnership and with Neighbour countries,** technical assistance through specific EC programmes[68] may be provided to support the deployment of future hydrogen usage, production and export potentials[69] that could enable partner countries´ green energy transition and socio-economic development. Moreover, in particular some regions of Africa could be ideal candidates[7071] for funding demonstration projects, showcasing directly the value of the

[64] Specifically the Ukraine is involved in one of the flagship initiatives of the European Innovation Partnerships EIP (Flagship 5), which has as core task increasing energy efficiency support for renewable hydrogen, together with its European partners.
[65] Corresponding to US$ 2 per kg (December 2021)
[66] See in particular Articles 74 of the Single Basic Act.
[67] https://www.eurekanetwork.org/
[68] Programmes on technical assistance exist e.g. in the EC department for international partnerships DG INTPA, (e.g. the Global Climate Change Alliance GCCA+ Support Facility), and in the Directorate General for Neighbourhood and Enlargement DG NEAR, (e.g. TAIEX Technical Assistance and Information Exchange).
[69] Export of renewable hydrogen to the EU should obtain "green certification", including for the whole transport scheme from production to final use, to avoid green washing.
[70] Joint Communication To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions; Renewed partnership with the Southern Neighborhood, A new Agenda for the Mediterranean, (JOIN (2021) 2 final). The EC-EEAS Joint Communication "Renewed partnership with the Southern Neighbourhood" has identified clean hydrogen production as a new strategic priority (see joint_communication_renewed_partnership_southern_neighbourhood.pdf (europa.eu))
[71] See also the EU hydrogen strategy

hydrogen solutions. Collaboration by joint R&I is foreseen to strengthen e.g. the EU-Africa partnership, mainly through an analysis of potential regions for a win-win[72] development of a clean hydrogen economy and through developing the current cooperation on renewable energy for producing clean hydrogen when economically relevant.

The Commission services will also continue to work together with **international energy organisations** active in the area of hydrogen, like the International Renewable Energy Agency (IRENA), the World Energy Council and the IEA (International Energy Agency), and especially with the IEA Hydrogen Technology Collaboration Programme (including the newly created tasks on Renewable Hydrogen production, Underground Hydrogen Storage and Hydrogen Export Value Chains).

7. CONCLUSIONS

The sustained EU support through the EU Research and Innovation Framework Programmes, including through the successive Joint Undertakings, has contributed to making the EU a world leader in hydrogen technologies. The steep increase in domestic electrolyser capacity and the success stories in (among others) fuel cell buses, hydrogen refuelling stations and hydrogen valleys bear witness to the strength of this targeted and coordinated EU approach.

The European hydrogen strategy lends vigour and urgency to accelerating the pace of innovation and to delivering a European Research Area for clean hydrogen. Synergies between the Clean Hydrogen Joint Undertaking under Horizon Europe, the European Hydrogen Alliance and other relevant partnerships and programmes will create the innovation ecosystem to scale up hydrogen supply and demand. Concerted action of the Commission and Member States in a 'green hydrogen R&I ERA pilot' will drive the implementation of a commonly agreed strategic research agenda and support open innovation, by for example improvement of technology infrastructures such as test beds, by data sharing and by the development of education and skills. Last but not least, the Clean Hydrogen Mission under Mission Innovation, in which the Commission has a leading role, will mobilise international cooperation to create a global hydrogen economy.

All stakeholders are invited to embrace and actively support the ongoing and planned initiatives set out in this Staff Working Document to deliver on the European hydrogen strategy.

[72] Supporting on equal footing both the development of a local hydrogen economy to match the local needs as well as potentially providing for exports to and connection with other hydrogen regions or economies, including the EU.