Position Paper

Hydrogen Europe Research

Research and Technology Infrastructures

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Introduction

The REPowerEU Strategy set out the aim of producing 10 million tonnes of renewable hydrogen and importing 10 million tonnes of the same by 2030. By 2050, renewable hydrogen is to cover around 10% of the EU's energy needs, significantly decarbonising energy-intensive industrial processes and the transport sector. Thus, renewable and low-carbon hydrogen stands as a key component in the EU's strategy within the energy transition, net-zero, and sustainable development.[1] Beyond that, hydrogen must be produced, stored, transported and distributed via efficient and sustainable technologies, minimising or even omitting critical and strategic raw materials as well as environmentally harmful substances while respecting strict safety rules. As solutions for this are either not sufficiently developed or do not exist at all, **production, transport, storage and usage need intensified research and development.[2]**

Already in 2021, the European Research Area (ERA) policy agenda identified **Research and Technology Infrastructures (RTIs)** as being crucial elements of European Research and Innovation (R&I) ecosystems, providing essential platforms for bridging the gap between research and market applications.[3] This position is promoted by the European Association of Research and Technology Organisations (EARTO) in its recommendations for the implementation of an EU strategy on technology infrastructures.[4] In September 2024, the EC published two reports on (i) a detailed analysis of European, national and regional initiatives, strategies and programmes addressing investments in Technology Infrastructures,[5] and (ii) mapping of the existing landscape of Technology Infrastructures in clean and renewable energy technologies.[6]

The significance of RTIs has been repeatedly underscored in strategic documents such as the Draghi report[7] (*'increased funding and stronger coordination is required to develop world-leading research and technological infrastructures'*), the Letta report[8] ('a key pillar of the fifth freedom is the empowerment of our research infrastructures') and the Heitor report[9] (*'Research and Technology infrastructures should be prioritised throughout Europe in order to foster the European RD&I ecosystem, attract and retain researchers'*). Most recently, the EC Communication on 'A Competitiveness Compass for the EU' from January 2025 establishes competitiveness as one the EU's overarching principles for action, so that tomorrow's technologies, services and clean products are invented, manufactured and marketed in the EU. The availability of support and investment for R&I is a key issue holding back the growth of tech start-ups and particularly for early-stage technologies that have game-changing potential. In this context, access to research and technology infrastructures for innovative companies is a key element.[10]


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Research and Technology Infrastructures: Context and Status

The European Union needs to develop a robust ecosystem of infrastructures supporting research, innovation and technology development that enable businesses to advance, scale and commercialise their innovations efficiently. Research Infrastructures (RIs) and Technology Infrastructures (TIs) are essential in this ecosystem, offering advanced facilities and expertise.

RIs and TIs complement each other with RIs focusing, but not exclusively so, on fundamental and applied research and TIs on technology development, testing, scale-up and deployment. Additionally, companies can invest in and build **industrial infrastructures** as part of their operations, which are understood as facilities developed typically with a focus on a specific product, technology or production process within an individual company, such as industrial demonstrators.[11] Thus, the capacities and services provided by RIs and Tis, on one hand, and industrial infrastructures and demonstrators, on the other hand, are complementary to each other by covering different steps needed for the scale up of technologies towards industrial processes and manufacturing.

2.1 Research Infrastructures

Research Infrastructures (RIs) are facilities that provide resources and services for research communities to foster innovation and achieve excellence in their fields. They include the associated human resources, major equipment or sets of instruments, knowledge-related facilities such as collections, archives or scientific data infrastructures, computing systems, and communication networks. They can be ‘single sited’, ‘virtual’ or ‘distributed’, are usually open to external users and, where relevant, may be used beyond research, for example for education or public services.[12]

2.2 Technology Infrastructures

Following the updated definition provided by the Expert Group on Technology Infrastructures (EGTI), Technology Infrastructures (TIs) are:[13]

'(…) facilities, equipment, capabilities and resources required to develop, test, upscale and validate technology. They enable and accelerate technological innovations towards societal/market adoption, fostering industrial competitiveness. They provide a wide range of capacities and services from pre-competitive applied research services, through demonstration and validation of technology, up to small-scale production. They include, amongst others, test beds, demonstration and testing facilities, pilot lines or living labs, usually embedded within non-profit research and technology organisations, universities active in technology fields or technology centres, which are open to private and public users. They can be public, semi-public or privately owned, physical or digital. '

Examples of TIs range from facilities to develop electrolyser stacks to biogas plants, clean-room facilities for chip production to test areas for automated shipping or road traffic safety solutions, from wind tunnels to testbeds for multi-functional nano-composites, or from multi-material 3D printing to thermo-plastics and industrial robotics. Regarding hydrogen, there are, amongst others, currently two Open Innovations Test Beds (OITBs) active : *CleanHyPro*[14] and *H2Shift*[15]. In addition, TIs related to hydrogen are hosted by several RTOs in Europe and strategically analysed by the *RITIFI*[16] project.

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RIs, TIs and industrial infrastructures in the hydrogen innovation ecosystem

In 2024, the EC launched an online survey addressed to diverse enterprise types and industrial ecosystems such as SMEs, very small enterprises and large companies, amongst others, from the key sectors of mobility, health, aerospace and defence, digital, energy, electronics, agri-food, and construction. While the majority of enterprises participating in the survey (80%) declared that they use TIs, **90% of the enterprises active in the area of electrolysers and fuel cells considered not to have adequate TIs to support their technology development plans**. Moreover, the related share of companies in the areas of micro/nano electronics and photonics (71%) and carbon capture and storage (70%), which are both closely linked to hydrogen, came in second and third, respectively. The mentioned reasons for why the offer of TI services is not sufficient were – most importantly – that **there are simply not enough TIs**, and – secondly – that **access to TIs are too complicated for industrial users**, and – thirdly – that **they are inconveniently located**, wherein missing relevance for industrial needs or missing state-of-the-art were comparably important reasons.[17]

According to the enterprises, **making existing TIs more visible by offering (better) insights into their services, as well as active dissemination of up-to-date information,** would be the most important elements to increase their usage of TIs. In this context, related inventories or roadmapping exercises to date include the mapping of the existing landscape of TIs in clean and renewable energy technologies by the EC[18], as well as the mapping of hydrogen RIs and TIs through Hydrogen Europe Research .

At the EU Member States level, dedicated support for TIs is currently focusing on fields such as **hydrogen**, semiconductors, ICT, advanced materials, and most recently on AI[19],[20]. On the other hand, the EU Hydrogen Strategy mentions '*pilot lines to test new solutions or perform early product validation*' as a priority area for collaboration between Member States and local and regional authorities[21], and the proposal for a Critical Raw Materials Act highlights the need for R&I for a sustainable materials value chain[22].

In 2024, Hydrogen Europe Research published a Research Position Paper 'For a long-term perspective impact of European research and industrial sectors'[23], pointing towards the importance of RTIs for '*fostering innovation and enabling breakthrough technologies, especially in scaling up manufacturing capacity for hydrogen-related industries*'.

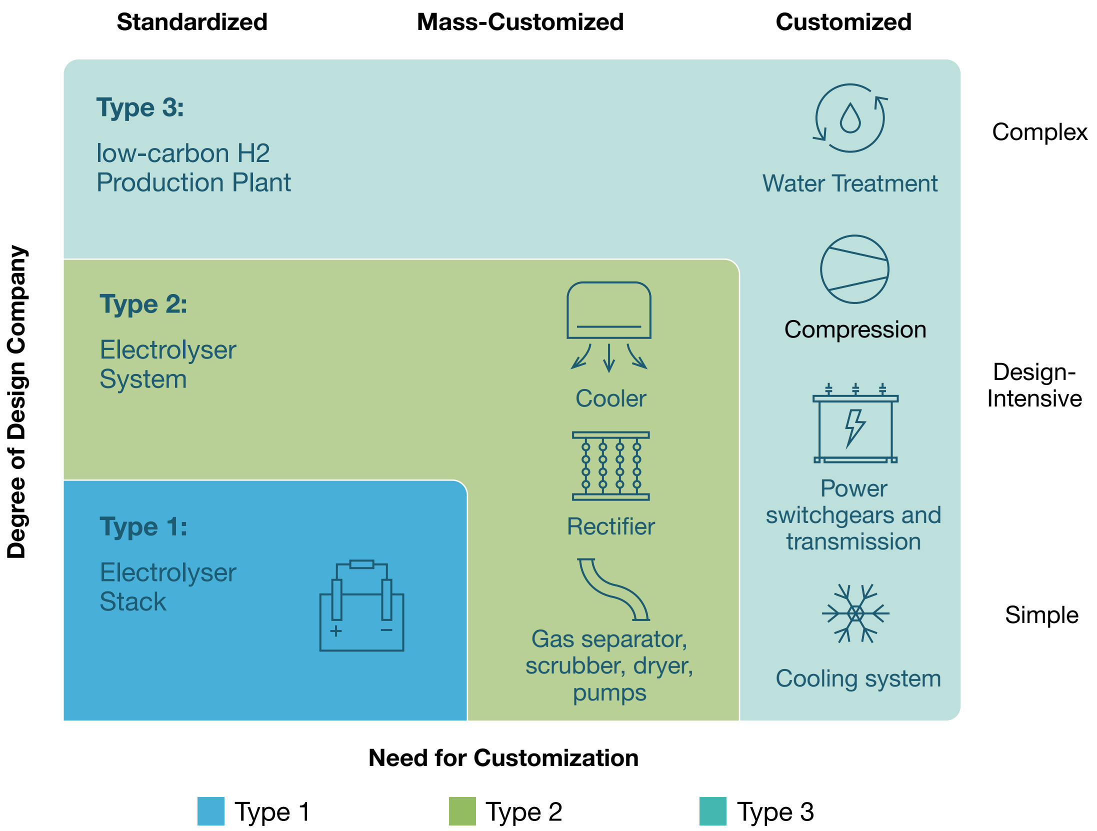
3.1 Accelerating technology development for the hydrogen economy

The European Union needs to advance a variety of hydrogen technologies if it wants to achieve carbon neutrality by 2050, focusing on scaling up renewable and low-carbon hydrogen production, storage, and distribution. Thus, a wide range of different technologies, with varying Technology Readiness Levels (TRLs), has to be covered. For example in the area of renewable hydrogen production, at higher TRLs, one focus is on water electrolysis using renewable electricity, with a particular emphasis on upscaling electrolyser technologies such as Alkaline Electrolysis (AEL), Anion/Proton Exchange Membrane Electrolysis (AEMEL/PEMEL), and Solid Oxide Electrolysis (SOEL) and Protonic Ceramic Electrolysis (PCEL). Beyond water electrolysis, many technologies such as direct solar-driven or biological processes are still at lower TRLs requiring substantial R&I efforts to achieve commercial readiness. On the other hand, scaling up production capacity, improving cost competitiveness, and establishing robust distribution infrastructure are key areas requiring coordinated efforts. As such, **besides the need for policy action to improve the accessibility of RTIs, user(technology)-focused services and capabilities are necessary to improve the applicability of RTIs and facilitate their collaboration with users**.

Based on a thorough literature review[24] of experience rates[25] of low-carbon technologies, a technology typology has been developed that explains systematic differences in technologies' experience rates by distinguishing these technologies based on (i) their design complexity and (ii) the extent to which they need to be customised. Accordingly, energy technologies are grouped into three types (*'Type 1/ 2/ 3'*), which have significant implications, such as, for example, the way the individual technologies and their costs develop, respectively, and therefore require different roles of national and international innovation and deployment policies.

Based on such *'Type 1/ 2/ 3 technologies'*, Doyle et al. developed an approach to map renewable hydrogen production plants towards a combination of these technology types (see figure 1)[26], building on the fact that a renewable or low-carbon hydrogen production plant essentially combines the (theoretical) simplicity and scalability of a mass-produced technology (electrolysers) with the complexity and customisation of an industrial-scale system. **This approach may therefore act as a guideline for the (strategic) planning and coordinated establishment of hydrogen-related research, technology and even industrial infrastructures, and to improve their accessibility and applicability.**

Figure 1: Green hydrogen production plant as a combination of Type 1, 2, and 3 technologies[27].



Adapted from Ramboll, "Achieving affordable green hydrogen production plants", 2023.

Type 1 technologies: Standardised components

Type 1 technologies such as (i) electrolyser or fuel cell stacks, (ii) components of multipurpose Hydrogen Refuelling Station (HRS) systems, or (iii) pipeline components, are comparably "simple" and mass-producible, and expanding production capacity will most likely lead to cheaper products.

Studies[28],[29] by policymakers, trade associations and industry often assign learning curves from the solar PV industry to predict the potential cost decline of electrolysers and ultimately the cost of renewable hydrogen based on the scaling of manufacturing. A recent academic study[30] compared forecasted and actual learning rates across solar PV, Li-ion batteries, and PEM electrolysers, and concluded that each of these technologies had demonstrated cost declines in line with Wright's Law (i.e. costs drop as a power law of cumulative production). However, the PEM dataset was significantly limited.

Nevertheless, although electrolyser manufacturing capacity doubled in 2023 to reach 25 GW/yr,[31] electrolysers CAPEX and levelized costs of renewable hydrogen were rising due to other macroeconomic trends and seemingly despite those announcements.[32] Given the huge demand for electrolysers in the renewable and low-carbon hydrogen-powered energy transition, it may still be assumed that **stack components** exhibit a sustained

5-20% year over year decline for the next decade, depending on stack technology (AEL, PEMEL, AEMEL, or SOEL).[33]

This can only be achieved if sufficient public and private investments are streamlined into R&I capacities, facilities and services. Related key objectives include (i) reducing the loading factors of the most expensive/critical minerals, (ii) increasing the efficiency to reduce energy needs and footprint per unit of hydrogen production, and (iii) improving reliability and lifetime via reducing degradation and poisoning processes.

When it comes to **testing and evaluating cells and (short) stacks**, there is still a huge variety of technology concepts, devices (cell assembly, cell area, stacking, etc.) and testing procedures. **Thus, RTIs applying harmonised testing protocols, clear codes, technical regulations, standards and related Pre-Normative Research are needed to prevent delays in technology deployment**. Harmonisation and certification schemes for hydrogen technologies and their components are required to guarantee on the quality of the commercial and novel technologies and components.[34] In this context, the *STASHH* project[35] developed an open standard for heavy-duty fuel-cell modules to kick-start the use of hydrogen in the heavy-duty mobility sector, which standard has been transformed into a pre-normative work in the IEC TC105.

Type 2 technologies: Mass-customised systems

Electrolysers or electrolyser systems are more than their stacks, and thus can be referred to a type-2 technology that relies on a mix of mass-produced products, also called BOS ('Balance of System') components, which are type-1 technologies such as stacks, rectifiers, switchgears, gas separators, etc. Electrolyser systems are therefore more complex and customised than the stack inside. Moreover, the requirements for the BOS components, such as the power electronics and water or gas purification systems, may depend on the region, location, and project design.

Original Equipment Manufacturers (OEMs) usually develop and deliver an electrolyser system with the required specifications, whereas the available systems (AEL, PEMEL, AEMEL, or SOEL) can vary widely regarding BOS components. Especially power electronics such as transformers and rectifiers have been shown to be the key limiting factor for stack and system size, currently staying at the 2-5 MW range.[36] **Thus, accelerated and increased R&I activities for these components are strongly needed.**

In terms of testing and evaluation, such OEM electrolyser systems are more applicable, since they are mostly containerised and to a certain extend 'plug-and-play'. **Challenges for TIs often arise from the large system size, necessitating sufficient electrical connection power, water supply and/or gas storage/usage capabilities. RTIs should also be able to address the electrical components of electrolyser systems, especially rectifiers or even fully DC-powered systems.**

Moreover, in manufacturing, these type 2 technologies require more than increased production volume to unlock significant cost reductions, such as, amongst others, the standardisation of electrolyser offerings , comprising more integrated and cohesive solutions with better integrated and improved BOS components. Beyond that, electrolysers systems for very large plants are made of several stacks/modules and, thus, the technology-specific standardisation of such stacks/modules will accelerate and accordingly reduce the costs of the entire project lifecycle, from design and engineering to procuring the necessary equipment and building the plant.

Type 3 technologies: Customised components for hydrogen production plants and end-use

A renewable or low-carbon hydrogen production facility usually contains an electrolyser or hydrogen production system, the balance of plant (BOP) components as well as multiple process loops that connect with the outside environment (such as the water, electrical, heat and gas streams). **These interfaces make the plants highly customised to their specific location and thus reduce the impact of learning and scale.** Moreover, the produced hydrogen must be supplied into an offtake infrastructure such as storage of different types (tanks, caverns, pipelines) or power-to-X processes, wherein, amongst others, the grid interconnection, the water systems, and the gas systems including the gas transport and storage infrastructure have to be considered.

Many of these factors interact not only with real infrastructure systems (e.g. the grid, the gas network) but also with a cascading system of national and local laws. So, at the plant level, technologies are so complex and customised in their design that they require collaboration across OEMs, developers, operators, end-users, financiers, regulators, local authorities and governments to unify the enabling environment for these technologies.

For hydrogen production, this will require the harmonisation of certification for hydrogen origin and regulatory frameworks for permitting and safety, the definition of interconnection standards and tariffs, and enhanced industry coordination on R&I, maybe even based on industrial infrastructures.

3.2 Materials development and AI Applications

Advanced material development plays a crucial role in hydrogen technology development, especially in type 1 technologies and e.g. storage, transportation (pipelines) or end-use technologies. In this context, the first three R&I priorities as defined by the new Co-Programmed HE partnership *'Innovative Advanced Materials for Europe' (IAM4EU)* are directly addressing hydrogen production, conversion and storage.[37] Moreover, recent advances in AI show promise in generating scientific breakthroughs in areas such as materials science where models can be trained on large datasets of existing examples.[38]

In February 2024, the EC published its Communication on *'Advanced Material for Industrial Leadership'*, **underscoring the need for more accessible TIs and better connections between existing infrastructures in different Member States**.[39]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Implementation Challenges and Proposed Actions

Fragmentation Across Member States

Evidence shows that the availability of TIs in clean and renewable energy technologies in the EU is fragmented and geographically imbalanced. There are often no overarching coordination mechanisms to oversee investments in TIs in Europe and no roadmapping or long-term investment planning[40].

To improve cooperation and overcome fragmentation, the promotion of such infrastructures can act as **vehicles for attracting and growing talent** and **create deep-tech innovation R&I ecosystems** within the infrastructures and beyond (e.g. between different types of infrastructures and/ or companies).

Regarding the hydrogen sector, **Hydrogen Europe Research conducted a mapping of RTIs** and set up a **RI&TI Working Group[41]** in order to "coordinate *a mapping exercise with a technology-oriented approach at the EU level, building upon national and institutional initiatives, set up through existing structures and coordinated at the European level".[42]* **A technology-type-focused value-chain approach** is promoted in order to create structured, business-oriented ecosystems near enterprise clusters, and fostering regional innovation. For this, the partnerships with its private partners, such as Hydrogen Europe Research, could provide a format for future road-mapping.

Regulatory and Funding Issues

To ensure the sustainability of TIs in the long run, support often needs the combination of public and private funding streams to cover various needs underpinned by relevant skills and expertise in the planning and creation phase as well as during implementation, upgrade and decommissioning. These funding streams can range from fully regional public funding to a multi-level combination of different funding schemes. **TI operators face difficulties finding instruments to cover their capital investment needs and support the operational use of TIs for actors with lower financial capacity**, such as SMEs. Moreover, outdated and stringent regulations in high-tech sectors hinder smooth operation and access.

Under Horizon 2020, the EU invested around €1.2 billion in research and TI projects, while the European Regional Development Fund (ERDF) has provided, during the 2014-2020 programmes, over €16 billion for building or upgrading RTIs. **Hydrogen Eu-**

rope Research strongly encourages the European Commission to maintain and consolidate this impetus in the forthcoming financial framework, amongst others by creating a dedicated EU funding scheme to support large-scale investments and operational costs of TIs and pool resources at the EU level. In addition, exploiting synergies and joint investments between institutional, regional, national, European and global funding streams can mobilize further investment in needed TIs, e. g. via the sectoral acts proposed in the Competitiveness Compass

Awareness, Use and Accessibility

Many enterprises lack awareness of the TI landscape and its benefits, resulting in underutilisation of the TIs and their services. Moreover, SMEs and startups, particularly in less economically developed regions, encounter significant barriers to accessing TI resources. These barriers include high usage fees, lack of geographical proximity, and insufficient awareness of available facilities. Finally, ambiguous and diverse access rules discourage engagement with TIs, wherein concerns about intellectual property (IPR) protection and data security further deter users, especially those worried about the risk of misappropriation.

Under Horizon 2020, around €21 billion were allocated to research and innovation support services that foster the exploitation and development of technologies, in particular by SMEs[43]. **Hydrogen Europe Research strongly encourages the European Commission to maintain and consolidate this impetus in the forthcoming financial framework, and to foster SMEs' access to RTIs by enhancing and incentivising the use of support instruments.**

To improve the awareness, each RI and TI should provide clear and transparent information on the infrastructure, its standardised services, and the support that can be provided. This would enable enterprises, particularly SMEs, to learn about TIs outside of their field of expertise and about available funding opportunities. Moreover, these infrastructures should provide training for SMEs on innovation management, technology transfer, IPR and data management.

RIs and TIs should be developed and organised on the basis of a technology-type-focused value-chain approach, ideally in the form of joint infrastructure frameworks between different types of infrastructures, to create structured, business-oriented ecosystems near enterprise clusters and industry infrastructures, and fostering regional innovation.

The digitalisation of infrastructures will be enabled by AI, and remote testing and simulation platforms can help to overcome physical barriers and expand access to distributed facilities as long as they are fully implemented in the communication and access strategy.

Market Alignment and Adaptability

Some RIs and TIs service offerings may not fully align with end-user needs, leading to a gap with market demand, thus lacking clear, industry-aligned business models, resulting in inefficiencies, fragmented efforts and inadequate services. Related pricing models often fail to address SMEs and start-ups financial constraints, creating further access barriers. This is particularly true in fast evolving technology fields, where rapid technological advancements require adaptable infrastructures and well-trained staff.

Go-to-market strategies should be developed, prioritising industry engagement to drive commercialisation and innovation. A business-oriented R&D approach should be chosen that is agile and responds to changing market demands. Seamless collaboration between technology providers and end-users should be established to improve the pathways of RIs towards industry. For a forthcoming European coordination body on TIs, the perspective of industry as TI users and research community as TI operators must be safeguarded. **Hydrogen Europe Research strongly encourages the European Commission to support this by European funding instruments such as the collaborative projects in HEU Pillar II.**


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Summary

Renewable and low-carbon hydrogen technologies require the development of Research, Technology, and Industrial Infrastructures to bridge the gap between research, innovation, and market adoption, thereby reducing the time-to-market for innovative solutions and enhancing Europe's industrial competitiveness.

Yet many companies lack knowledge of the facilities and services they could use to develop, validate or scale up their technologies, or face barriers in accessing them. Despite growing demand, existing infrastructures are often insufficient, difficult to access, or poorly aligned with industrial needs. This limits the ability of enterprises – especially startups and SMEs – to develop, test, and scale breakthrough technologies.

To accelerate progress, the European Union must build a more connected and responsive ecosystem that supports the full development cycle of hydrogen technologies, from research to commercial deployment. This includes improving visibility and accessibility of infrastructures, strengthening collaboration across regions and sectors, and ensuring regulatory and funding frameworks that are fit for purpose.

By aligning infrastructure investment with R&I and market needs, fostering innovation ecosystems near enterprise clusters, and simplifying access and support for companies, the European Union can unlock the full potential of hydrogen technologies. This will not only drive competitiveness but also contribute meaningfully to the EU's climate and energy goals.

Hydrogen Europe Research

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