European Innovation Council

PATHFINDER CHALLENGE

Novel routes to green hydrogen production
CHALLENGE GUIDE – PART I

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Challenge page: https://eic.ec.europa.eu/calls-proposals/eic-pathfinder-challenge-novel-routes-green-hydrogen-production_en

CONTENT

The Appendices that are referred to in this document are common to the different Challenges and bundled in Part II of the Challenge Guide, published on the Challenge page on the EIC Website https://eic.ec.europa.eu/calls-proposals/eic-pathfinder-challenge-novel-routes-green-hydrogen-production_en.

1. About this document

The Challenge Guide is the reference document accompanying a Pathfinder challenge along its whole life cycle, from call to achieving its objectives.

The Programme Manager in charge of this Pathfinder Challenge is the editor of the Challenge Guide. The Challenge Guide captures, at any moment, the state of play, achievements and remaining challenges, and documents the process by which the Programme Manager and Portfolio members jointly establish an evolving set of Portfolio objectives and a shared roadmap for achieving them. The most recent version can be found through the corresponding Challenge page on the EIC Website https://eic.ec.europa.eu/calls-proposals/eic-pathfinder-challenge-novel-routes-green-hydrogen-production_en.

The Challenge Guide starts out as a background document to the initial Pathfinder Challenge call. It details the intention of the call by complementing notably the scope, objectives (see Section 5 - Challenge call text) or criteria (see Appendix 3: EIC 2021 Work Programme – Evaluation criteria) set out in the EIC Work Programme. In no case does it contradict or supplant the Work Programme text. After the call evaluation, the Challenge Guide further documents the initial Challenge Portfolio that resulted from the call.

As the actions in the Portfolio unfold, the Challenge Guide further documents the evolving Portfolio Objective(s) and the progress towards achieving them, notably through the Portfolio Activities that the Programme Manager puts in place.

The Challenge Guide serves as a reference for the common understanding, rules-of-play and obligations for the EIC beneficiaries that are involved in the Challenge Portfolio. Contractual Obligations are further reference material from the EIC Work Programme are collected in Part II of the Pathfinder Challenge Guide, published on the Challenge page on the EIC Website https://eic.ec.europa.eu/calls-proposals/eic-pathfinder-challenge-novel-routes-green-hydrogen-production_en.

2. Overall objective of the Pathfinder Challenge

This section sets out the rationale of the Challenge. Building on the state of the art in the relevant scientific and technological domains, it motivates the challenge, sets the boundaries of its scope and explains the overall objectives. This section should be read as further background to the Challenge specific part of the EIC Work Programme text (see Section 5).
Proposals to this Challenge are expected to explain how they relate to and intend to go beyond the state of the art, and how they interpret and contribute to the objectives of the Challenge.

Novel routes for green hydrogen production

Background – Scope - State of the Art

The Green Deal sets ambitious goals for the EU climate neutrality by 2050, through the deep decarbonisation of all the sectors of the economy, and specific greenhouse gas emission reductions targets by 2030[1]. Today's energy system is mainly built on vertically integrated energy value chains, which rigidly connect energy resources and end-users, not properly capturing the broader opportunities from cross sectorial coupling and systems integration. The transition towards a safe, affordable, resilient and decarbonised EU energy system requires an integrated and systemic approach for the coordinated planning and operation of multiple energy carriers, infrastructures and demand sectors, as well as a stronger integration with the circularity of EU economy.

The future energy system will rely on an increased share of distributed renewable energy technologies, integrating different green energy carriers, minimizing resources deployment, promoting carbon recycling and avoiding pollution and biodiversity loss[2].

Hydrogen (H2) has the potential to contribute to the above-mentioned objectives of clean and secure energy systems[2], being an energy carrier that can facilitate the penetration of an higher share of intermittent renewable energy, the decarbonisation of hard-to-abate industrial sectors (e.g. industrial processes which require high-grade heating or rely on hydrogen as a feedstock) and the cross-sectorial coupling (linking power, gas and other energy vectors or energy intensive commodities and replacing them in their respective usages).

Currently H2 is largely produced from fossil fuels, commonly referred to as grey (fossil-based H2), or blue (fossil-based with carbon capture and storage). However, efforts are being made to produce H2 using technologies with the full life-cycle greenhouse gas emissions close to zero (hereafter green H2) such as with the electricity stemming from renewable sources, or direct conversion of renewable heat (solar, geothermal) or biomass and biowastes

[1] COM(2019) 640 final

[2] COM(2020) 299 final, Strategy for energy system integration

processing. The baseline technology for green H2 production is the water-electrolysis, where the main challenges are the cost reduction and the use of non-critical raw materials (CRM)[3]. Green H2 can be used to store surplus renewable electricity when the grid cannot absorb it, help to decarbonise hard-to-abate sectors such as heavy-duty or long-distance transport and heavy industry (e.g. steel, cement, chemical), and contribute to the replacement of fossil-based materials via combined production of chemical feedstock, fertilizers for agriculture and synthetic fuels.

In July 2020, the EC adopted the Strategy for Energy System Integration and the Hydrogen Strategy[45]. Together, they aim to address a vision on how to accelerate the transition towards a more integrated and clean energy system, in support of a climate-neutral economy. The Energy System Integration strategy addresses the planning and operation of the energy system 'as a whole', across multiple energy carriers, infrastructures, and consumption sectors. It sets out several actions to implement the necessary reforms, including the promotion of renewable and low-carbon fuels, such as hydrogen, for sectors that are hard to decarbonise.

The Hydrogen Strategy aims at creating an enabling environment to scale up renewable hydrogen supply and demand for a climate-neutral economy. It also tries to address the issue that the majority of hydrogen production today is fossil-based, as low-carbon hydrogen has yet to become cost competitive. To achieve this, the Strategy outlines a number of key actions and presents three strategic phases in the timeline up to 2050.

Building on the EC's new Industrial Strategy for Europe[6] and the Recovery Plan for Europe[7], the Strategy sets out a vision of how the EU can turn hydrogen into a viable solution to decarbonise different sectors over time. Most notably, it sets the ambitious goal of at least 6 GW of renewable hydrogen electrolysers in the EU by 2024 and 40 GW of renewable hydrogen electrolysers by 2030. In addition, EU climate-neutral strategic vision[8] sets an increasing share of H2 in Europe's energy mix from current 2% to 13-14% by 2050[9].

To reach these targets it is crucial to develop **new biological, chemical, and physical routes** for green H2 production, and massive public investment in R&D together with increased efforts to direct private capital will be required, avoiding the adoption of unsustainable practices. All stakeholders, both public and private, should work together, across the entire green H2 value chain, to foster sustainable growth and jobs creation[10].

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3 https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

4 COM(2020)301, a hydrogen strategy for climate neutral Europe

5 COM (2020) 299, Powering a climate-neutral economy: An EU strategy for Energy System Integration

6 COM (2020) 102, New Industrial Strategy for Europe

7 COM(2020) 456, Europe's moment: Repair and Prepare for the Next Generation

8 COM(2018) 773, A Clean Planet for all: A European strategic long-term vision for a prosperous, modern ,competitive and climate neutral economy

9 Moya et al., 2019, JRC116452

10 https://ec.europa.eu/growth/industry/policy/european-clean-hydrogen-alliance_en

To achieve such sustainability goals, a particular support should be given to solutions aimed at increasing lifetime, reliability and flexibility and at decreasing the cost and environmental impact of the green H2 pathways over the whole supply chain, and including green H2 generation solutions without the use of electricity, such as with renewable steam reforming, direct solar energy conversion to hydrogen or advanced biological/thermo chemical biomass processing.

In addition, the European Environmental Agency is fostering research towards a "circular economy" with effective waste and carbon recycling strategies as a core task. The end of life commodities should be reused, recycled and resourced for a better life-cycle design[11].

It is therefore of paramount importance to develop breakthrough novel processes and technologies – chemical, biological, physical - to produce green H2, at different scales (from small to large) capturing cross sectorial coupling and system integration opportunities, entirely based on renewable sources and avoiding or limiting the use of toxic and critical raw materials, with a circular and life cycle thinking approach.

In the following, some examples of processes and technologies for green hydrogen production are reported, without being exhaustive as other breakthrough technologies for green hydrogen generation with a focus on circularity, systems integration and/or avoiding or minimizing the use of critical raw materials (CRM) could be in scope with this call.

In the field of electrochemical reforming for H2 production via electrolysis, filling the anode tank with an aqueous solution of organic materials (**biomass electrolysis**) is a promising option for low overpotentials oxidation[12]. This process could reduce the energy requirements of ambient temperature water oxidation, while the energy saving obtained using such compounds is paid for by the chemical energy contained in the compound itself. Renewable alcohols, which contain the energy derived from photosynthetic processes, are in this case the most promising candidates[13]. In addition, other widely available biomass such as agricultural wastes, forest residues, wastewaters or organic fraction of municipal wastes could be used as feedstock in electrolyser to produce green H2, with preliminary upgrade processes. As an example, urea electrolysis has applications to enable H2 production from the urea-rich wastewater[14] as well as on-demand fuel production for portable applications[15]. Also, black liquor has been shown to be a suitable feed solution for electrolytic H2 production[16], and lignin oxidation and depolymerisation products could also add value to the

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[11] J. B. Zimmerman, P. T. Anastas, H. C. Erythropel, W. Leitner, Science, 80, 2020, 367, 397

[12] H.A. Miller, A. Lavacchi, F. Vizza, Storage of renewable energy in fuels and chemicals through electrochemical reforming of bioalcohols, Current Opinion in Electrochemistry, Volume 21, 2020,140-145, https://doi.org/10.1016/j.coelec.2020.02.001

[13] Y. Chen, A. Lavacchi, H. Miller, H.et al., Nanotechnology makes biomass electrolysis more energy efficient than water electrolysis. Nat Commun 5, 4036 (2014). https://doi.org/10.1038/ncomms5036

[14] D. Wang, S. Liu, Q. Gan, J. Tian, et al., J. Electroanal. Chem. 2018, 829, 81

[15] R. L. King, G. G. Botte, J. Power Sources 2011, 196, 9579

[16] H. R. Ghatak, S. Kumar, P. P. Kundu, Int. J. Hydrogen Energy 2008, 33, 2904

production stream[17]. The possibility of using waste biomass raw materials, such as food residue or sawdust for H2 production in an electrolysis cell has been also explored[18].

The development of biomass electrolysis faces a number of challenges, such as (i) the development of electrocatalysts to reduce the activation energy, so affecting both the energy consumption for H2 production and the selectivity towards valuable chemicals, (ii) the fundamental understanding of the main electrocatalytic and interfacial processes for different reactants, to obtain stable process and manipulate the selectivity towards desired products, (iii) the scale up and systems integration of such technologies. Other key research issues, which can be addressed in the proposals, are the sustainability, energy balances and life cycle analysis of the conversion process, the whole energy system benefits from the temporal and spatial decoupling of the biomass supply, upgrade and H2 production, and the potential use of the products of oxidation as biodegradable polymers or green chemicals. Integrated solutions such as direct coupling of a biomass electrolyzer and a H2 fuel cell for self-powered electrolytic processes could be addressed, in order to reduce the system cost[19].

Producing H2 directly from water and sunlight via **photocatalysis**, including green H2 production derived from biomass sources, holds great promise. In this case, key aspects are the requirements on the semiconducting photocatalyst, which should both absorb the maximum amount of the solar spectrum to generate photoexcited electron-hole pairs and also efficiently transfer these electrons and holes to the semiconductor-electrolyte solution junction to drive the reduction and oxidation processes. In this context, proposals should pay particular attention to the use of renewable photocatalysis for biomass photo reforming.

The state of art H2 generation technology from renewable energy is nowadays the **water ectrolysis** with renewable electricity. In both water electrolysis, biomass electrolysis, photocatalysis, the processes highly rely on the deployment of **critical raw materials (CRM)** and this also determinates vulnerabilities along the supply chain[20]. Extensive use of CRM (Pt, Ir) in the catalyst and coatings and Ti as base material for manufacturing the stack components for lower temperature PEM electrolysis could hinder its market penetration. Similar considerations can be made for the use of rare earth elements and cobalt in high temperature solid oxide electrolysis. Routes for recycling the CRMs are not a convincing solution considering the fast-increasing demand for electrolysers. Large use of green H_2 produced through electrolysis can be provided through breakthrough innovation able to reduce systems costs, strongly impacted by raw materials cost, while improving its performance and reliability. To reach such objectives while facilitating the uptake of the circular economy concept during the whole life cycle of electrolysers, it is necessary to avoid the use of the CRM for the different components of the electrolysers, such as

[17] H. Oh, Y. Choi, C. Shin, T. V. T. Nguyen, et al., ACS Catal. 2020, 10, 2060
[18] T. Hibino, K. Kobayashi, M. Ito, Q. Ma, et al., ACS Sustain. Chem. Eng. 2018, 6, 9360
[19] Y. Li, W. Liu, Z. Zhang, X. Du, et al., Commun. Chem. 2019, 2, 67

electrocatalysts, membrane-electrode assemblies (MEAs), diffusion layer, stacks etc., and proposals addressing such topics, also using computational materials design, are well aligned with this challenge-based call important. Raw materials are crucial to Europe's economy. Wide access to raw materials is becoming an important aspect. The European Commission has created a list of critical raw materials (CRMs) for the EU, which is regularly updated[21]. This list includes raw materials of relevant interest for the EU economy and characterized by an associated supply chain risk. Specific challenges deal with the fact that using CRMs-free components for advanced electrolysers could reduce the performance and increase the stack size and therefore the cost of other components. This could be compensated by improvement of performance, efficiency and durability for advanced membrane/ solid electrolyte-based CRM-free electrolysis technologies are specifically targeted in this program.

Advanced **thermochemical processes** for biomass upgrade to biocrude and green H2, such as hydrothermal processing or pyrolysis, are other promising alternatives. In this case, key aspects are the valorisation of residual organic products for H2 production, whole life cycle analysis, system integration and combined production of green H2 and other useful co-products from H2 production such as biochar, biofuels and biochemicals, in a circular approach.

Biological processes that convert bio-wastes into green H2 are also of interest for their promising energy conversion rates and whole cycle environmental balances. Proposals could address these processes, and in particular direct and indirect bio-photolysis, photo and dark fermentations, and multi-stage or sequential dark and photo-fermentation. The feeds for bio-H2 is in this case water for photolysis, where H2 is produced by some photosynthetic bacteria or algae directly through their hydrogenase or nitrogenase enzymatic system, or biomass for fermentative processes where the carbohydrate containing materials are converted to organic acids and then to H2 gas by using bio-processing technologies. The engineering of biohybrid systems, where bacteria (photosynthetic or not) are coupled to inorganic components, has the potential to enhance yield and maximize substrate/waste utilization while decreasing the organic carbon load of the waste stream. The possibility to implement biohybrid systems into existing technologies for H2 production or waste treatment should be taken into consideration for this call.

Microbial electrochemical systems combine the catalytic activity of microorganisms with abiotic electrodes. In such systems the biocatalyst (bacterial cell) can be organized in biofilms on the electrode surface, thus exceeding the concentration of bacteria in bioreactor, with the possibility to maximize H2 production[22]. Biofilm engineering and tailoring of materials for artificial immobilization of bacteria in microbial electrochemical systems for H2

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[22] M. Kitching, R. Butler, E. Marsili. Microbial bioelectrosynthesis of hydrogen: Current challenges and scale-up. Enzyme and Microbial Technology, 96, 2017, 1–13

production might be also addressed. Photosynthetic bacteria harvest sunlight through molecular assembly in order to absorb photons to carry out charge separation of water and metabolize carbon dioxide into energy-rich organic compounds (photoautotrophic metabolism), or using organic substrates as photosynthetic electron donors (photoheterotrophic metabolism). Both types present specific advantages, enabling their application in the development of multiple biotechnologies. Specifically, cyanobacterial photochemistry and photo-bio-electrochemistry have been investigated for sustainable power generation systems and photo-bio- electrosynthesis[23]. Purple non-sulfur bacteria present an extremely versatile metabolism, growing both aerobically in the dark by using oxygen as the terminal electron acceptor, and anaerobically in the light by producing hydrogen. Besides utilizing a broad variety of organic acids, under illumination purple bacteria can at the same time degrade organic compounds that are environmental pollutants, such as benzoic acid, nitrophenols, and halogenated aromatics[24], making their application in biohybrid and bio-electrochemical systems for H2 production a sustainable alternative to classical inorganic catalysis.

Synthetic biology offers further opportunities to introduce heterologous electron transfer pathways and to engineer the metabolism of yeasts and bacteria so that they can transform cellulose/glucose contents of biomass into H2 or introduce extracellular electron transfer pathways[25,26]. Current technologies face cost-effective conversion and upgrading challenges (e.g. new designs of bioreactors for bacteria-cells growth), while specialised synthetic cells may allow the optimization of their metabolic pathways and significant improvement of production yields.The green H2 produced from innovative biomass based processes in comparison to more developed water electrolysis makes it very attractive for **industrial symbiosis**, towards decarbonisation of high energy intensive industrial sectors such as cement and steel production, where hydrogen, carbon and/or high temperature heat are required at the same time, and one could also look at **the broader process system integration opportunities** to maximize the benefits in the most critical industrial sectors and contribute to the production of decarbonised materials in a circular approach.

Another example is hydrogen generation from steam reforming processes if the steam is produced from renewable energy such as solar, geothermal or biomass and renewable organic substrates. In this case, a specific focus should be given to system integration opportunities and whole value chain, making clear how the use of renewable energy sources is integrated to the green H2 generation.

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[23] H. Chen, O. Simoska, K. Lim, M. Grattieri, M. Yuan, F. Dong, Y.S. Lee, K. Beaver, S.Weliwatte, E.M. Gaffney, and Shelley D. Minteer. Fundamentals, Applications, and Future Directions of Bioelectrocatalysis. Chemical Review, 2020, 120, 12903-12993

[24] C. Sasikala and C. V. Ramana, Biodegradation and Metabolism of Unusual Carbon Compounds by Anoxygenic Phototrophic Bacteria, in Adv. Microb. Physiol, ed. R. K. Poole, Academic Press, Great Britain, 1997, 39, 339–377

[25] L. Su and C. M Ajo-Franklin. Reaching full potential: bioelectrochemical systems for storing renewable energy in chemical bonds. Current Opinion in Biotechnology, 2019, 57, 66-72

[26] N. Schuergers, C. Werlang, C. M. Ajo-Franklin, A. A. Boghossian. A synthetic biology approach to engineering living photovoltaics. Energy & Environ. Sci. 2017, 10, 1102

Green H2 generation can be addressed both centralised and/or on-demand (i.e. at the premises of the end users and for onsite consumption), and ideas, approaches and knowledge could be adopted from disciplines that are typically not in this kind of research. Highly multidisciplinary and cross-sectorial approaches addressing the previously mentioned environmental, system integration and logistic issues are particularly important.

For the purpose of technology monitoring and progress against the state-of-art and helping to indicate project contributions towards the targets of the European Commission's Green Deal as well as identifying further support needed via other fundraising mechanisms, all actions related to hydrogen and fuel cells funded under this work programme shall report directly or indirectly on an annual basis in a secure online data collection platform managed by the Clean Hydrogen Joint Undertaking and the European Commission during the course of Horizon Europe. The reporting shall consist of filling in the template questionnaire(s) relevant to the project content (and the technology development and TRL).

Objective of the Call

The proposals should target breakthrough novel processes and technologies – chemical, biological, physical - to produce green H2, at different scales (both small and large). The processes or technologies should be based entirely on renewable sources and should:

1) adopt a circular and life cycle thinking approach possibly including the use of bio-wastes and the co-production of green chemicals, fertilizers and/or decarbonised materials, and avoiding or minimizing the use of toxic and critical raw materials.
2) capture cross sectorial coupling and system integration opportunities (i.e. energy systems, industrial symbiosis contributing to net-zero industrial districts, bio-wastes supply chains);

The expected outcome of the call is a green H2 production technology proof of concept.

An efficient deployment strategy should operate at scale, hence scaling up of green H2 production in an economically efficient way is particularly important. In this perspective, a strategy is to focus large-scale hydrogen production on industrial decarbonisation, and in this case, H2 has a strong role to play as fuel and industrial feedstock, also if combined with the production of decarbonised chemicals. Industrial processes tend to sit in clusters where several users of H2 are adjacent. So large-scale production for multiple users, including secondary applications such as supporting transport hubs (e.g. trucks, and local authority buses or vehicle fleets) and/or feeding into the local gas distribution network are economically sustainable. In parallel with this, a complementary strategy is to focus on green H2 produced at small scale and in distributed fashion, which can be used for fleet transport or for decentralized heat and power generation in tertiary and residential sector, so establishing a complete value chain where minimizing transport costs (generation, storage, small transport and end use). Both these strategies, as well as the production of green H2 as seasonal storage for large renewable energy power plants, could be pursued and the scope of the portfolio of projects arising from this challenge is to address them in a synergic and integrated fashion.

Proposals should indicate their positioning within the whole value chain, highlighting the potential collaborations with key actors during the project implementation. Proposals should also mention their deployment strategy and the steps required to scale up the process. There should be a clear description of the value proposition and a preliminary risk analysis to secure the probability of achieving each deliverable in the estimated time frame and within the allocated funding. Proposals should be flexible in modifying project targets and key directions, if needed, explaining how the DBTL (design-build-test-learn) cycle[27] will be applied. Proposals should also address, if relevant, process or technology certification issues (safety conditions).

3. Proactive portfolio management

This section describes the EIC proactive management applied to the Pathfinder Challenge, based on the definition of its objective and roadmap. The beneficiaries are expected to collaborate to achieve the Portfolio's objectives under the guidance of the PM. To this end, the PM will work cooperatively with the beneficiaries to define the governance structure of the Portfolio, to establish expectations from the projects collaboration, to define rules for resource and data sharing within the Portfolio in accordance to Annex 7 of the EIC 2021 WP, and to identify the exploitation, communication and dissemination strategies for the Portfolio. All these elements will be defined at the Portfolio kick-off meeting and in the Portfolio Implementation Plan, which will be an ongoing document accordingly updated with the project development. The projects are expected to have the following common activities and associated deliverables:

- Portfolio kick-off and progress meetings;
- Portfolio web page with link to all the projects;
- Portfolio Implementation Plan;
- Portfolio annual meetings and its report one month after the annual meeting.

The projects are expected to include a sub-task specific for portfolio objectives and activities and to allocate a budget for these activities.

a. Allocation of the actions into the portfolio

This section provides the Challenge specific elements of the way in which the evaluation results in a coherent Challenge Portfolio. It should be read in conjunction with the overall evaluation process as described in the EIC Work Programme text (Appendix 3). This section provides guidance to proposers on how to align their proposal with the architecture of the Challenge Portfolio as envisaged by the Programme Manager.

[27] Deep Tech: The Great Wave of Innovation, Boston Consulting Group, 2021

The European Commission, Member States and Regional government are funding many research activities in the field of the H2 value chain (JTI-FCH, DG RTD, DG ENER, etc..), including in particular green H2, and also EIC has defined a thematic portfolio on hydrogen technologies, including already funded projects.

This EIC green H2 production pathfinder call and the associated Portfolio have the objective to position Europe strategically at the forefront of the sustainable technologies for energy decarbonisation and net zero industrial districts development through hydrogen-based solutions. EIC green H2 thematic portfolio activities will stimulate the collaboration of the funded projects as well as the networking with the innovation ecosystem to enhance the development of the EU technological sovereignty in this field. The call aims to fund a portfolio of breakthrough and complementary researches on advanced production of hydrogen without the use of fossil fuels or critical raw materials and enhancing whole system integration and circularity approaches, clearly reporting how the proposed research will be positioned within the whole hydrogen value chain. In the second evaluation step, the evaluation committee, chaired by the Programme Manager, builds a consistent portfolio of projects to achieve strategic common objectives, with specific actions.

In order to do so, the evaluation committee will allocate proposals into categories. These categories define the overall architecture of the targeted portfolio.

The evaluation committee will look at complementarities among proposals in the following categories:

Process or technology proposed: the evaluation committee will seek to facilitate a wide range of breakthrough renewable generation technologies, from electrolysers to thermochemical or from biological processes to photocatalytic technologies.

System integration of proposed technologies and processes: will seek to cover all aspects of system integration, value chain and cross-sectorial opportunities, also considering the adoption of high fidelity spatial/temporal optimization tools and industrial symbiosis opportunities (i.e. in steel, glass, cement, fertilizers). For instance integration could also be achieved in agriculture (i.e. use of biomass and biochar), water supply chain (i.e. salt water or wastewater valorization), transport (heavy duty / long distance transport) or in renewable energy supply streams (solar, geothermal, wind, biomass).

Circular and life cycle approach including the use of non-critical raw materials, and valorisation of materials and energy streams: the evaluation committee will seek for projects that avoid or minimize the use of critical raw materials and propose a circular approach (life cycle thinking) and a full life cycle analysis, including input and output resources and energy streams as well as using, if needed, computational materials design.

The PM will ensure that the evaluation committee will examine the projects along these considerations in order to ensure that the final set of funded proposals covers the objectives of the call without major gaps.

The contractual obligations subsequent to the participation of an action into a Challenge portfolio are described in Appendix 1.

b. Portfolio objectives and roadmap

This section documents the approved objectives and roadmap of the Pathfinder Challenge.
Depending on the level of granularity of the scientific and technological domain, the Programme Manager may detail at the time of the call an indicative roadmap and milestones to reach the overall objective of the challenge portfolio. When a roadmap and/or milestone are set in the challenge guide prior to selection, please keep in mind that their purpose is only to give a potential overview for the applicants. They are in no case definitive. Roadmap and milestones will be updated following close discussion with selected beneficiaries.
The objectives and roadmap are revised on a regular basis, as part of the portfolio implementation plan, based on various elements during the execution of the challenge: e.g. projects' achievements, new technology trends, external inputs (other projects, new calls…), and discussion with stakeholders/community.

After the allocation of the actions in the Challenge portfolios, and based on these, the Challenge portfolio objectives will be defined in more detail. The EIC Programme Manager will propose to the granting authority the Challenge Portfolio's objectives and roadmap, building on:

- the overall objective set out in the relevant call text (see Section 5 – Challenge call text),
- this Guide (see Section 2: Overall objective of the Pathfinder Challenge),
- other actions selected in consultation with beneficiaries, other interested members of the EIC Community and other third parties.

For this specific Challenge, the initial Portfolio objectives are the following:

- <u>Portfolio position statement</u> on challenges and opportunities in the field of green H2 production technologies. This EIC green H2 production pathfinder call and the associated Portfolio have the objective to position Europe strategically at the forefront of the sustainable technologies for energy decarbonisation and net zero industrial districts development through hydrogen-based solutions. EIC green H2 thematic portfolio activities will stimulate the collaboration of the funded projects as well as the networking with the innovation ecosystem to enhance the development of the EU technological autonomy in this field. The portfolio position statement will be further updated on the basis of the material in this Guide and with the expertise gathered in the portfolio.

- Portfolio benchmarking: systematic comparison of processes or technologies forming the portfolio against established benchmarks, allowing comparison inter-portfolio and with current solutions.
- Portfolio demonstration: a yearly joint workshop/event, also part of a high-profile scientific event, comparing the technologies and approaches developed.
- Portfolio proof of concept: the proposals should develop a proof of concept or lab-scale validated innovative green H2 production technology, which adopts biological, chemical or physical routes without the deployment of fossil fuels. Projects are strongly encouraged to apply the life-cycle thinking including the recovery and recycling of by products and wastes, as well as the use of abundant natural resources. The safe use of non-critical raw materials is mandatory and the projects should include a full life cycle analysis of the proposed solutions and their impact on Europe's decarbonisation goals.

Further targets may be agreed with the beneficiaries.

For this specific Challenge, the roadmap to reach the Portfolio objectives will be co-designed and agreed between the Programme Manager and the participants of the projects in the Portfolio, once it is in place.

c. Portfolio activities and EIC Market Place

With this Call, EIC aims at bringing together leading consortia targeted to the above-mentioned green H2 areas, leading to the creation of a critical mass. Portfolio activities will involve all beneficiaries within the Challenge Portfolio. They are proposed and designed by the EIC Programme Manager in consultation with the beneficiaries, and where appropriate with other interested EIC Community members and other third parties. They aim at developing the cooperation within the EIC Portfolio in order to:

- achieve the Portfolio Objectives or the objectives of the actions,
- enhance research,
- prepare transition to innovation,
- stimulate business opportunities,
- strengthen the EIC Community.

Such activities may cover - notably but not only – organisation and participation to conferences, workshops or any EIC Portfolio or networks meetings, experience and data sharing, as well as participation in any relevant EIC Business Acceleration Services events. The Programme Manager will advise the participants in the orientations of their work, or explore potential synergies with others, including with businesses, corporates, investors, start-ups, other stakeholders on a mutual benefit basis for benefiting from each other's assets and know-how.

To facilitate the exchange of information and data, to enhance cross-fertilization activities, and to stimulate and nurture potential innovation, the EIC Programme Manager may request any beneficiary to make available - through the EIC Market Place - information on preliminary findings and results generated by the action, with the aim to probe their potential for further innovation.

The EIC Market Place will support the proactive management of the portfolio by allowing the Programme Manager to have an overview of the actions, their preliminary findings and potential links between those, thanks to the underlying Artificial Intelligence tool.

EIC aims at building a reputation of delivering high impact innovation intelligence activities to the green H2 projects constituting the respective portfolio. The Programme Manager will accelerate the most promising projects. To accomplish that, the Programme Manager disposes of EIC tools such as, fast tracking a project to Accelerator (EIC WP,“ Proactive project and portfolio management by EIC Programme Managers”) and a EUR 50,000 grant that can be used more than once, to the benefit of a beneficiary (EIC WP, Annex 6). Regarding the latter, the beneficiary must provide to the Programme Manager convincing and fully documented evidence that the project has arrived at a new, rather unexpected outcome that opens new opportunities and, therefore, new or additional studies on market potentials, techno-economic analyses or applications in different segments are needed.

For this specific Challenge, the following Portfolio Activities are being scheduled (will be updated throughout the lifetime of the Portfolio):

Table 1: Portfolio Activities – Novel routes to green hydrogen production

Date	Description	Main outcomes	Reference/report
Tbd	**Portfolio Kick-Off meeting**	**First draft of the Portfolio Roadmap**	

4. List of actions in the Pathfinder Challenge Portfolio

(to be updated after the portfolio selection)

5. Challenge call text

(extract from https://eic.ec.europa.eu/system/files/2021-03/EIC%20Work%20Programme%202021.pdf)

The development of efficient, sustainable and flexible energy systems is a key challenge for Europe's energy decarbonisation and a corner stone of Europe's 2050 climate-neutrality goal, set out in the European Green Deal. To achieve such viable energy system, a particular support should be given to solutions aimed at increasing lifetime and decrease the cost of the overall system. In this context, Hydrogen (H2) has the potential to contribute to the above-mentioned objectives. Currently H2 is largely produced from fossil fuels, commonly referred to as grey H2, or promising but still expensive blue H2 options, combining methane-to-H2 with carbon capture and storage, or renewable H2 pathways (green H2), entirely based on renewable electricity. Referring to green H2 production, the state of art technology is based on water electrolysis, with costs still higher than grey H2 and production processes affected by the use of critical raw materials.

This Pathfinder Challenge aims at developing novel processes and technologies to produce green H2, at different scales (from small to large) and capturing cross sectorial coupling and system integration opportunities, entirely based on (i) renewable sources and (ii) non-toxic, non-critical raw materials. It focuses on the potentials of new biological, chemical, and physical routes for green H2 production, which could also facilitate the implementation of the circular economy principles, possibly including the co-production of decarbonised chemicals. The specific target is to support the development of innovative technologies and platforms for green H2production, including both centralised and/or on-demand generation (i.e. at the premises of the end users and for onsite consumption). Reaching these objectives requires multidisciplinary competencies and cross sectorial approaches addressing also environmental, industrial and logistic issues.

Specific conditions for this challenge

In order to apply, your proposal should develop a proof of concept or lab-scale validated innovative green H2production technology by biological, chemical or physical routes without the deployment of fossil fuels, potentially including the use of salt or waste water, air moisture, biomass or recycled by-products, or the co-production of decarbonised chemicals.

Projects with multidisciplinary and cross sectorial approaches, looking for inspiration, ideas and knowledge in disciplines that are typically not in this kind of research, are particularly welcome. Projects are strongly encouraged to consider the recovery and recycling of by-products and wastes (circular approach), as well as the use of abundant natural resources. The safe and sustainable use of non-critical raw materials is mandatory and the projects should include a full life cycle analysis of the proposed solutions and their impact on Europe's decarbonisation goals.