ERA LEARN

Funded by the European Union

ERA-LEARN

Translational Research into Innovation. The case of Clean Hydrogen Joint Undertaking: pathways to innovation and the regional dimension

Dimitri Gagliardi

November 2026

Acknowledgements:

The author is extremely grateful to the management of the partnerships, principal and coinvestigators and researchers, scientists and entrepreneurs who have dedicated their time helping us to structure the report and provided important information through their interviews. We are also indebted with the ERA-LEARN Advisory Board Members and reviewers who went through earlier versions of the report providing important comments and suggestions. The responsibility for this report remains solely with the author

Please cite as:

Gagliardi Dimitri (2026). Translating research into innovation. The case of Clean Hydrogen Joint Undertaking: pathways to innovation and the regional dimension. ERA-LEARN - Strengthening the European Partnership community (CSA) project n. 101102316

Contents

EXECUTIVE SUMMARY 5

1) Strategic Context and Institutional Mandate 5
2) Translational Pathways and Non-Linear Realities 5
3) The Regional Dimension: European Hydrogen Valleys 7
4) Policy Implications 9

SECTION 1. INTRODUCTION: 10

1. Governance, Structure and Role of the Clean Hydrogen Joint Undertaking 10
1.1 Historical milestones towards the Clean Hydrogen JU 12
1.2 Synthesis of Strategic, Macroeconomic, Geopolitical and Policy Contexts 14
1.3 Objective of this study and organisation of the report 15

SECTION 2. METHODOLOGY OF THE STUDY 17

The translational journey and the translation continuum. 17

SECTION 3. PATHWAYS FROM RESEARCH TO INNOVATION 20

1. Introduction 20
2. Findings from the fieldwork: R&I pathways to impact 21
3. Collaborations and R&I pathways to impact 26
4. Research and Technology Infrastructures 28
5. Specialist technical knowledge 31
6. Capacity building 33
7. Ways to markets 36
8. Defining and achieving success 38

SECTION 4. THE REGIONAL DIMENSION OF THE CLEAN HYDROGEN JU: A SOCIO-TECHNICAL AND POLICY ANALYSIS OF THE HYDROGEN VALLEYS 40

1. Introduction 40
2. The Hydrogen Valley: Regional value chain and ecosystem 41
3. The strategic policy mandates of Hydrogen Valley 42
The EC perspective 42
The Valleys as Socio-technical Gyms 43
4. How the Hydrogen Valleys organise their role in the European Hydrogen Economy 44
Self-perception: nucleation point of ecosystem building 44
Structured vs flexible governance 44
Extending cross-borders and inter-valley coordination 45
5. The Complex Architecture of Regional Ecosystems 46
Multi-Level Governance and Policy 47

Intermediaries as Systemic Matchmakers and Market Stabilisers 48
Connecting SMEs in Large Industrial Clusters 49
The Human Capital conundrum 50
6. A reflection on the analysis *51*
SECTION 5. DISCUSSION AND CONCLUSIONS **53**
1. A synthesis of R&I Pathways and policy *53*
2. The Regional Dimension and Hydrogen Valleys *54*
The Hydrogen Valleys as demand-side 55
3. Conclusions *56*
REFERENCES. **57**

EXECUTIVE SUMMARY

1) Strategic Context and Institutional Mandate

The Clean Hydrogen Joint Undertaking (JU) is an institutionalised public-private partnership within Horizon Europe Cluster 5. Its Partners are the European Commission, Hydrogen Europe – industry association with organisations representing European hydrogen business stakeholders - and Hydrogen Europe Research – the research association connecting European universities and research organisations engaged in hydrogen research -.

Operating under Council Regulation (EU) 2021/2085, the partnership's legislative architecture explicitly binds its wide research and innovation objectives (Clean Hydrogen JU, 2022) to broader Union-level climate and energy governance, supporting the European Green Deal, the 2030 Climate Target Plan, and the European Climate Law.

To execute its legally mandated objectives, the JU implements an initial public operational budget of €1 billion from Horizon Europe (2021-2027)—matched equally by in-kind contribution from private industrial and research stakeholders—which was subsequently increased by a €200 million REPowerEU top-up specifically to accelerate market deployment of European Hydrogen Valleys. This financial commitment builds upon a rich legacy portfolio spanning the Fuel Cells and Hydrogen Joint Undertaking and the Fuel Cells and Hydrogen 2 Joint Undertaking, which collectively invested over €1.1 billion in public funding across over 260 projects with a total public and private investment exceeding €2.5 billion (EC & Zhechkov, 2024).

Within this multi-level governance framework, the JU orchestrates its strategic research and innovation agenda across three main distinct pillars encompassing renewable production, midstream logistics, end-use transport and industrial applications and horizontal activities (non-tech related) such as cross-cutting regulatory issues, regional Hydrogen Valleys, supply chain resilience, and foundational scientific challenges.

2) Translational Pathways and Non-Linear Realities

From a socio-technical standpoint, translating clean hydrogen technologies from foundational laboratory discoveries into commercial applications is an inherently non-linear process fraught with systemic friction and high rates of attrition. Rather than following a smooth, predictable progression along Technology Readiness Levels (TRLs), research pathways are continually disrupted by institutional re-alignments and macroeconomic shocks. By institutional design, the JU relies on blue-sky academic research - without a predefined technical concept – and focuses

on a structured public-private partnership model spanning TRL 2 (from defined technology concepts) to TRL 7 (prototype demonstration in operational environments) or even 8 (system integration).

Empirical fieldwork investigates how at the earliest stages of frontier science and material exploration (up to TRL 3 – experimental proof of concept), university researchers drive fundamental exploration focusing on micro-level phenomena and concepts such as mechanical stress, thermal conductivity and cryogenic insulation. As projects transition toward meso-level applied research and platform testing (TRL 4 – technologies validated in laboratory to TRL 6 – technologies demonstrated in relevant environments), they usually encounter a clash of incentive generating a structural data paradox. In fact, public funding rules mandate open data dissemination across the research community, while commercial original equipment manufacturers and research organisations require strict non-disclosure agreements and intellectual property protections to shield proprietary designs from market competitors.

Academic institutions and engineering organisations routinely face communication and linguistic barriers in translating complex physics and experimental metrics into the simplified, business-ready parameters required by venture capitalists. When innovations advance into higher TRLs (TRL 7 and above) involving industrial system integration and field demonstration, execution shifts to corporate engineering teams, where real-world operational environments introduce new technological and implementation challenges; in the specific of our fieldwork we meet, amongst others, “severe micro-level failure risks previously invisible during laboratory simulation” that redirect the attention of the R&I process. Other similar challenges include, maritime fuel cell modules developed in joint projects encounter aggressive performance degradation due to salt-air particulate contamination, necessitating multi-stage ambient filtration systems which may not be readily available. Similarly, retrofitting heavy industrial furnaces from natural gas to oxyfuel-hydrogen combustion eliminates carbon emissions but radically intensifies internal water-vapor concentration and this may cause chemical corrosion and/or structural cracking of standard ceramic refractory linings.

Moreover, aside technical advances and adaptation to real-world conditions, the technological trajectories of some projects driven by the Clean Hydrogen JU have been often heavily disrupted by external geopolitical and macroeconomic shocks. For example, a continental pipeline sabotage in 2024 forced a consortium to radically shift transport blueprints toward flexible sea transport – whilst this is has not affected the activities of the Clean Hydrogen JU activities, it certainly required a rethink of the beneficiaries R&I activities. Another example that had a wider

impact is the shifting of high-level policy mandates under REPowerEU following the war in Ukraine.

Nonetheless, our study highlights a decoupling between high TRL technology validation and commercial deployment due to corporate's risk aversion and lagging market readiness. This combination of factors eventually contributes to leave mature technologies stranded in a prolonged commercial standstill despite successful project-level completion. Basically, while individual consortia achieve (and often exceed) contractual TRL targets within protected project boundaries, macro-level social and market impacts remain limited as global fossil fuel use continues to rise and high electricity input costs—accounting for 50 to 90% of operational expenditure—combined with low initial factory utilisation rates (~10%) restrict the economies of scale necessary to drive down production costs.

3) The Regional Dimension: European Hydrogen Valleys

To bridge the persistent gap between research and innovation, and therefore facilitate the adoption of novel technologies in the market, the Clean Hydrogen JU is championing place-based innovation demonstration/adoption through the deployment of Hydrogen Valleys. The valleys function as localised socio-technical ecosystems; these territories integrate hydrogen production, transport, storage and multi-sector end-uses within bounded geographic areas. Of course, evolving from isolated pilot projects, these are increasingly organised across multi-regional corridors such as the North Adriatic Hydrogen Valley spanning Friuli Venezia Giulia, Slovenia, and Croatia, and the Ebro Hydrogen Corridor connecting the Basque Country, Navarra, Aragon, and Catalonia.

From a policy and regional studies perspective, the valleys operate as socio-technical testing grounds that compress intermediate testing and real-world operational validation (TRL 4 to 8). This aspect is particularly important as it captures vital operational data for pre-normative standardisation and is positioned as essential building blocks for European energy sovereignty and REPowerEU deployment targets.

Regional operators view their mission as establishing *nucleation* points of ecosystem building (term used by one of our contributors). This, in practice, means translating high-level European climate directives into local industrial assets, regional energy security and employment opportunities for regions allowing them to transitioning away from coal-mining or their heavy manufacturing pasts. Moreover, many other possible use-cases are set out in the valley with the objective to complement real value creation and impact for regions.

Organisational governance structures across these valleys vary significantly, ranging from highly structured, centralised models managed by regional development agencies through quarterly committees with detailed competence matrices drawn in order to both improve on their structural capabilities and to use such capabilities in operations appropriately, to flexible, project-based models where independent actors coordinate on a project-by-project basis so that cumulation of experiences along a longer term strategy may drive advancements of the local hydrogen economy.

A central systemic barrier identified in our research is that the market "waiting game" – characterised, for example, by a standoff where transport operators refuse to procure hydrogen fleets due to missing refuelling infrastructure versus energy providers declining to build refuelling stations because of absence of active commercial demand – can be effectively bridged within Hydrogen Valleys. In fact, regional intermediaries, local public authorities and development agencies amongst other specific roles, are also key to breaking such types of deadlocks by deploying targeted public procurement of fleets, taking direct equity stakes in regional distribution companies and also pooling legal resources to protect small and medium-sized enterprises from prohibitive regulatory and permitting barriers.

Moreover, because central JU grants typically act as seed funding covering roughly 20% of total project costs, regional coordinators have begun engaging in complex financial engineering, layering private equity with national modernisation funds and European Regional Development Funds (ERDF). These operations may create heavy administrative burdens across multiple auditing frameworks but also unlock further opportunities. To assist regions in this growth trajectory, including knowledge building and management, the JU established the Hydrogen Valley Facility (H2V Facility). This is a funded initiative designed to assist, Hydrogen Valleys, project developers, regional and national authorities as well as investors and other H2 practitioners and provide assistance in areas such as commercial, governance, regulatory or technical issues. The initiative targets either the development of embryonal-stage projects or more advanced projects which may have a strategic or operational role for the EC’s target of creating 50 Hydrogen Valleys by 2030.

This financial and operational complexity is mirrored by human capital challenges, as the transition toward market maturity relies on diffused academic and scientific skills, it also increasingly needs technicians and maintenance engineers specialised in hydrogen technologies. These stages of implementation are prompting regions to embed specialised vocational training matrices such as the Green Skills for Hydrogen pilot, and more targeted academic programs into their local governance frameworks.

4) Policy Implications

Our analysis of the Clean Hydrogen JU yields critical policy implications. Most notably, achieving high Technology Readiness Levels within protected project boundaries is proven to be a necessary but fundamentally not sufficient condition for successful commercialisation and broad societal impact.

To overcome the structural deadlocks and market stagnation currently facing the European hydrogen economy, policy frameworks must evolve beyond isolated technological funding and work towards streamlining multi-tier public funding mechanisms to alleviate the severe administrative burdens associated with stacking distinct auditing frameworks across regional, national, and European levels. In addition, whilst we have identified several multi-level governance frictions, perhaps, regional authorities and local actors—who operate as the primary execution agents on the ground within Hydrogen Valleys— should be better integrated into core decision-making and call-drafting architectures to ensure alignment between top-down strategic mandates and ground-level operational realities.

We have also noted that many contributors would have benefitted of institutional support for pre-normative standardisation, proactive regulatory harmonisation and guidance towards achieving certified safety compliance protocols. These factors may be better established and deployed at a project's inception to prevent late-stage regulatory/permitting rejections or operational failures. Another aspect that has been brought to our attention by several interviewees is that stable, long-term funding streams, which are generally used by Clean Hydrogen JU beneficiaries to advancing their technological projects, also foster continuity for workforce capacity-building and to fund vocational reskilling programs which will eventually prevent critical labour shortages of specialised technicians.

Finally, we have seen that when technology-push funding is tightly coupled with demand-pull mechanisms - such as coordinated regional public procurement, strategic equity participation and enforceable procurement mandates that guarantee domestic supply chain integration -, advances towards the budding hydrogen economy are much more effective and, evident also at the regional level, is accruing significant benefits towards industrial sovereignty against international cleantech competition.

SECTION 1. INTRODUCTION:

1. Governance, Structure and Role of the Clean Hydrogen Joint Undertaking

The Clean Hydrogen Joint Undertaking (JU) represents an institutionalised public-private partnership established under the European Union's Horizon Europe Framework Programme. It is positioned within Cluster 5 governing Climate, Energy and Mobility. Functioning as a central mechanism for mission-oriented research, development and innovation (R&I), the partnership is set out by a governance framework including public authority, represented by the European Commission, private industrial stakeholders organised under Hydrogen Europe and the scientific community represented by Hydrogen Europe Research. The organizational structure of the Joint Undertaking consists of the Governing Board formed by members of all three partner organisations and responsible for strategic decision-making and allocation of resources, an Executive Director, the legal representative of the partnership supported by a dedicated Programme Office managing daily operations. The structure includes a States Representatives Group (one representative from each Member State and Associate Country) ensuring alignment with national interests and an advisory Stakeholders Group formed by organisations and agencies representing hydrogen and adjacent sectors (*eralearn.eu*; Zhechkov, 2025; Clean Hydrogen Partnership, et al, 2025).

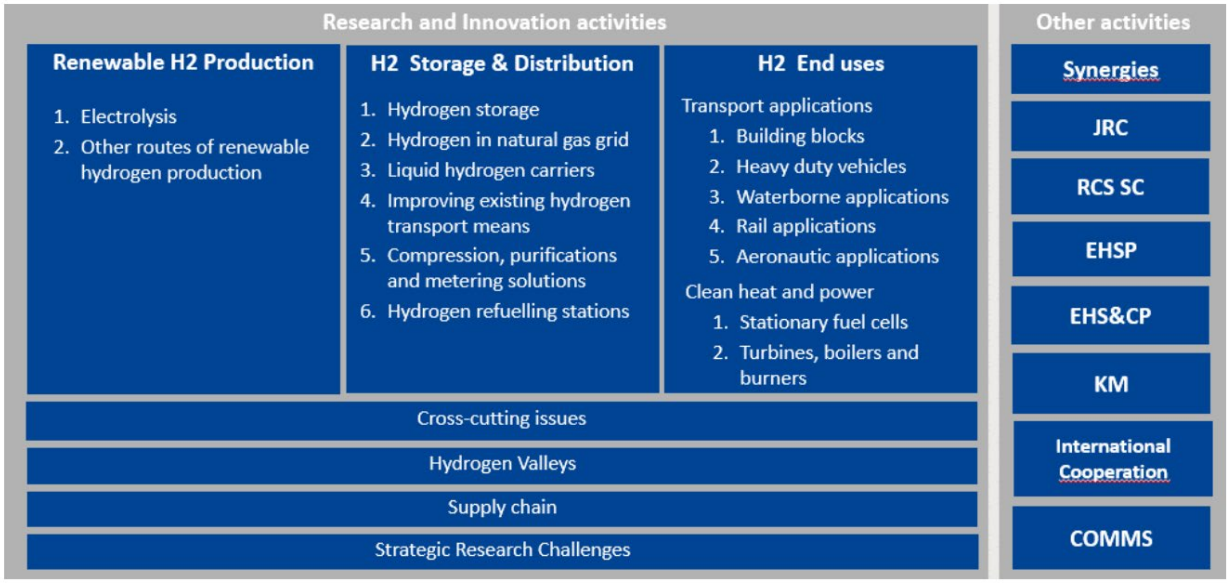
The legal foundation of the Clean Hydrogen JU is codified under Council Regulation (EU) 2021/2085 - the Single Basic Act - in particular, Article 73 expands on the legal basis by codifying specific mandates that tie the partnership's scientific activities to the Union's overarching climate legislation whilst explicitly maintaining the principle of technological neutrality. Specifically, Article 73 mandates that the partnership must contribute directly to the objectives set out in the 2030 Climate Target Plan, the European Green Deal, and the European Climate Law, supporting the legally binding ambition to reduce net greenhouse gas emissions to at least 55% below 1990 levels by 2030 and achieve absolute climate neutrality at the latest by 2050. Complementing these objectives, Article 73 legally obligates the JU to contribute to the implementation of the European Commission's 2020 Hydrogen Strategy for a climate-neutral Europe (Clean Hydrogen JU SRIA, 2022; Clean Hydrogen Partnership, et al, 2025). These foundational legal pillars are further expanded under the same article by provisions requiring the Joint Undertaking to strengthen the industrial competitiveness of the Union's clean hydrogen value chain—specifically providing structural support to small and medium-sized enterprises (SMEs) to accelerate the commercial

market entry of innovative clean solutions—whilst stimulating focused research and innovation across production, distribution, storage, and multi-sectoral end-use applications.

To execute these legally mandated objectives, the Clean Hydrogen JU operates with an initial operational budget of €1bn for the 2021–2027 programming period under Horizon Europe, which is matched by an equivalent amount of private investment from the industrial and research partners. Following the geopolitical disruptions of 2022, the European Commission allocated additional top-up funds of €200m under the REPowerEU plan; this brings the total public operational commitment to over €1.2bn specifically designed to accelerate market deployment and double the number of operational European Hydrogen Valleys[1] (EC & Zhechkov, 2024; Clean Hydrogen Partnership, et al, 2025).

The Clean Hydrogen JU categorises its actions across 3 Pillars and 4 Horizontal activities set out in the SRIA:

Figure 2: Overview of the Clean Hydrogen Joint Undertaking activities



Source: Clean Hydrogen JU SRIA, 2022, Page 28

[1] These figures also to be contextualised taking into account the legacy portfolio of its predecessors—the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) under the Seventh Framework Programme and the Fuel Cells and Hydrogen 2 Joint Undertaking (FCH 2 JU) under Horizon 2020—which collectively invested €1.1 billion of public funding matched by private investments leveraging a combined public and private investment of over €2.5 billion (Clean Hydrogen JU, 2025; EC &Zhechkov, 2024).

Pillar 1. Renewable Hydrogen Production: Focuses on advancing low- and high-temperature water electrolysis alongside alternative solar and biological pathways to maximize efficiency, lower costs, and eliminate critical raw materials.

Pillar 2. Hydrogen Storage and Distribution: Addresses midstream logistics by developing large-scale underground and aboveground storage, chemical hydrogen carriers, compression systems and safe pipeline networks.

Pillar 3.1 Hydrogen End-Uses (Transport Applications): Validates fuel cell power systems across heavy-duty road freight, rail, maritime and aviation sectors where direct electrification is difficult.

Pillar 3.2. Hydrogen End-Uses (Clean Heat and Power): Supports flexible heat and power generation by retrofitting industrial gas turbines, boilers and stationary fuel cells for buildings and heavy industry.

Horizontal Activity 1. Cross-Cutting Issues: Focuses on non-technical enablers including regulations, safety codes, environmental life-cycle sustainability, workforce education and international energy partnerships.

Horizontal Activity 2. Hydrogen Valleys: Demonstrates integrated regional energy ecosystems that link local renewable hydrogen production, storage, distribution and multi-sector end-uses to prove commercial viability.

Horizontal Activity 3. Supply Chain: Strengthens European manufacturing resilience and technological sovereignty by automating and scaling up the production of key stack components and equipment.

Horizontal Activity 4. Strategic Research Challenges: Funds early-stage fundamental science to solve long-term technical hurdles, such as complete raw material substitution, novel storage materials and cell degradation under dynamic loads.

1.1 Historical milestones towards the Clean Hydrogen JU

The integration of a specific hydrogen framework within the broader European Union energy mix is the outcome of a long-term legislative evolution, transitioning from post-war industrial commodity management to modern green energy systems (Vivanco-Martín & Iranzo, 2023; Eikeland et al. 2024; Vezzoni, 2024; Genovese et al., 2025). Early EU Framework Programmes actively supported research and development in fuel cells and hydrogen technologies, allocating €145m under the Fifth Framework Programme (FP5) and increasing to €315m under the Sixth Framework Programme (FP6). However, because these early funding efforts remained highly

fragmented and uncoordinated across different sub-programmes, an institutional review was sought to build critical mass and excellence (Vivanco-Martín & Iranzo, 2023; *clean-hydrogen.europa.eu*). In October 2002, European Commission President Romano Prodi, alongside Commissioners Loyola de Palacio and Philippe Busquin, launched the informal High-Level Group on Hydrogen, comprising 19 stakeholders from industry, research, and public authorities, who mapped out the structural blueprints for a formalised public-private partnership.

The European Commission established the European Hydrogen & Fuel Cell Technology Platform (HFP) in January 2004 (Strategic Research Agenda and Deployment Strategy available at: clean-hydrogen.europa.eu/about-us/our-story_en), but during this same period, targeted sectoral laws emerged leaving hydrogen un-harmonized and granting Member States individual tax discretion (Vivanco-Martín & Iranzo, 2023; Zabanova, 2024; Genovese et al., 2025).

In October 2005, a unified European energy policy was approved at the European Council in London and in 2007, was published the strategy "An energy policy for Europe" which quantified sustainability, competitiveness and security of supply targets up to 2020[2]. To elevate hydrogen research to a cohesive industrial scale, a Council Regulation officially established the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) on May 30, 2008, under the Seventh Framework Programme (FP7). Operating with a total matched budget of €940 million—split equally between a €470 million public contribution from the European Commission and industry/research stakeholders—the FCH JU drove the maturation of core technical components (clean-hydrogen.europa.eu/about-us/our-story_en). Building on these successes, in 2014 the Council of the European Union agreed to extend the initiative under Horizon 2020 (FCH 2 JU was established with Council Regulation (EU) No 559/2014).

Running through 2020, this second-generation partnership expanded its matched budget to at least €1.33bn (including a €665 million public contribution), focusing heavily on accelerating commercialisation, driving down product deployment costs and securing European global leadership in megawatt-scale electrolysers and refuelling stations (*clean-hydrogen.europa.eu/about-us/our-story_en*)[3].

[2] The regulatory landscape shifted further with the 2005 launch of the EU Emissions Trading Scheme under Directive 2003/87/EC, which penalised carbon-intensive processes and made low-carbon alternatives more competitive.

[3] The post-2020 modern era represents a major regulatory shift, marked by the formal release of the "Hydrogen strategy for a climate-neutral Europe" by the European Commission in July 2020,

Moving fundamentally away from historical carbon-intensive grey hydrogen, post-2020 policies explicitly prioritise green hydrogen to close emission loops, interconnect hard-to-abate sectors and establish a circular energy economy (Clean Hydrogen JU SRIA, 2022; Vivanco-Martín & Iranzo, 2023; Eikeland et al. 2024). As mentioned above, the modern Clean Hydrogen Joint Undertaking was officially institutionalized on November 19, 2021, under Council Regulation (EU) 2021/2085, narrowing its primary production funding exclusively to renewable pathways.

1.2 Synthesis of Strategic, Macroeconomic, Geopolitical and Policy Contexts

The strategic positioning of the Clean Hydrogen Joint Undertaking (JU) is contextualised within the intensifying global cleantech competition, acute macroeconomic friction and the relatively rapidly evolving European regulatory architecture. Globally, the European Union faces a critical race to secure industrial competitiveness against major state-backed strategies (Zabanova, 2024; Eikeland et al., 2024; Vezzoni, 2024; Tomomewo et al., 2026). In the United States, the 2022 Inflation Reduction Act (IRA) has introduced generous production-based tax credits creating a powerful fiscal pull that threatens to displace European manufacturing capacity (Zabanova, 2024; Tomomewo et al., 2026). Concurrently, China has captured over half of global manufacturing capacity by leveraging lower labour costs, state-directed industrial clusters, and massive domestic deployment to produce equipment at capital costs several times lower than Western counterparts (Tomomewo et al., 2026). To counter these external pressures and safeguard industrial sovereignty, the EU has deployed aggressive economic de-risking tools, including state-aid relaxations under the Temporary Crisis and Transition Framework (TCTF), Important Projects of Common European Interest (IPCEI) funding waves, and European Hydrogen Bank (EHB) competitive auctions designed to bridge the green premium.

Despite these extensive interventions, the sector faces severe macroeconomic hurdles during its market ramp-up. A persistent gap remains between ambitious policy targets and private Final Investment Decisions. Real-term capital expenditure for multi-megawatt projects significantly exceeds early techno-economic models due to grid connection charges, supply chain bottlenecks, and rising interest rates (Bolard et al., 2026). High electricity input costs—accounting for up to 90 percent of operational expenditure—combined with low initial factory utilization rates (~10%), hinder the realization of the economies of scale necessary to drive down production costs (Bolard et al., 2026; Delpisheh et al., 2026). Externally, while REPowerEU import targets establish vital international trade corridors, they also expose complex socio-political risks, including local water

---

which established an explicit roadmap to deploy at least 40 GW of renewable hydrogen electrolyser capacity within the Union by 2030.

stress and broader ethical critiques regarding resource equity (Zabanova, 2024; Buonomenna & Patonia, 2025; Joint Research Centre / Clean Energy Technology Observatory Report, 2025).

Complementing this economic landscape, the statutory mandate of the Clean Hydrogen JU is anchored in the Council Regulation (EU) 2021/2085, directly binding its research and innovation agenda to the European Climate Law (Regulation (EU) 2021/1119). To implement REPowerEU targets of 20 million tonnes of hydrogen by 2030, the "Fit for 55" package established binding demand-side mandates via the revised Renewable Energy Directive (RED III, Directive (EU) 2023/2413), requiring Renewable Fuels of Non-Biological Origin (RFNBOs) to constitute at least 42% of industrial hydrogen use by 2030. These targets are governed by strict Delegated Acts enforcing additionality, temporal correlation, and geographical correlation, alongside a 2025 framework for low-carbon and pink hydrogen.

Furthermore, market deployment is reinforced by the Alternative Fuels Infrastructure Regulation (AFIR, Regulation (EU) 2023/1804), sector-specific decarbonization tools like FuelEU Maritime and ReFuelEU Aviation, and the Carbon Border Adjustment Mechanism (CBAM, Regulation (EU) 2023/956) to prevent carbon leakage. Finally, the Net Zero Industry Act (NZIA, Regulation (EU) 2024/1735), the Clean Industrial Deal, and the Critical Raw Materials Act establish crucial domestic benchmarks—targeting 40% domestic production capacity and 100 GW of electrolyser manufacturing by 2030—to ensure Europe remains a competitive leader in the global clean energy transition.

1.3 Objective of this study and organisation of the report

The aim of this study is to investigate translational research pathways into innovative outcomes, that is understand how, partnerships and their projects manage the application of the findings originating from their research activities and navigate the journey to delivering innovation. The report focuses on the activities of the Clean Hydrogen Joint Undertaking and its projects using 1) a Science, Technology and Innovation approach into interpretating R&I activities and 2) analysis of the relationship with the wider European economy mediated by the Hydrogen Valleys, a policy instrument linked to defined geographical areas (cities, regions or industrial clusters) involving sectors where Hydrogen technologies have an economic, environmental and social impact.

The themes have been selected on the basis of our previous research into impact assessment of partnerships, methodology design and validation, in consultation with EC Officers, the ERA-LEARN Advisory Board and ERA-LEARN Partners.

The remainder of the report is organised as such. In the next section – SECTION 2 - we describe the methodology followed to investigate the Clean Hydrogen JU translation activities and the pathways to Innovation.

In SECTION 3 we delve deeper into said translational activities by providing the findings of our fieldwork analysed through the lens of a Science, Technology and Innovation perspective.

In SECTION 4, we present a socio-technical and policy analysis of the regional dimension of the Clean Hydrogen Partnership. Here look at how the Hydrogen Valleys are creating market space for emerging hydrogen technological systems.

Finally, in SECTION 5 we provide a discussion of the issues previously analysed highlighting the variety of pathways to impact and the hurdles they overcome in the process.

SECTION 2. METHODOLOGY OF THE STUDY

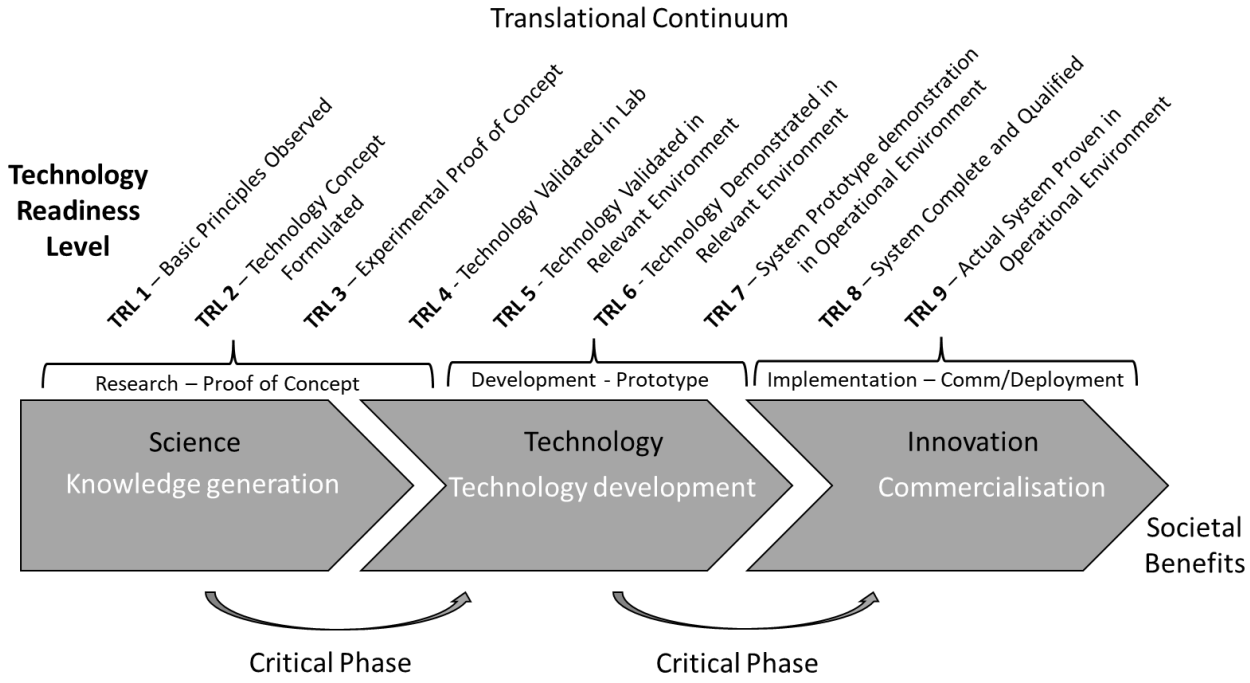
This section outlines the methods used to investigate pathways through which the transnational partnership generates long-term impact. This study deliberately distances itself from traditional programmatic or summative evaluations, functioning instead as an exploration into how research translates into practical innovation for business and society.

The research design focuses on studying the translational journey from research to innovation investigating the diversity of R&I pathways. We apply a dual-track analytical framework configured to pursue two separate but interrelated lines of enquiry. 1) in line with Title III of the Council Regulation (EU) 2021/2085, one track investigates the general translational journey from foundational laboratory science to commercial applications, mapping out the progression, metrics and bottlenecks across the technological development milestones and carried out together with its beneficiaries (Art 78.1 and the Clean Hydrogen JU objectives). 2) the second track explores the R&I pathways within the spatial and territorial dynamics of transition, focusing explicitly on the regional policy dimensions, smart specialisation strategies, and local cluster networks that define the real-world deployment of European Hydrogen Valleys (Art 78.2 and RePowerEU – COM(2022)230 final).

The translational continuum and the relative R&I pathways are explained as such:

The translational journey and the translation continuum.

In general terms a translational journey is the pathway through which research results such as discoveries and proofs of concepts find their way to practice and the market. We recognise that the translation journey is fraught with uncertainty and cannot be easily and linearly deconstructed in practice. However, we use the translational continuum as a ‘tool’ or ‘shorthand’ to simplify the journey from basic research (i.e. principles observed - proof of concept), to applied research (i.e. validation), development (i.e. demonstration and prototyping), and other activities facilitating use of products and services on their way to market (implementation and commercialisation).



Primary empirical data collection was operationalised through a qualitative interview campaign that engaged a varied group comprising over twenty-four key stakeholders of the Clean Hydrogen JU ecosystem.

To ensure a multi-level perspective capturing the views of all stakeholders a purposive sampling was adopted across all aspects of the innovation lifecycle, we interviewed partnership board executives from the three types of partners including a representative of the research stakeholder groups, a representative of the business community and a policy officer within the European Commission Directorate dealing with this specific partnership. We have also interviewed Clean Hydrogen JU senior management team representatives, regional agents and policy makers.

The institutional viewpoints were complemented with ground-level insights collected from regional development facilitators, national industrial chamber executives, and beneficiaries such as researchers and engineers operating in business, applied research organisations and universities driving fundamental scientific exploration and applied research activities.

The primary data gathering process relied upon a semi-structured, highly conversational interview format designed to capture narrative nuances rather than a rigid question-and-answer survey.

To facilitate cross-comparative validity while allowing informants to elaborate on their specific operational mandates, we deployed a standardised, open-themed interview script and protocol kept identical for all participants. This protocol was structured around eight core analytical themes—including collaborations, infrastructure, technical capability building, and marketisation

trajectories—supplemented by detailed explanatory textual guides embedded beneath each primary query to maintain conceptual clarity during data collection.

Informants were permitted to pre-fill these scripts or submit additional supporting documentation, data matrices, and national strategy papers via email to enrich the final empirical material.

To guarantee scientific rigor and manage the dense volume of qualitative accounts, all recorded interactions were transcribed verbatim and a systematic comparative analysis has been conducted using the Gioia method (Gioia et al, 2013, Gioia, 2021). This qualitative technique enabled us to categorise first-order operational concepts into second-order structural themes and then allowing for a more in-depth analysis of the findings. The analytical framework and findings of the study have been further validated with stakeholders: advanced report drafts were shared with the respondents to verify the accuracy of the statements and ensure conceptual alignment before final publication.

The fieldwork was initiated only after obtaining formal ethical clearance from the University of Manchester (Proportionate UREC N.2025-21433-39416), and all data processing steps were executed in full compliance with General Data Protection Regulation mandates, using formal informed consent forms and ensuring anonymisation across final reporting outputs.

SECTION 3. PATHWAYS FROM RESEARCH TO INNOVATION

1. Introduction

The translation of hydrogen technologies from foundational laboratory discoveries into active commercial deployment is not a linear process; it is characterised by a highly fragmented pipeline and high rates of attrition. The hydrogen science, technology and innovation 'continuum' presents structural gaps between low-TRL fundamental science and high-TRL – industrial applications. Moreover, the hydrogen economy is frustrated by unpredictable market frictions and diverging institutional/market-based incentive systems. The framework within which the Clean Hydrogen Joint Undertaking operates includes the whole translational continuum and a wide spectrum of technological development fields tracking progress from technology readiness level 2 (formulation of technology concept/application from basic principles) up to technology readiness level 7 or 8 (technology working in pre-market/controlled settings). By institutional design, the partnership avoids allocation of public funds toward basic, blue-sky academic research aimed at fundamental discovery without a predefined technical concept or a clear industrial target. Instead, it implements a structured public-private partnership model established to co-ordinate and align the motivations of its constitutive actors across Europe (Clean Hydrogen JU SRIA and 2 Interviews).

Within this framework, our impact assessment of the Clean Hydrogen JU ecosystem brings to the fore that pathways from early materials discovery to real-world industrial validations is deeply non-linear, frequently interrupted by operational and operationalisation challenges, disclosure dilemmas and misaligned of institutional boundaries across the different tiers of the innovation lifecycle.

The fundamental justification for the Clean Hydrogen JU architecture rests upon the realisation that hydrogen (and green hydrogen in particular) does not function as an isolated commodity entering an already fluid or mature market. Rather, it emerges and negotiates its role in the green economy from a complex systemic infrastructure that demands the simultaneous maturation of production methods, transport logistics, storage designs and specialised end-use applications. All these are supposed to happen in very varied industrial settings spanning from transportation, energy, materials and others. Historically, European research funding has suffered from a disjointed operational approach, where early-stage academic breakthroughs remained isolated from commercial supply chains due to a lack of co-ordinated transition mechanisms (Clean Hydrogen JU SRIA). By bringing together public policy officers, researchers, and industrial partners into a unified governing board, the joint undertaking framework enhances these

uncoordinated development loops with an integrated approach to the European Hydrogen ecosystem. Yet, despite a comprehensive institutional strategy, the real-world trajectory for clean hydrogen translation of research into impactful innovations continues to face deep strategic tensions between the long-term, non-commercial horizons of fundamental science and the immediate, risk-averse constraints of the industrial market.

The structural configuration of the partnership seeks to resolve most of these tensions by ensuring that all parties involved in the European Hydrogen Ecosystem are sitting at the same table and that technology validation is systematically monitored through observable metrics. At present, though, according to our informants, the reality remains highly fluid.

There are several high-level findings of our study that point towards the fact that, from the perspective of such a large institutional programme, the strategic alignment of research targets must continuously adapt to shifting external pressures as diverse as international technological breakthroughs and major macroeconomic supply shocks. This fluid landscape demands that partnership executives maintain a highly dynamic oversight mechanism, balancing the prescriptive guidelines of the baseline research agenda with the practical realities of industrial supply chains. At the same times, these aspects place major pressure on the beneficiaries, both those involved in applied research and in industrial applications to adapt operations to the shifting market conditions, institutional demands and public research standards. As a result, the translation of research into the innovation pathways is not only a Science & Engineering challenge, but an institutional management exercise that requires continuous recalibrations of the multi-stakeholder incentives across the entire European Hydrogen research and innovation community.

2. Findings from the fieldwork: R&I pathways to impact

The operational realities of the green hydrogen lifecycle highlight sharp variations in stakeholder roles and regulatory demands across successive technology readiness level milestones.

At the earliest stage of frontier science and material exploration, corresponding to early to TRL 3, university researchers drive fundamental exploration, focusing on complex micro-level phenomena. The list of beneficiaries, especially universities and public research organisations, involved in such fundamental research spans all aspects of H2 science from projects devoted to cleaner and more efficient methods of hydrogen production, to storage and use in a ‘greener’ hydrogen economy. Early phases of research are focusing on modelling and testing (i.e.

mechanical stress, thermal conductivity and contact mechanics under extreme conditions)[4]. There are, in fact, academic groups involved in devising and testing novel methods of hydrogen production and utilisations including projects focusing on the re-evaluation and the engineering of retrofitting old industrial applications enabling the employment of newer and cleaner hydrogen-based methods, other groups are working on specialised cryogenic insulation concepts producing critical baseline calculations to develop insulation technologies for long-distance transport of liquid hydrogen. Within this great variety of projects[5], university and public organisation researchers are responsible for developing the theoretical and numerical models to capture the underlying details of the "*mechanisms of production, transportation and storage and use of hydrogen operating at the theoretical and low-scale/experimental conditions*" characteristics of more fundamental research.

Applied research and technology organisations, including some important market players in the energy and technology areas, set out to integrating models and processes originating from foundational research and early development to technological solutions characteristics of the high-tier readiness levels. However, these foundational phases – academic research and technology integration -, even though progressing into seemingly integrated projects, remain quite distinctive especially concerning institutional reward structures centred strictly on academic publishing, system engineering and, finally, markets dynamics. These different institutionalised reward structures frequently delay technology transfer because, for example, academic beneficiaries may not be well versed in protecting the intellectual property generated through patenting activities and, at the same time, patenting strategies, requiring non-disclosure of data, may delay publication of findings[6].

As foundational projects transition toward meso-level applied research and platform testing, corresponding to TRL 4–6, they encounter a structural data paradox. While public funding rules under early joint undertaking calls frequently mandate that project deliverables remain public to ensure open data dissemination across the research community, commercial OEMs/businesses and research organisations require some form of protection (i.e. non-disclosure agreements) to shield proprietary engineering designs from market competitors. This friction is highly pronounced

---

[4] These operations require high-cost and specialist machinery, high-resolution physics modelling, drawing from thermodynamics and basic contact mechanics to predict structural durability under stress such as thermal strain or high pressure.

[5] https://www.clean-hydrogen.europa.eu/projects-dashboard/projects-repository_en

[6] This aspect was brought up by several informants from different points of view and will be discussed further in the reminder.

especially during component-level scaling operations usually managed by independent research organisations.

Applied research organisations, whether embedded within universities, other public bodies or research technology organisations, are engaged in specialist tasks – testing and analysing single cells, low-temperature technologies, pipeline valves etc. - "*under realistic conditions to test particular technologies or components to investigate/validate operational limits*". To make these benchmarking activities reliable across borders, "*businesses supply commercial-grade settings and specialised components to [*research units*] for testing", "participating in comprehensive round-robin testing configurations designed to standardise characterisation protocols before attempting system upscaling*". RTO platforms often act as neutral validation intermediaries, balancing the public need for open validation data with the private constraints of proprietary corporate clients.

When innovations advance into higher-TRL (industrial system integration and field demonstration), TRL 7 and above, the execution responsibilities shift entirely to large corporate engineering teams and business researchers focusing on system efficiency, lifecycle costs and modular configurations. At this deployment stage, projects must withstand real-world industrial environments, which introduces severe micro-level failure risks that were previously invisible during laboratory simulation. For instance, "[maritime fuel cell] *modules developed in joint projects encounter aggressive performance degradation due to salt-air particulate contamination*" this means that when technologies are introduced in real-world testing conditions there are additional operational requirements to consider and new technical solutions to be found. In this specific case, our informant talks about "*multi-stage ambient filtration systems to avoid common failure modes in open sea waters*".

It emerges that, in this phases, technological choices force systems integration engineers to account for environmental interactions early in the module design phase. In other contexts, for example, "*retrofitting heavy industrial furnaces from natural gas to oxyfuel-hydrogen combustion eliminates carbon emissions but radically intensifies internal water-vapor concentrations within the furnace atmosphere*". This means that retrofitting hydrogen fuel into existing technologies may need further adjustments which were not be immediately evident during the project development: "*it is observed that accelerated water-vapor production causes severe chemical corrosion and structural cracking of standard ceramic refractory linings"* these occurrences then require further specific research into real world industrial applications. In this specific case the informants referred of new research on: "*high-temperature composite materials to avoid catastrophic furnace*

failures during extended trial operations" (these examples were reported by academic researchers).

Also, it is important to highlight that translating operations from the research benches to the real-world, especially when operating in hybrid environment, means that standardisation, security and safety need to be assured early and in operative shop-floor conditions and not in laboratory conditions. This means that "*securing commercial certifications, CE markings and local safety approvals add other non-technical layers of risk"* which *"must be managed by factory operators while running twenty-four-hour manufacturing plants with workers on the floor*" (reported by applied researchers / company's scientists).

Further analysis of the information obtained during our fieldwork uncovers another level of understanding of the non-linearities, deadlocks and structural shocks affecting exogenously the functioning of hydrogen economy and of the activities of the Clean Hydrogen JU. Whilst our reporting of the analysis along the Technology Readiness Level (TRL) framework provides a standardised reference across impact pathways, it risks creating a false impression of a smooth, sequential progression. **The empirical reality of devising and deploying the Partnership's strategy through its activities and its projects demonstrates that translating research into fully fledged innovation is not simply an engineering feature nor technical validation at a high TRL guarantees commercial market entry. Technological progress routinely encounters non-linear systemic blocks that force projects backward into infrastructural re-engineering or prolonged market stagnation.**

The non-linear nature of these pathways is starkly illustrated by sudden macroeconomic and geopolitical events that invalidate initial technical roadmaps mid-project, forcing consortia to radically alter their underlying design parameters. One of our informants provided an example of how a logistical disruption caused by continental infrastructure sabotage, changed their R&D timeline: "*the whole plan from the EU was* [either]*… to transport or … import hydrogen by pipelines. Later on, there was attack on the German pipeline and … the transport pipeline could be not very useful... So then … in 2024* [transport] *by sea because … sea transport is much more flexible*". This sudden shift required to rethink the possibility of developing a maritime transport system that was entirely unmapped during early planning phases.

Structural disruptions are bound to present whenever new high-level policy priorities are set; this is corroborated also by other informants, for example, the strategy manager of a hydrogen foundation tracks how rapid modifications of the European policy forced their facility to re-engineer testing infrastructure "*to match changing political priorities of the European Union in 2019... But*

everything changed with the European strategy, with the REPowerEU after the war in Ukraine and COVID... "

Furthermore, **research pathways are characterised by a decoupling between high TRL hardware validation and commercial deployment, a non-linearity that leaves mature technologies stranded in a market standstill**. Technical beneficiaries find that achieving high technology readiness levels does not automatically translate into a viable business opportunity due to lagging commercial readiness parameters. A Research Director outlines this point explaining that the transition between market-ready technologies and their effective introduction in the market has devolved into an industrial waiting game driven by corporate risk aversion: "*While technology as such has reached typically could be TRL 8, it doesn't really, or it doesn't necessarily mean that it's picked up by the market... The green transition is currently, … stagnating somewhat... given the turbulence and the reluctance and stagnation* [driven by] *risk adverse behaviour* [where] *you can see the oil and gas companies kind of milking the old cow a little longer compared to what they at least is bragging about in their speeches* [sic.]"

This stagnation means that **while individual project consortia successfully achieve (and more often exceed) their contractual TRL targets within the protected boundary of the Partnership, the macro-level impact on the broader European hydrogen economy remains somewhat missing.** An informant offers a highly critical assessment of the translational pipeline by noting that despite successful project-level scaling, "*the macro-level impact has still been quite small at this stage*" because global fossil fuel use continues to rise steadily and is not being phased out anytime soon. This macro-level lag is explicitly recognised also by our institutional informant, who warns that the pathways to impact cannot rely on minor laboratory successes but must rapidly achieve massive technology deployments to create the critical mass necessary to make the entire funding stream sustainable "*otherwise, you don't create the critical mass to make it sustainable*".

Overall, looking at the European hydrogen economy, there are clearly gaps in the pathways to innovation that **require not just policy attention but the orchestration of multiple competencies in terms of capabilities and in terms of complementary assets** - testing platforms, machineries, large infrastructure and application technologies -. In other words, the European hydrogen economy, whilst well positioned in several aspects such as foundational science, science-based specialised providers and has several important industrial players (with both global reach and local/small and medium sized enterprises), presents critical gaps especially in the types of investments for scale-up and diffusion of technologies.

The Clean Hydrogen JU appears **particularly well positioned to bridge some of these gaps** since it operates as coordinator across the stakeholder groups of the European hydrogen economy and has competences in several interconnected science and technology domains. The board executives explained how the partnership "*deploys non-overlapping cross-sectoral synergy architectures across projects and ensures that foundational material discoveries are systematically matched with secure, demand-driven commercial value chains*". Importantly, the Clean Hydrogen JU bridges core sets of technologies and innovation areas linking them to other partnerships and joint undertakings by 'promoting' hydrogen-based technological solutions without interfering with the operations of said partnerships.

However, this configuration ensures that public funding is used efficiently by connecting overlapping and complementary areas of R&I whilst avoiding duplication of initiatives, it allows specific partnerships to manage their own strategies in their respective (industrial) sectors whilst linking to hydrogen technologies and maintaining, the however large, organisational costs confined within single partnerships. There are many examples of cross sectoral dependencies but we should consider that such dependencies highlight the necessity of maintaining dense and non-overlapping connection lines between different specialisation areas both within the Clean Hydrogen JU and with other partnerships to ensure that technical requirements flow seamlessly across sector boundaries. As one informant remarked: "*without this co-ordination, individual initiatives risk selecting sub-optimal technology configurations, leading to premature component failures or costly design modifications during active field trials*". In this context, cross-sectoral synergy mapping represents not merely an administrative exercise, but a critical operational requirement for ensuring the long-term durability of European clean energy systems. Nonetheless, this configuration does not provide the magnitude of investments, public and private, that some of our informant believe it to be necessary for accruing the critical mass nor in anyway comparable to those of Europe main counterparts in the hydrogen economy namely China and the US.

In the reminders we will be looking in more detail the various aspects of impact generation pathways specifically: 1) Collaborations, 2) Infrastructure, 3) specialist technical knowledge, 4) capacity building and 5) ways to markets. We then conclude with some informant-led observations on factors and measures of success.

3. Collaborations and R&I pathways to impact

Partners and the senior management team have a dual cognition of collaboration one consistent with the structure of the JU and the other concerning their 'place' in the European hydrogen economy. specifically: 1) as a shared public-private partnership where top-down policy guidelines

from the European Commission blend with bottom-up technical advice from industrial partners and the research community. 2) as strategic positioning whereby to maximise the impact of public spending, partnership board executives see the JU as central to sectors where hydrogen may "*actually or potentially*" play a critical role[7].

For the beneficiaries on the ground, collaboration is defined by the melding of divergent priorities of university researchers, independent applied research organisations, infrastructure providers, governmental organisations and businesses across the hydrogen value chain. Whilst we have seen some such examples in the previous section, it is opportune to highlight that there are levels of dependency which differ enormously from case to case. To this extent it is necessary to understand where such dependencies lie in order to minimise attrition and foster successful collaboration ventures.

Focusing on R&I pathways, evidence reveals that collaborations function as a means to highly technical, interdisciplinary co-creation process that is exceptionally successful at low TRL boundaries but faces severe translational challenges as it approaches high TRL market demonstration.

At the foundational stages of the R&I Process, collaboration is driven by the necessity of data validation and cross-disciplinary integration. Consortia successfully combine distributed public laboratory assets through extensive round-robin testing to eliminate experimental variances and generate reliable baseline models. This technical co-dependence forces separate academic fields—ranging from high-pressure cryogenics to contact mechanics and thermodynamics—to establish a shared basic research and engineering nexus, directly feeding empirical data into more theoretical models in order to advance through higher TRL and overcome the "*burden of novelty*" such as international standardisation to close current pre-normative legislative gaps. It is important also to acknowledge that, in order to advance towards higher TRL, early-stage R&I collaborations rely heavily on institutional delegation. One such example can be that of academic scientists at universities driving early-stage innovation by studying basic physics and material properties under extreme (either cryogenic or high temperatures) conditions. These actors rely heavily on industrial partners to supply substrate variations or specialised test materials. Also, scientific networks tend to leverage centralised technology transfer offices and specialised legal

[7] This, according to one of our informants, is also "*a sort of structural alignment which aims at ensuring that the primary development of hydrogen technologies remains within the core hydrogen partnership*", while its practical applications extend in the wider ecosystem "*without duplicating funding efforts across the Commission*".

departments/offices to manage intellectual property filings and patent protections at the project's inception, allowing laboratory researchers to focus entirely on the research and engineering challenges.

However, as R&I pathways move beyond the proof-of-concept stage, collaborations are - sometimes severely - disrupted by non-linear structural shocks and a profound communication gap between public research organisations and other actors emerges. This is mostly due to the fact that the academic reward system is built upon continuous publishing and this directly compromises the commercial requirement to keep data hidden for commercial exploitation/patenting etc.. In fact, moving along the technology readiness level continuum, we can see how frictions may extend directly to applied research organisations, whereby lab teams on intermediate testing platforms are found to continuously balance the public data-reproducibility mandates with the private corporate/commercial demands employing complex round-robin testing setups with strict non-disclosure agreements.

Another aspect, evidenced by several of our informants, concerns "*the linguistic barrier*". Academic institutions and engineering organisations routinely fail to translate complex physics and/or experimental metrics into the simplified, business-ready parameters required by venture capitalists. To this extent, high-TRL collaborations require systematic integration of "*specialised systems engineers translating laboratory findings into commercial speak*". Overall, the translational pipeline does not operate as a smooth technology handover from one TRL to the next; and even at the end, when technologies or components begin to take shape for market deployment, the handover is constrained by the conflicting "*differences in risk appetites*" of RTOs and large industrial OEMs. While public researchers are eager to deploy validated innovations, large energy companies frequently adopt risk-averse behaviours, choosing to delay capital deployment to extend the lifespans of their traditional assets.

4. Research and Technology Infrastructures

The research and development pipeline within the clean hydrogen ecosystem relies on a tiered distribution of physical infrastructure across separate institutional actors. Rather than operating within a single centralised laboratory framework, asset provision is divided systematically according to i) technological maturity and ii) sectoral necessity. In particular, infrastructure resource pooling is almost exclusively employed in early-stage R&I projects relying on university laboratories for digital/numerical simulation platforms, thermodynamic modelling tools, and custom low-scale testing rigs designed to evaluate basic material characteristics pushing towards 'theoretical' extreme conditions. Progressing towards proof-of-concept, Research and Technology Organisations (RTOs) tend to provide more advanced/mid-stage testing

infrastructure, including specialised high-pressure gas exposure loops, environmental validation benches capable of operating within safety thresholds. One informant observed that "*all the partners have the existing infrastructure that is needed to carry out the work... Between all of us, we have what we need to put it this way*."

Physical self-sufficiency access to basic infrastructure allows low-TRL consortia to standardise data regimes and implement synchronised testing networks across separate international public bodies.

Of course, in many projects there is also the need for using larger scale infrastructure especially when projects move towards integrating early-stage components into larger technologies. For example, an early phase translation of technologies into existing infrastructure presents its own peculiarities. One informant reported that retrofitting high-temperature manufacturing infrastructure with hydrogen fuel "*creates severe physical volatility, explicitly reporting that the main risk is safety... it is to have an explosion in the furnace*." To manage this infrastructural threat, a strategy is to build parallel digital frameworks; an informant explaining that: "*we have PhD students working on modelling to map … profiles before running live gases through the physical pilot lines*". This use of digital infrastructure assets is heavily complemented by the broader European data repositories constructed at the programmatic layer. A European Commission official highlights that the data generated across these networks is systematically funnelled into a centralised digital architecture, describing it as a public infrastructure asset designed to remain openly accessible: "*you have now a quite big amount of information, a wealth of information that you can access and to help build up your knowledge and publicly accessible as well*." Here, the integration of physical, digital and simulated testing environments allows open-access research infrastructures to function as critical upscaling facilities especially when deployed synergistically within multi-user engineering hubs is configured to test larger undertakings such as megawatt-scale hardware configurations under realistic operational loads. A partnership executive specified that "*By absorbing the capital-intensive costs of initial hardware scaling, these research infrastructures provide the empirical proof required to lower early-stage technological risks to a point where private industrial partners can confidently invest in full-scale commercial manufacturing plants"*.

However, interviewees highlighted how their reliance on internal (to consortia) infrastructure whilst fundamental at the early stage of research and development "*become soon insufficient to progress towards commercial transition on their own*". Beneficiaries across all types "*depend fundamentally on the availability of externally available infrastructure*". One such example provided by one small company researcher is that: "*intermediate RTO testing*

platforms provide physical validation benches, but we rely entirely on external corporate hardware infrastructures to establish reliable operational benchmarks". In other words, to make benchmarking activities reliable across the various phases of integration – necessary for validation of emerging technologies (and their components) –, rigorous testing and prototyping must be performed with the technologies in real-world conditions and these tests can be executed only in large public and corporate infrastructure.

Also, as technologies progress toward a close-to-market stage, they will need testing in conditions that are close to the environments (real-world or technological) where they are supposed to operate; in such context, **managing physical innovation infrastructure becomes highly intertwined with 1) regulatory frameworks and 2) shifting/evolving legislation.** The risk that high-TRL hardware demonstrations are blocked from real-world operating environments due to compliance rejections is very high, perhaps as high as the need to make sure that testing is accurate and reliable in different settings, and that prototypes and market-ready parts can work together outside of laboratory conditions. One informant referred of a case whereby "*a multi-million euro … demonstration had to be rapidly re-engineered into an isolated laboratory simulation because the physical technology failed to secure compliance with regulation*" in the end, testing was performed forsaking real-world conditions but it was noted that "*high-TRL infrastructure management is frequently forced to decouple from physical market assets and retreat to controlled institutional environments to complete technical validation*".

Shifting legislation and change of policies are also greatly affecting operational conditions with repercussions on large scale (and capital intensive) infrastructure; "*a mere change in the high-level strategic roadmap from hybrid (gas blending) rigs to pure hydrogen stream*" at the European level, forced several stakeholders/beneficiaries "*to overhaul their testing infrastructure mid-project*. … *The change in the operational maintenance of complex high-pressure installations … caused great cost …*[and] *the need to independently train specialised technical workforce. And these people, they are not researchers, they are technicians*".

To conclude, beneficiaries perform multiple rounds of testing on the same technologies under different conditions allowing the parties involved to work towards a standardised set of rules and testing methods. These activities can ensure that pieces of technologies work safely and predictably before full-scale systems – and relative investments - can be manufactured. At the same time, it is necessary to underline that large capital investments either at European, national or local level, serve the partnership and its beneficiaries in those operations fundamental for their functioning, such as pipelines for Hydrogen transportation, ports, heavy transport terminals, large

furnaces etc for real-world trials in industrial settings, and large digital and data infrastructure for computation and analysis.

5. Specialist technical knowledge

In a highly complex sectors like the hydrogen economy, core R&I progress depends also on the continuous availability and reachability to external (to the Partnership and to the projects/consortia) specialist knowledge. We may specifically think about standardisation processes, testing under special conditions, but also reach out for legal, business and management, intellectual property frameworks or specific logistics. Most of these types of specialist and technical knowledge often reside outside the primary boundaries of the partnership and/or project consortia. The capacity of the partnership and/or project consortia to systematically access ancillary technical, legal, and pre-normative knowledge structures acts as a critical determinant of a project's translational velocity. Specifically, academic and applied research organisations frequently lack the internal legal literacy and specialised infrastructure required to navigate international patent applications, safety certification protocols, and volatile logistics landscapes. To prevent administrative friction from stalling scientific execution, high-performing consortia implement explicit structural delegation strategies to delegate these "*burdens through highly organised institutional hubs*". The system engineer and project coordinator informing us on this issue outlines a centralised model where international scientific partners entirely transfer their non-technical legal protection burdens to a designated coordinator to exploit institutional economies of scale: "*We take the opportunity to cooperate with XXX, … . They have a very well organised lawyer office [sic.]... We fed them with the technical and scientific details, but the administrative part of the patent is being handled by them... This is how we decided to move forward in order to avoid all that you mentioned, you mean mainly lawyers, advocators, things like that*".

This deliberate administrative delegation allows laboratory researchers to focus exclusively on their research and innovation activities while ensuring that the resulting intellectual property remains legally protected.

However, where such centralised institutional structures are absent, academic partners rely heavily on their internal Technology Transfer Office to secure early-stage assets before commercial exposure. Such strategy, can be further carried out as technology development progresses through higher TRL. The academic coordinator of a project reports that "*early legal intervention is an uncompromisable* [sic.] *prerequisite for close-to-market translation*", noting that their university's Technology Transfer Office actively reviews early laboratory breakthroughs and

moves rather swiftly to submit patent applications because "*there is no commercial reason to proceed with the publication of experimental findings if early-stage protection is left unmanaged*".

Of course, as hydrogen technologies advance toward high-TRL industrial applications, the requirement for ancillary specialist knowledge transitions sharply from baseline patenting law to highly complex pre-normative standardisation and technical safety to meet engineering guidelines. Consortia operating at the boundaries of innovation find that standard rules for new technologies are only emerging and that there are many areas of ambiguity, forcing them to produce the empirical safety metrics required by global standardisation bodies. A project coordinator emphasises this structural gap outlining that working in the area of extreme cryogenic transport regimes "*requires combining distinct engineering disciplines to actively provide data inputs for missing international rulebooks. This is an interdisciplinary area." …* and there are several scientific disciplines involved at each stage and along the different R&I hydrogen pathways *... "we need to standardise this area, provide input for standards to be developed. At this time, there are several gaps*" and this is true also in the other developing hydrogen R&I (from hydrogen production to transport/storage and the different technological uses including integration into existing technological regimes).

Likewise, **when projects attempt to deploy close-to-market hardware without integrating certification and classification expertise from the outset, they face rather high hurdles especially when integrating their effort within real-world operating environments.** Sometimes these may end in operational failure. One informant documented that the deploying a fuel cell demonstration suffered severe late-stage delays because their engineering team failed to link early testing within the appropriate classifications: "*This is a strict warning that you must seek permits early and identify regulatory problems at the project's inception, otherwise the entire physical deployment will fail*". In other words, the R&I leaders must look beyond pure engineering parameters and maintain continuous outreach to external compliance organizations like to secure a string of authorisations and certifications go beyond those of Health and Safety applied in the labs. One of our informants listed a series of compliance activities that are potential hurdles for project progression "out of the lab" these include – but are not limited to -: *official fire brigade authorisations, safety interpretations, and CE markings etc. ".*

Finally, as already mentioned, these processes are heavily vulnerable to external shocks that can potentially disrupt technical planning (such as the sabotage of pipelines or change in the RED III directives) and steer consortia to needing acquire different specialised knowledge at a very short notice. To manage these cross-cutting challenges programmatically, one of our contacts in the Clean Hydrogen JU informed us that "*the partnership has structurally institutionalised a dedicated*

horizontal pillar explicitly tasked with supplying pre-normative research, centralised safety guidelines, and curriculum models to project participants, ensuring that technical consortia are not forced to source this vital specialist knowledge in total isolation".

6. Capacity building

The instituted reliance on structured capacity-building initiatives function as a **vital mechanism to foster and protect the long-term knowledge pipeline of the European hydrogen ecosystem.** Specifically, academic and technical beneficiaries do not view degree programs and technical training as isolated educational targets; instead, in most cases, they embed higher-tier educational and research programmes — including PhD positions and Master's engineering programmes — directly into the operational architecture of their R&I work packages. This is particularly evident at the lower tiers of the technology continuum where the acquisition of advanced scientific competence relies heavily on leveraging university research talent to pioneer and apply novel scientific ideas and discoveries, computational simulation models and of digital infrastructure[8]. As we saw in the previous section, universities usually implement computational methods and digital simulations to predict and validate physical models before application reach the real world. This work is usually done through research project associated to post-doctoral studies and PhD projects (as evidenced by several informants).

This reliance on advanced academic training becomes obviously mandatory when consortia venture into highly complex, interdisciplinary scientific/technical domains where little pre-existing literature exists to guide research and engineering choices. Several academic coordinators and scientists we have interviewed outline that even exploring one single characteristic (i.e. material safety, durability etc) at extreme conditions requires a level of scientific literacy that cannot be fulfilled by standard training and require the "*production of new theoretical knowledge… and empirical validation*". Of course, in highly volatile or dangerous areas, before embarking physical experimentation, is necessary/appropriate "*to simulate and compute possible outcomes under given conditions*".

According to our informants, the data generated across these academic activities is subsequently pooled and act as a cross-organisation knowledge base. To ensure that the 'distributed' academic work (both in terms of theory and empirical findings) are analysed and exploited across the

[8] We would like to recall the contribution of a European Commission official that we reported in the previous section (on infrastructure) according to whom, the digital infrastructure is a bedrock of higher education and postgraduate research especially concerning testing data generation and computational facilities.

different beneficiaries' facilities. Here is also where "*project networks implement peer-to-peer technical training routines to advance the competence of the entire collaborative workforce*". As the Research Coordinator of a project highlights: "*when a project introduces highly specialised methodologies like advanced Life Cycle Assessments (LCA), the technical partners do not rely on external consultants, but rather implement internal training*", adding that "*internally … within the project people* [produce training material] *by generating … instructional videos and parameters to eliminate cross-border experimental variances*.

However, **serious structural challenges often occurs as technologies transition toward higher TRL demonstration environments where links with higher education, postgraduate and postdoctoral studies are much tenuous**. In fact, close-to-market engineering frequently decouple from university-type training. An applied scientist details a critical capacity gap within close-to-market projects, expressing frustration that "*some phases* [WPs] *of the consortium completely exclude higher education institutions due to rigid eligibility boundaries*", noting that: "*we don't have in this project. We don't have universities. It's a bit pity*". This omission, according to our source, creates a latent deficiency, as "*the project loses the capability to host PhD students who can publish empirical data and systematically convert raw commercial testing lessons into open-access*" university curricula.

This aspect is also confirmed by another informant who suggested that, to mitigate this lack of academic integration, applied research organisations are forced to implement alternative, hands-on, non-academic learning "*pedagogies*" to maintain their physical infrastructure. The strategy manager of a hydrogen foundation pointed out that also some public facilities are "*forced to recruit newly and untrained university graduates and upskill them into specialised infrastructure technicians*". This is particularly taxing and it happens because they "*cannot afford the salary levels needed to compete with large industrial manufacturers*" who have already well-trained hydrogen engineering teams operating at the more innovative edge of their operations. To some extent, both these experiences point at an ongoing shift towards "*operational capability*" oriented towards innovative commercial competence-building programmes. In other words, as the sector is becoming more mature, approaching close-to-market levels, research organisations need to adapt their operations in line with those of their corporate partners and need to embed their engineering teams with specialised technicians. This happens at increasingly lower levels of the technology readiness scale including, for example, in the RTO's physical operations facilities. This trend shows that there is structural need to acquire practical hydrogen competencies.

This structural need has been known for some time and, to some extent, important steps forwards have been made. A European-wide initiative was set out to deal with this educational landscape;

the European Hydrogen Academy was conceptualised as a specialised pan-European knowledge hub designed to standardise clean hydrogen education. Funded through an early Horizon Europe and the Joint Undertaking call around 2023, the 2024-2028 European Hydrogen Academy's main mandate was to move away from fragmented, ad-hoc courses and build comprehensive and standardised educational pathways across the EU. Coordinated by the University of Chemistry and Technology of Prague (Czech Republic) and supported by a distributed network of European institutions, the Academy focused on developing standardised core materials, textbooks, and webinars for advanced university tracks. A representative of the Clean Hydrogen JU summarises this explicit focus on advanced university programming: "*This initiative is initially dedicated to high-level education, so from degree, master degree, PhD levels... it's mostly concentrated in developing standardized materials for the trainees*." However, beyond traditional university boundaries, the Academy's role is to function as an open-access repository feeding directly into the European hydrogen economy by generating structured curricula for advanced engineering, technicians for maintenance and safety and specialised training for emergency first responders. The Academy's early set up and operations was highly praised, one of our informants explicitly noting that the consortium did "*an amazing job actually, from creating curricula for various degrees of teaching to creating training sessions for reskilling*". However, our desk research reveals a more complex timeline regarding the Academy's current status, exposing a significant multi-level governance bottleneck within the European Commission. This is also confirmed by another informant mentioning that as the JU initially designed its 2026 work program with the strategic intention that the Hydrogen Academy would have scaled up and transitioned into the Net-Zero Industry Academies for Hydrogen[9], as mandated by the Net Zero Industry Act. However, a jurisdictional clash between different DGs seems to have altered this trajectory. As detailed by our informant: "*We had a setback because this idea of the academy was actually to evolve to the [Net Zero] Academy... and we were hoping that we would keep this academy that would actually become the [Net Zero] Academy in terms of what concerned hydrogen... Unfortunately, in terms of the policy of the [C]ommission... the [Net Zero] Academy would be not be part of, would not be under the [DG RTD]... [it] would be [DG] employment... So we weren't able to have a topic that would be the continuation of the Hydrogen Academy*." In summary, it seems that as a consequence of this shift in institutional jurisdiction from different DGs, the dedicated continuation funding topic has been disrupted. A senior leader confirmed that the next funding phase for the

[9] https://commission.europa.eu/topics/competitiveness/green-deal-industrial-plan/net-zero-industry-act_en

Hydrogen Academy has effectively "*been put on hold... for now*" leaving the initiative stalled in a bureaucratic limbo.

7. Ways to markets

Translating experimental hydrogen research into viable business opportunities requires navigating the complex terrain of technology transfer, intellectual property management, and industrial risk mitigation. At low Technology Readiness Levels (TRLs), the way to market is heavily structured around early intellectual property curation to protect foundational inventions before they are exposed to commercial actors. The academic coordinator outlines that early-stage research cannot establish commercial traction without securing robust legal protections at the project's inception, explaining that their university's technology transfer office actively reviews early laboratory breakthroughs to exploit discoveries through patents. **Usually is technology transfer office at universities that, together with the research teams, goes through the research work, findings and processes in order to assess** whether "*there is something which can be protected, yes, we can also exploit through patents... no reason to go through this procedure if you don't secure early your work*". Again, this is a baseline legal protection which allows early-stage innovations to attract corporate interest. The coordinator of RTO noted that "*while contractual milestones satisfy the funding authority, the genuine pathway to market is measured by whether external industrial players absorb the technology".* An informant working in a similar organisation noticed that "*the ultimate commercial objective is to see that at least one of the solutions is taken up or is followed up by an industry partner who is interested in spin-offs.*"

To move laboratory concepts - either patented or not - into competitive markets, universities and research organisations need highly capital-intensive pilot investments for demonstration and scale-up. Such resources are usually not available to these beneficiaries however they may include, within the project consortia, partners whose activities may be conducive to carrying forward interesting research findings and propositions. Specifically, one informant reported that their work within the project is to exploit their networking capabilities as their business model relies on acting as an upscaling intermediary, mapping out the industrial stakes early to: "*transfer and upscale development from TRL 4-5 to TRL 6-7 and until industrialisation*".

However, **when high-TRL demonstration projects attempt to enter the market, they must overcome at least two important hurdles, one concerning official certification so that technologies can be integrated into existing systems and the other is commercial risk,** which means gaining enough support in terms of investments and diffusion/dissemination, so that

implementation into existing systems is economically viable. As we have seen in the previous sections, high TRL projects are frequently put on hold due to:

1) taxing procedures to obtain standardisation and certification which, often are local (i.e. such as local fire regulations) and varying from member state to member state (such as certificates of conformities or declarations of conformity – CE – for relatively new materials and technologies that are not covered yet by European directives or that require the involvement of a notified body) and

2) the differing approaches to risk by universities public research organisations compared to technology businesses and energy firms. In fact, technologies or specific components, though achieving TRL 8 and are close-to-market deployment are stalled because of risk aversion or need for extra investments by firms.

There are, of course ways to "build-in" capacity within the activities and strategies of the partnership that can be adopted to overcome these hurdles form relying on consortia with a large industrial company acting as front-runners and many distributed small to medium sized companies working at the regional level operating locally and helping distribute the financial risk until a viable business case for large-scale production plants can be made. However, many beneficiaries, especially those involved on the technical aspect of technologies and component development, have reported that their ways to market is to manage market entry by downscaling their initial applications to smaller, highly localised (almost)commercial niches where regulatory and capital barriers are lower and trial runs are within economic reach. This focus on replication pathways, a strategy disclosed by many informants according to whom generating small scale demonstration serves to establishing a clear empirical blueprint that competing manufacturing firms can readily replicate.

To conclude, an intermediary technology organisation involved in several projects stated that their **ways to market are strongly dependent on the trends steering the technological/energy transition. To this extent their best ways to market has revealed to be a shift in business model away from pure research grants and toward providing testing and piloting services to private commercial contracts.** This has meant that whilst the research organisation had to transform/adapt their internal structures as commercial service providers, they are still substantially linked to the activities of the beneficiaries of the Clean Hydrogen JU and other publicly funded projects: "*80% of the private contracts that come to* [Name] *exist because the client has a public funding project supporting them*."

8. Defining and achieving success

Success within the Clean Hydrogen JU assumes different meanings depending on the types of translational commitments between fundamental laboratory validations to scaled industrial applications.

Specifically, at the earliest stages of low-TRL research, a project coordinator notes that at a baseline level: "*success for us would be that we reach our milestone and we deliver what we promise to do contractually*". Within this academic and basic research framework, success is explicitly measured through peer validation and scientific visibility, where the objective is achieving "*a high publication type: Nature, Science etc.*" and that these findings and publications reach a certain diffusion in the discipline measured by citations. One academic informant specifically referred as indicator of success that other publications "… *further citing it. That's success*".

However, as technological concepts mature toward applied engineering benchmarks, progressing through to higher TRL, the definition of success shifts to highly specific, measurable performance metrics. In cryogenic engineering, for example, success is defined by the physical capability to "*provide this solution, this insulation solution that will enable an effective thermal conductivity 10 times less than the one applicable right now*", which directly marks essential "*steps towards market, otherwise no reason to go through this procedure*". Similarly, in industrial high-temperature contexts like furnace retrofitting, operational success is when a system achieves "*full scale operation, 100 hours, 100% H2. Low emissions and … no safety concerns*" while proving there is "*no effect of hydrogen on the quality of the material*".

Whilst beneficiaries consider success meeting (and often exceeding) their project objectives and commercial scaling a dynamic consequence, the Clean Hydrogen JU partners and the managing authorities view both inter-project synergies and their place in the formation and driving of the European Hydrogen economy as objectives and success stories. Particularly, "*a key to success... the fact that we are able to have to find synergies with other European partnerships in the same area*".

On the commercial front, capitalising on research entails engineering components yielding a permanent "*reduction, optimize the total cost of ownership … of Hydrogen technologies in transport, industrial context, transports etc.*", because "*This spin-off* [sic.] [spillover] *would also be a huge success if it gets on the pattern*". In fact, in line with high-TRL operators, at the furthest end of the innovation continuum, long-term success requires large-scale technological integration (such as vehicles fleets, transportation and logistics etc.). the mechanism at play would be very

simple, an official underscored that having "*more vehicles on... at least you have to have three times this number in three years*" to firmly cement a "*coupling between industrialisation and market creation*". Linking the technology push with the demand pull would, eventually, build a stable trajectory where "*market success and technological improvements reinforce* [each other] *and can be used in the relevant areas*", culminating in an institutional status rather that progressing through "all these shocks". In other words, success means achieving "*the role and recognition of our work, recognition of role of the hydrogen sector*" in the European economy.

SECTION 4. THE REGIONAL DIMENSION OF THE CLEAN HYDROGEN JU: A SOCIO-TECHNICAL AND POLICY ANALYSIS OF THE HYDROGEN VALLEYS

1. Introduction

Energy transition policy frameworks often operate under a highly centralised, top-down paradigm that treats technological deployment as a progression of engineering achievements. Real-world clean-technology shifts are fundamentally distributed processes and this is particularly evident in the deployment of alternative sources of energy requiring structural alignment between technical configurations, ecosystem-wide adoption and the development of localised institutional, economic, and geographic capabilities. One example that highlights the importance of this distributed process is the spatial and behavioural dimension of transition theory, acknowledging that the actual work of building and deploying new energy infrastructures and technologies occurs within specific territories and communities[10].

Within this landscape, the Clean Hydrogen JU functions not merely as a centralised funding mechanism for research, but, through the various Hydrogen Valleys, as a complex socio-technical network that negotiates regional variety. This aspect is particularly important since, how we have seen in the previous section, stakeholders consistently point out there is not a typical journey from technology development to community-embedded assets. A senior Innovation Manager at Hydrogen Europe Research summarises the process as such: "*The path from an early laboratory … up to a functioning system on the street is never a straight line. It is a highly cyclical*[sic.] *process where you take three steps forward, hit a local regulatory or engineering wall, and are forced to loop back to intermediate testing tiers to re-validate the entire setup … .*" This means that developing and implementing a technological solution is not entirely predictable through a development ladder, translating clean-tech hydrogen research into functional applications is an iterative process potentially following a variety of pathways each characterised by continuous administrative, economic and technical feedback loops often embedded in regional ecosystems including local economies and specialisations, infrastructure, administrative and physical constraints. To navigate these intertwined dynamics, the Clean Hydrogen JU strategy has

[10] We can think of the case of co-evolution of electric vehicles and charging stations. Diffusion of electric vehicles concerns the adoption of technologies driven by consumers behaviours whilst charging station infrastructure affects such behaviours through making such technology usable over increasingly wider geographies (see Muratori at al, 2020). Further discussions on this specific topic are developed in the remainder of this section.

developed the concept of Hydrogen Valley therefore embracing the principles of place-based innovation frameworks. In fact, by focusing directly on the physical integration of supply chains, regional governance and local capital, these frameworks set out to leverage localised structures to transform decentralised research concepts into stable, self-reinforcing markets.

2. The Hydrogen Valley: Regional value chain and ecosystem

The Hydrogen Valley has become a foundational mechanism for place-based orchestration of the European Union's strategy. The idea, developed in earlier projects by the predecessors of the Clean Hydrogen JU, is to move away from the traditionally highly fragmented and isolated demonstration projects of earlier multi-annual funding programmes and position this novel institutional lens on regional or local ecosystems - Hydrogen Valleys – for demonstration, scale up and integration of key components of the hydrogen value chain and the hydrogen economy[11]. A Hydrogen Valley can, in fact, be defined as a localised socio-technical ecosystem where a substantial hydrogen value chain – from research to market application/innovation - is deployed within bounded regions. This configuration is usually structured and brings together clean hydrogen production, transport, storage, and diverse end-use sectors. Depending on the regional characteristics, these may include heavy industry, public mobility and different types of logistic systems. The main aspect is that the activities are contained within a coherent geographic area. Regional project leaders define the valleys as "*clear examples of territorial success because they involve all stakeholders in the ecosystem, ensuring that every segment of the value chain is integrated from the ground up*".

In a historical context, the evolution of these systems constitutes a significant scaling up of hydrogen technologies and the hydrogen economy: "*in the earliest iterations, local projects were often limited to isolated production sources, small-scale refuelling stations, and demonstrative public transit fleets*". Over years of iterative regional experimentation, these localised initiatives managed to catalyse a shift toward system-wide integration. To date, Hydrogen Valleys are expanding both in numbers (there are almost 30 Hydrogen Valleys projects currently funded by the Clean Hydrogen JU and their number is growing) and into significant local economic systems, integrating regional networks that are also spanning across traditional member-state borders.

One such example of this cross-border integration is the North Adriatic Hydrogen Valley, a multinational initiative that systematically connects public authorities, research centres and industrial actors of the Friuli Venezia Giulia region in Italy, Slovenia, and Croatia into a single,

[11] https://www.clean-hydrogen.europa.eu/get-involved/working-regions_en

unified ecosystem. Similarly, in Spain, the Ebro Hydrogen Corridor connects the territorial capabilities of the Basque Country, Navarra, Aragon, and Catalonia ultimately linking activities on the Atlantic ocean with those on the Mediterranean shores. The importance of such progresses is key to the evolution and sustainability of the Valleys and their role in the European hydrogen economy, an informant explained that: "*We realised that isolating our domestic wind and solar assets within the borders of* [a region] *was creating a structural production bottleneck. By engineering the* [network], *we established a multi-regional energy pipeline that links our inland generation directly with the high-volume industrial ports and consumption clusters".*

The spatial configuration obtained through the Hydrogen Valleys allows the shift from simple hardware testing sites into comprehensive socio-technical "*gyms*" for the entire hydrogen sector, collecting experimental data that feeds directly back to research institutions, signalling technical improvements and potential pathways to widespread commercialisation. All these occurring through linking local institutions, universities and research centres with industrial partners and infrastructures such as ports and pipelines nodes for a more organic place-based development.

3. The strategic policy mandates of Hydrogen Valley

The EC perspective

Considering the Hydrogen Valleys as "*gyms*" for developing locally the European hydrogen economy may seem somewhat reductive of the role of regions as mechanism of enactment of strategic STI and industrial policies. In fact, from our desk and field work emerges that at the level of the European Commission, officials and high-level Clean Hydrogen JU representatives view Hydrogen Valleys not merely as local infrastructure projects, but as strategic building blocks for European energy sovereignty and decarbonisation and this is also evidenced in policy documents. Within the strategic framework of the REPowerEU plan, the European Commission explicitly tasked the Clean Hydrogen Joint Undertaking with accelerating the deployment of these systems, setting a formal policy target for the establishment of Hydrogen Valleys across Europe. To support rapid scaling, the European Commission allocated additional funds specifically aiming to significantly raise the number of operational valleys (COM(2022) 230 final, p.7). This high-level political backing reflects a realisation that meeting the European Union's ambitious climate targets requires a rapid, place-based scaling of clean hydrogen production and consumption.

Furthermore, Hydrogen Valleys are viewed as critical nodes for implementing the Alternative Fuels Infrastructure Regulation (AFIR). This regulation legally mandates European Union member states to deploy hydrogen refuelling stations (see Paragraph 35, p. 7, Regulation (EU) 2023/1804) at regular intervals along major trans-European transport network (TEN-T) corridors

and within major urban nodes. In summary, Hydrogen Valleys provide the baseline refuelling infrastructure and production nodes necessary to make these cross-continental transit routes viable. As an EC official emphasised: "*The individual valleys currently tracked across Europe cannot exist as isolated territorial islands. They are the exact bottom-up market nucleation points required to fulfil our AFIR mandates. If we do not successfully tie these regional hubs into the trans-European freight corridors, the cross-continental transport routes outlined in our master regulations will completely fail due to localised infrastructure gaps*". In addition, the same informant noted that the valleys operate as localised sandboxes supporting also the European Hydrogen Backbone (ehb.eu)—a pan-European interconnected hydrogen infrastructure network.

The Valleys as Socio-technical Gyms

Again, referring to the concept of socio-technical gyms, Hydrogen Valleys compress the transition between intermediate system testing and real-world operational validation, usually operating across the Technology Readiness Level (TRL) 4 to 8. Within these regional boundaries, the primary objective is validating how a highly complex system of interconnected parts functions together, rather than focusing solely on testing isolated individual components.

This operational verification requires local authorities and development agencies to provide a long-term vision and certainty to private actors, ensuring that infrastructure investments match the specific needs of local supply chains.

The practical deployment of these technologies inside regional socio-technical systems, rather than deploying them at the European scale or globally is that whenever they reveal severe technical, logistical and/or environmental challenges that do not appear in laboratory models, they can be tackled and resolved locally and economically. One informant underlined that: "*by testing system reliability on a small scale, these regional ecosystems allow the European Union to gather critical performance, economic, and safety data that directly shapes macro-level pre-normative research and global competitiveness tracking*". Moreover, operational strain can be further assessed in the real-world conditions in the environment when the technologies are set to operate. This factor looks somehow marginal, however, "*system integrators deploying multi-megawatt fuel cells in coastal ferry networks or river shipping lines must design specialised filtering solutions to protect fuel stacks from the corrosive impact of salt-laden marine air or volatile ambient environments*". Even at low-TRL material development, testing must eventually be evaluated against the hard physical boundary of the context and environment where the component of the technology will be deployed. Consequently, "*regional testing environments must maintain a high degree of structural and operational flexibility, allowing operators to continually adjust technical components based on real-world learning*".

4. How the Hydrogen Valleys organise their role in the European Hydrogen Economy

Self-perception: nucleation point of ecosystem building

Within the broader European energy landscape, Hydrogen Valleys perceive themselves not merely as temporary, public-funded demonstration projects, but as the foundational blocks and - to borrow the terminology from one of our informants - "*nucleation points*" of an emerging new ecosystem. Regional operators, public institutions and privately own research-based enterprises, view their mission as the stabilisation of a highly volatile clean fuel markets through the enactment of supply (producers) and demand (users). In fact, by localising a substantial portion of the lifecycle of the energy vector, valleys can effectively, albeit only partially, insulate their local economies from global price fluctuations and supply chain disruptions. This is rather important considering that they see themselves as physical spaces where the high-level goals of European Union climate directives are translated into concrete industrial assets, local employment opportunities and regional energy security.

This self-perception is deeply tied to a sense of place-based/local knowledge and industrial transition. This is particularly evident in regions with coal-mining histories, declining heavy manufacturing sectors, or maturing offshore oil and gas industries. These view the Hydrogen Valley as a strategic lifeline. It represents a structured pathway to transitioning their existing engineering workforces, regional supply chains and public infrastructure toward a sustainable economic future. As a territorial representative from a Regional Authority explained: "*Our region cannot afford to sit passively as a consumer of foreign green energy. We perceive* [our Region] *as a mechanism of local sovereignty. By pairing our legacy* [industrial] *workforce with regional transport networks, we are actively retraining local engineers to* [greener options], *ensuring our territory becomes an independent exporter within the emerging clean-tech economy.*". To reiterate, valleys do not see their role as passive recipients of European Union funding; rather, they view themselves as active, self-governing innovators that are proving the technical and economic viability of the hydrogen economy.

Structured vs flexible governance

Rather than following a rigid, single template mandated by central European authorities, the organisational structure of a Hydrogen Valley is shaped in the proposal and highly linked to its local geography, industrial history and regional institutional architecture. A distinct organisational spectrum has emerged across the European Union. There are valleys organised around a highly structured, centralised governance models and others operating flexibly on distributed project-

based networks, and, of course, a plethora of Valleys that have various degrees of structured governance models.

On the one end of this spectrum where highly structured, centralised governance models are deployed, the regional council, local authority or a dedicated regional development agency manage the ecosystem through arm-length operations, processes and dedicated institutional actors. In the […] region, for example, the territorial framework is sustained by a formal dedicated committee that meets quarterly and has a detailed competence matrix: "*Our regional committee functions as a mandatory administrative rhythm*[sic.]. *Every three months, municipal transit officers, vocational training heads, private … manufacturers and academic scientists from the labs meet in the same room. If a public transport authority, for example, is planning a bus procurement, our energy desk analyses the* [characteristics of the] *local infrastructure grid in lockstep, ensuring that no public or private capital is deployed out of alignment with the overarching territorial roadmap*". This model provides a highly coordinated, long-term vision that significantly reduces risks for private investors by ensuring that all local policy levers are pulled to achieve the established objectives.

On the other end of the spectrum are more flexible, project-based models which are usually used in territories and regions where multiple private and public actors operate along the hydrogen value chain and there is less need to coordinate synergies across different competences and capabilities. In these cases, the valleys operate as loose, overarching political umbrella coordinating a variety of initiatives along the hydrogen value chain including market-driven commercial initiatives. Rather than being governed by centralised committees, these setups allow independent organisations, including companies, to coordinate logistics and technical delivery on a project-by-project basis. Again, whilst this model lacks the centralised alignment of the structured approach, it offers some room for self-coordination, greater commercial agility and allows private actors to respond rapidly to shifting market opportunities and technological advancements without being constrained by heavy municipal/local administrative processes.

Extending cross-borders and inter-valley coordination

As Hydrogen Valleys mature, they are increasingly organising across traditional regional and national borders to maximise their geographical assets and create broader economic corridors. This cross-border expansion represents a more sophisticated form of regional organisation that bypasses centralised national structures to form direct territorial alliances. We introduced two examples in the previous section, the North Adriatic Hydrogen Valley (NAHV) extending across the Friuli Venezia Giulia region in Italy, Slovenia, and Croatia, and the Ebro Corridor, connecting the Basque Counties to Catalonia via Navarra and Aragon in Spain. The NAHV formally connects

public authorities, research institutes and industrial clusters across three distinct national jurisdictions into a single, unified ecosystem. In such way, the valley overcomes the limitations of localised energy markets and allows cross-border distribution of clean hydrogen, sharing of specialised academic and industrial capabilities providing a clear trajectory towards reaching critical mass. This strategic expansion was identified by one of our informants - a representative of the Clean Hydrogen JU Board - as evolving physical scale of territorial configurations as such: "*Today, [hydrogen] valleys are considered—even cross-border [hydrogen] valleys like [the] North Adriatic that is involving the region of [Friuli] Venezia Giulia, all Slovenia, and all Croatia. So they became bigger in size showing market potential through size, reaching critical size for profitable operations*". Similarly, the Ebro Hydrogen Corridor in Spain demonstrates how regional actors can coordinate to link complementary geographical assets. This corridor unites several sources of energy including the wind and solar production capabilities of Navarra and Aragon with the high-volume industrial ports and consumption hubs of Catalonia and the Basque Country. This is a rather strategic use of resources as by organising this territorial corridor, the regions ensure that the surplus renewable electricity generated in the interior of the country is converted to hydrogen and transported efficiently to coastal industrial users. According to one informant: "*through these networks, Hydrogen Valleys are demonstrating that the future European hydrogen economy will not be built as a collection of isolated islands, … but as an interconnected web of regional corridors and such … that match localised production strengths with industrial demand centres*".

5. The Complex Architecture of Regional Ecosystems

It is important to understand that these organisations are not simple policy tools that are created on the paper and then operating on the territory. The physical realisation of a single Hydrogen Valley requires a highly complex, multi-layered financial architecture that reflects its public-private nature.

A key challenge for regional coordinators is that the Clean Hydrogen JU typically provides only a strategic seed grant. This central funding covers a small fraction — roughly 20% — of the total project scope (large valleys, for example, benefit of up to €20mil). Consequently, regional coordinators must bridge the remaining 80% funding gap by building sophisticated financing models that blend multiple public and private funding streams. To secure final investment decisions, valley developers must systematically layer and combine different financial instruments. They blend private venture capital and corporate investments with regional public resources, national modernisation funds, and European Cohesion funds, such as the European Regional Development Fund (ERDF). This layering of capital requires deep financial expertise and represents a significant administrative burden for regional actors, who must align different

eligibility criteria, reporting timelines and auditing frameworks of multiple public funding programmes. A policy lead from [Region] highlighted the immense administrative friction embedded within this financial architecture: "*The central JU grant is merely an architectural starting point. Closing that remaining eighty percent funding gap requires our […] desks to engage in high-level financial engineering. We are forced to layer private corporate equity alongside national modernisation funds, while simultaneously matching the rigid eligibility criteria of regional ERDF allocations. This creates a severe administrative burden because you are managing three or four separate auditing frameworks on a single physical installation*."

To support regions in this process, the Clean Hydrogen JU setup a centralised H2VFacility (h2v.eu/about). The H2V Facility is developed across three pillars providing 1) a Platform for Hydrogen Valleys – a digital hub tracking progress in the hydrogen economy, 2) a specialised H2V Knowledge Centre - providing materials, seminars/webinars and expert resources and 3) Project Development Assistant - supporting with services and coaching embryonic-stage projects and more advanced/mature ventures that are functional/strategic to the EC's target of reaching 50 Hydrogen Valleys by 2030.

Multi-Level Governance and Policy

Hydrogen Valleys have a clear strategic role in the European Union's energy mix targets but operate within a multi-level governance framework that, according to many of our informants, usually leads to some significant institutional frictions and policy overlaps. We can report the claim of regional authorities, local development foundations and municipal bodies that they are the main policy actors "*operating on the ground*" within the Hydrogen Valleys and though their work towards building these ecosystems is fundamental, they remain largely excluded from the core decision-making and call-drafting mechanisms of the partnership. From a number of interviews it emerges a sense of marginalisation and exclusion deriving from the ways governance boundaries separating territories from the partnership: "*On the policy side, many of the points* […] *raised* […] *were then taken by the* [C]*ommission... But* [regions] *cannot have a word on the draft goals or on the governance of the partnership*". However, it seems that call topics and funding priorities decision are taken in accordance with European Union's strategic actions and are subject to specific practical constraints where regional capabilities and timelines faced by local operators are frequently overlooked. This governance gap creates a highly fragmented public funding landscape.

The situation is not simplified by the fact that local managers are often navigating a complex network of overlapping initiatives, sometimes "… *struggling to distinguish*" between the Clean Hydrogen JU's "Hydrogen Valleys", Horizon Europe's "Regional Innovation Valleys" and more

recently proposed "Renewable Energy Valleys". As a regional policy leader noted: "*We are currently wasting vital administrative hours trying to decipher where the mandate of a Hydrogen Valley ends and where a DG REGIO Regional Innovation Valley begins. The European Commission is proposing separate 'Renewable Energy Valleys' without providing a unified regulatory matrix, leaving local cluster managers caught in a web of overlapping definitions and competing reporting channels*." Through networks like The European Hydrogen Valleys S3 Partnership, regional teams are frequently consulted on program synergies but, ultimately, they remain takers of central policy rather than active co-designers. This lack of alignment often results in administrative duplication and funding gaps that stall high-TRL demonstrations on the ground.

Intermediaries as Systemic Matchmakers and Market Stabilisers

Intermediaries play a vital role in this socio-technical transition context. They are systemic matchmakers, boundary spanners and tend to shape the market to accommodate the different systems of incentives driving stakeholders' motivations. These intermediaries, which include regional development organisations, chambers of commerce, cluster organisations and local public authorities, operate as bridges that connect the various elements of the network together. They indeed set out to mediate those systemic failures that cannot be settled by private commercial actors or central policy mandates alone.

During the course of this study informants often made references to "the waiting game approach" of businesses. By order of importance, this is considered a "*primary point of failure in the building of clean hydrogen ecosystem*". It is a persistent barrier erected by risk-averse private actors who somewhat delays committing long-term - patient - capital due uncertainties linked to the green transition.

In practice, political and market uncertainties fuel a series of occurrences that tend to generate high fuel price volatility and underlying demand instability. At the same time, manufacturers delay the commercial production of clean-energy technologies because localised infrastructure (i.e. refuelling stations, pipelines etc) are missing. Infrastructure providers and technology suppliers delay capital investments in fixed assets because there is no immediate demand (i.e. commercial fleets or consumers vehicles) to guarantee steady profitable business. This looks like a "high-stakes standoff" which, effectively, paralyses the last leg of market creation. A Clean Hydrogen JU partner detailed this: "*The 'waiting game' is a fundamental market failure. Logistics operators openly tell us they will not buy a hundred hydrogen trucks because there are no stations on their routes, while the energy providers refuse to build a multi-million-euro station because there are zero trucks on the road to buy the fuel. In Cologne, Germany, this exact standoff caused an industrial refinery plant to delay its final investment decision for over a year and a half because*

neither side was willing to absorb the underlying off-take risk." What happens in the road transport segment however, is also happening in other sectors such as retrofitting industrial furnaces with hydrogen technologies or long-range transportation and storage amongst others.

Intermediaries are uniquely positioned to break this system's deadlock by actively deploying localised public policy levers to, for example, stabilise demand. In some valleys, local public authorities have directly intervened in the ecosystem through the public procurement of municipal hydrogen bus fleets. By acting as a guarantor, high-volume/bulk purchaser, local governments can create those conditions increasing predictable demand needed to unlock private investment in refuelling stations and even production facilities. Similarly, in another region, the regional council took to its role as intermediary by acquiring direct public equity stakes becoming a formal shareholder in several strategic nodes of the hydrogen ecosystem including a newly established regional hydrogen distribution company and a public-private partnership for electrolysis and storage.

Overall, by using public capital to accelerate the rollout of high-TRL local infrastructure, these interventions demonstrate that intermediaries are essential for transition governance, as they transform abstract economic potential into a functioning, low-risk local marketplace.

Connecting SMEs in Large Industrial Clusters

Beyond demand stabilisation, intermediaries act also as crucial organisational links between small and medium-sized enterprises (SMEs) especially by connecting them with major multinational industrial players. In fact, integrating local SMEs into broader regional industrial clusters, helps small, innovative firms access specialised supply chains, build commercial capability and survive the high-risk early commercialisation phases of the technology transition. An example of this type is a country-wide organisation which acts as a powerful systemic intermediary by coordinating around 130 diverse corporate, legal, and academic members (at the time of the interview). This organisation provides combined technical, regulatory, and legal advice services directly to national ministries whilst, importantly, supporting its smaller local members. As the representative from such organisation explained: "*A small regional engineering company or a local university spin-off simply does not have the legal capital to navigate dense environmental […] laws or clear complex safety classifications. Our* [organisation] *operates as a collective legal buffer, pooling resources to provide specialised advisory briefs that allow local SMEs to easily pass permitting hurdles that would otherwise be cost-prohibitive, ensuring they aren't crushed by multinational competitors*."

Finally, one of our informants pointed to us that at the European level, the JU supports the nascent hydrogen entrepreneurship through structured startup and scale-up programs, using specialised tenders to provide small regional innovators with access to open innovation test beds, business model coaching, and private venture capital networks (Clean Hydrogen JU work programme, 2026). Moreover, the activities of the Partnership are somewhat embedded in the larger European Hydrogen strategy which includes other institutions such as the European Hydrogen Bank. In fact, the sourcing rules of the European Hydrogen Bank mandate that seventy-five percent domestic procurement minimum for electrolyser stacks are to be sources within the Union. To this, local intermediaries such as the Hydrogen Valleys, Regions' representatives etc are vital in translating these rules into economic activity hence ensuring that European SMEs are integrated into the supply chains of large-scale funded projects.

The Human Capital conundrum

As clean hydrogen R&I transitions from theoretical science to large-scale commercial reality, an important barrier holding back deployment at the regional level is the level of human capital which has increasingly added to the demand for highly specialised basic and applied scientists also the an additional demand for engineering professionals and technicians which currently goes unmet. In fact, as technology maturity increases, a relative shortage of specialised technicians and maintenance engineers able to support technological deployment is felt on the implementation sites. This shortcoming is typical of most emerging technology paradigms especially when the overall labour force transition requires coordination of human capital training consisting in matching high-level academic research with practical, ground-level vocational operations. Many of our regional informants have in fact highlighted how specialists supporting operations in the laboratories (both or universities and research organisations) are not matched by engineers and technicians supporting those on the market. Also, companies' scientists have signalled in many occasions the lack of technicians that could operate efficiently hydrogen technologies in the real-world setting.

Whilst in the previous section we have looked at the partnership's and its projects' contribution to capacity building, the balancing between scientists and engineers/technicians remains rather delicate, especially during research translation and technology implementation in real-world settings. This is indeed a **policy bottleneck** that has forced **regional actors to step in and rely on localised funding** mechanisms to maintain training capacity on the ground. To finance this essential labour shift, some of the regional authorities are linking their research and training goals directly with European Regional Development Fund (ERDF) and European Social Fund (ESF). The operational execution of this

multi-level funding alignment is highlighted by a Program Officer, who documents how the partnership actively bypasses central roadblocks by embedding capacity building into regional managing offices: "*One of the regions that we signed with is … region. [...] and we've signed with the managing authority that managed ERDF, but also ESF... and we are working with them on activities related to skills*." Similarly, another regional institution established a coordinated educational track funding 12 distinct PhD students across multiple universities. The research coordinator of such regional institution highlighted the intentional localised bounding of this academic design: "*We explicitly rejected the idea of traditional, isolated doctoral paths. Under the* [Regional] *framework, all twelve of our coordinated PhD tracks are directly tied to local corporate requirements. For example, a student analysing alkaline membrane degradation is working with raw data supplied directly by an active manufacturing SME near [city], ensuring that advanced academic human capital immediately translates into local economic value.*"

Furthermore, because real-world market readiness demands practical, blue-collar vocational reskilling rather than just high-level academic degrees, local clusters have partnered with industrial training organisations to implement vocational matrices. Examples include the Green Skills for Hydrogen pilot and other cross-border projects. These programmes explicitly train field mechanics and operators in hydrogen safety, pipeline management and fuel cell powertrain maintenance. Localised training and knowledge transfer actions, albeit of a different nature, are also critical for public administrators: "*in the [French] region, local civil servants and specialised municipal teams undergo formal, bi-annual technical training directly at the Alternative Energies and Atomic Energy Commission laboratories to ensure regional planners can competently operate and monitor scaled valley deployments*".

6. A reflection on the analysis

Analyses of the Clean Hydrogen JU at the regional and local level demonstrates that successful energy transitions cannot be achieved through isolated technological breakthroughs or centralised, top-down funding mandates alone. Energy transitions are also place-based processes that depend on the careful integration of local specialisations, technology adaptation, regional policy, community capital and capabilities. By compressing value chains into bounded geographic areas, **Hydrogen Valleys operate as the essential links where macro-level European Union policy meets localised industrial execution.** True, they serve as vital socio-technical gyms, validating complex, interconnected systems and gathering the ground-level data required to shape future European standards and infrastructures, but they also constitute examples of a resilient and self-sustaining European hydrogen economy. Here, public administrators, central policymakers, academic and research organisations and businesses work

to address the significant multi-level governance frictions and market deadlocks that currently stall high-TRL demonstrations. The Hydrogen Valleys are a **clear example that when combining science and engineering capabilities with robust regional public procurement and targeted vocational approaches to capacity building, European Regions can move past fragmented pilot phases and eventually establish a competitive industrial ecosystem.** These aspects signal that there is a great variety of potential translational pathways emerging and establishing across the Union.

SECTION 5. DISCUSSION AND CONCLUSIONS

1. A synthesis of R&I Pathways and policy

The transition of clean hydrogen technologies from early laboratory concepts into widespread commercial deployment is a highly non-linear process: involves a variety of organisations, it relies on different types of knowledge and it is marked by substantial attrition. Green hydrogen does not simply enter a mature, pre-existing market as an isolated commodity. Instead, it **depends on – and contributes to the emergence of - a multi-faceted systemic infrastructure that requires a *de minimis* maturation of production methods, transport logistics, storage systems and specialised end-use applications.** Moreover, hydrogen technologies are employed across diverse sectors such as land and maritime transport, heavy industry and energy. European research and innovation into clean hydrogen is spearheaded by the Clean Hydrogen JU. The Partnership is involved in the translational journey from low-scale concept formulations to high-scale pre-market validation and, through its partners, it coordinates public and private actors' interests.

However, as our fieldwork suggests, **managing this transition is fundamentally a multi-level institutional governance challenge** rather than a simple sequence of technical milestones. In fact, by focusing on the agency of the stakeholders and the beneficiaries' level, we see that as projects move along the hydrogen STI trajectories, they encounter structural tensions driven by conflicting institutional reward systems. Considering the early research stages, for example, university researchers focus on basic physics, material discoveries and thermodynamic modelling under determinate conditions. Their primary incentives are scientific publications and peer citations. However, as applied research organisations and private firms step in to integrate these models into low-to-mid TRL testing platforms, an acute data paradox emerges. Public mandate pushes for open data access to ensure community-wide learning, whereas commercial partners require strict non-disclosure agreements and patent protection to shield proprietary engineering designs from market competitors. Furthermore, between academic/applied and business development teams there seem to be a further barrier since they routinely struggle to translate complex theoretical and experimental parameters into the business-ready metrics required by the private investors.

Moving technologies outside of controlled laboratory environments into real-world industrial settings introduces failure risks that laboratory simulations and experimentation cannot predict. This is evident when looking at the technical/engineering level. For example, as we have seen in the cases of testing maritime fuel cell modules in open sea conditions reveals severe performance

degradation from salt-air particulate contamination, necessitating specific filtration systems. Similarly, retrofitting industrial furnaces to run on hydrogen intensifies internal water-vapor concentrations, causing chemical corrosion and structural cracking of standard ceramic refractory linings.

Proceeding along the translation journey, **while consortia regularly achieve contractual TRL targets in protected project environments, macro-level market uptake remains limited.** Large corporate actors often display risk-averse behaviour, choosing to extend the lifespans of traditional fossil fuel assets rather than committing capital to unproven commercial markets.

Compounding these more systemic science and engineering hurdles with the purely strategic approaches to market actors somewhat makes advancing to **high TRLs only a necessary but not sufficient condition to marketisation** exposing the completion of translation and innovation pathways to market forces.

The translation pathway is also disrupted by **external geopolitical and macroeconomic shocks** that, whilst might have a limited impact on the overall remit of the partnership, certainly, in more than one occasion, have invalidated technical roadmaps mid-project and forced rethinking of novel ways to fulfil consortia obligations. Specifically, we have seen that geopolitical events leading to the disruption of continental pipeline plans forced projects to abruptly re-direct their objectives toward maritime transport architectures, necessitating completely new R&D activities. Navigating such types of changing demands, introduces setbacks and reconsideration of operations whilst already charting through uncertain paths, requires high level of institutional capacity building. On a more fundamental level, the 2022 energy crisis triggered by the war in Ukraine changed clean hydrogen from a means for long-term climate mitigation into an immediate imperative for energy security and strategic autonomy. This transformed hydrogen from a technical R&I domain seeped in Environmental regulations to a central pillar of foreign policy and energy diplomacy.

2. The Regional Dimension and Hydrogen Valleys

Energy transitions are inherently spatial processes; the Clean Hydrogen JU has championed place-based innovation through Hydrogen Valleys. Within these localised ecosystems emerges operates a substantially complete value chain including hydrogen production, transport, storage, and consumption. Whilst originally these were regionally defined geographic boundaries they are increasingly extending through cross-border arrangements such as the North Adriatic Hydrogen Valley and the Ebro Hydrogen Corridor.

Hydrogen Valleys can be intended as both socio-technical gyms, as it has been highlighted by several partners, but also as – as noticed by regional actors and policymakers - policy anchors. In particular, the Valleys act as socio-technical gyms spanning intermediate to high TRLs, allowing stakeholders to test how complex, interconnected systems perform under real-world operational stress before attempting continental rollouts. From a strategic policy perspective, however, the European Commission views these regional hubs as essential building blocks for European energy sovereignty, helping meet REPowerEU mandates and providing the practical refuelling infrastructure required by the Alternative Fuels Infrastructure Regulation along trans-European transit corridors.

Deploying a Hydrogen Valley, according to our informants, requires navigating several financial and governance complexities. Because the central JU grant acts merely as seed funding - covering roughly 20% of the total investment - regional coordinators engage in complex financial engineering to cover the remainder. They usually work by layering private corporate equity alongside national modernisation funds and regional European Regional Development Fund allocations. Whilst this allows appropriate resourcing, managing three or four separate auditing frameworks for a single physical installation is somewhat taxing. On the governance level, regional leaders report a feeling of marginalisation from central policymaking activities and a fragmentation of objectives especially whilst managing overlapping differently labelled European initiatives.

The Hydrogen Valleys as demand-side

We have discussed the pervasive "waiting game" as a systemic failure. This can be exemplified by the case whereby logistics companies refuse to buy hydrogen vehicles due to missing stations and energy providers refuse to build stations due to a lack of vehicles. In such situations regional intermediaries play a vital role. Local public authorities actively break this deadlock by deploying public procurement or taking direct equity stakes in regional companies to guarantee a baseline demand. Other regional actors, operating as intermediaries, usually pool regulatory and legal resources involving small and medium-sized enterprises in the ecosystem and protecting smaller innovators from being overwhelmed by complex administrative and regulatory processes – which are usually managed with ease by larger companies and use them as barrier to entry. Furthermore, regions are increasingly using local resources and funding to retrain legacy industrial workforces, ensuring that shortages in field technicians do not halt regional market expansion.

3. Conclusions

The analysis suggests that **technological advancement along Technology Readiness Levels is an incomplete measure of success for clean energy transitions**. Having as overall objective or achieving high TRLs within protected project boundaries, whilst necessary to advance technologies and components nurtured by the Clean Hydrogen JU, does not automatically guarantee market entry or macro-level environmental impact. The translational pathways are much more complex and to bridge the gap between research and commercial applications several components need to be implemented complementarily. **Technology validation**, for example, to advance technology towards markets, must be systematically **paired with early intellectual property curation; in emerging technological fields, pre-normative standardisation and proactive regulatory actions should be taken from the inception of a project.** Moreover, market-based dynamics are bound to have profound effects on any technology deployment.

Place-based regional governance is indispensable for overcoming market paralysis. In fact, regional-level actors such as the Hydrogen Valleys seem well positioned to at least affecting positively the commercial "waiting game" especially when their actions are combined with that of policy and local intermediaries. This combined action has shown that can stabilize market demand through public procurement, financial layering and targeted vocational training.

Critically, **policy coherence across multi-level governance** structures remains paramount. For example, whilst the clean Hydrogen Partnership plays a fundamental role in promoting advancements in hydrogen technologies and their deployment, to foster a European hydrogen economy is necessary to achieve the critical mass required to compete internationally and this means comparable levels of investments to those of competitors and the institution of a European hydrogen framework that streamline the administrative burden of stacking multi-tier public funds, resolve policy frictions between institutions and foster a denser, non-overlapping cross-sectoral synergies linking foundational laboratory discoveries directly to secure demand-driven commercial supply chains.

REFERENCES.

Atanasiu, M. (2021). Fuel Cell and Hydrogen Joint Undertaking: A European R&I success story. *Panorama Estratégico*, 2021, 1–11.

Bleischwitz, R., & Bader, N. (2010). Policies for the transition towards a hydrogen economy: The EU case. *Energy Policy*, 38(10), 5388–5398. https://doi.org/10.1016/j.enpol.2009.03.041

Bolard, J., Dolci, F., Weidner, E., Gryc, K., Eynard, U. et al., (2026) *Clean Energy Technology Observatory: Water Electrolysis and Hydrogen in the European Union - 2025 Status Report on Technology Development, Trends, Value Chains and Markets,* Publications Office of the European Union, Luxembourg, 2026,

Bravo Diaz, L., & Boillot, L. (2024). *Historical analysis of Clean Hydrogen JU fuel cell electric vehicles, buses and refuelling infrastructure projects: Evaluation of contribution towards the state of the art* (EUR 31876 EN). Publications Office of the European Union. https://doi.org/10.2760/892745

Buonomenna, M. G., & Patonia, A. (2025). Green hydrogen in Europe: Where are we now? *Hydrogen*, 6(1), 105–122. https://doi.org/10.3390/hydrogen6010005

Clean Hydrogen Joint Undertaking. (2022). *Strategic Research and Innovation Agenda 2021 – 2027* (Annex to GB Decision No. CleanHydrogen-GB-2022-02). Clean Hydrogen Partnership Programme Office available at: https://www.clean-hydrogen.europa.eu/about-us/key-documents/strategic-research-and-innovation-agenda_en

Clean Hydrogen Joint Undertaking. (n.d.). *Our story*. Clean Hydrogen Partnership. https://www.clean-hydrogen.europa.eu/about-us/our-story_en

Clean Hydrogen Partnership & European Commission, Joint Research Centre. (2025). *Programme Review Report 2025*. Clean Hydrogen Partnership. https://doi.org/10.2843/3345554

Delpisheh, M., Moradpoor, I., Souhankar, A. H., Koutsandreas, D., & Shah, N. (2026). Advancing the hydrogen economy: Economic, technological, and policy perspectives for a sustainable energy transition. *Renewable and Sustainable Energy Reviews*, 226, 116238. https://doi.org/10.1016/j.rser.2025.116238

Eikeland, P. O., Inderberg, T. H. J., & Skjærseth, J. B. (2024). *Against all odds? Explaining the new clean hydrogen strategy of the European Union* (Fridtjof Nansen Institute Report). SSRN Preprint. https://ssrn.com/abstract=5387536

European Commission. (2004). *The share of renewable energy in the EU: Commission Report in accordance with Article 3 of Directive 2001/77/EC, evaluation of the effect of legislative instruments and other Community policies on the development of the contribution of renewable energy sources in the EU and proposals for concrete actions* (COM(2004) 366 final). Brussels, Belgium.

European Commission: Directorate-General for Research and Innovation and Zhechkov, R., (2024) Clean hydrogen Joint Undertaking and its predecessor Fuel Cells and Hydrogen 2 Joint Undertaking (FCH 2) – Horizon Europe and the green transition interim evaluation support study – Partnership evaluation report, Publications Office of the European Union, 2024, https://doi.org/10.2777/577004

European Hydrogen & Fuel Cell Technology Platform. (2005). *Strategic Overview: Covering Strategic Research Agenda & Deployment Strategy*.

Gatto, A., Sadik-Zada, E. R., Lohoff, T., Aldieri, L., Vinci, C. P., & Peitz, K. A. (2024). An exemplary subsidization path for the green hydrogen economy uptake: Rollout policies in the United States and the European Union. *Journal of Cleaner Production*, 440, 140757. https://doi.org/10.1016/j.jclepro.2024.140757

Genovese, M., Piraino, F., Corigliano, O., Schlüter, A., Scionti, E., & Fragiacomo, P. (2025). Hydrogen economy development in the European Union. In T. A. Kurniawan & M. N. V. Prasad (Eds.), *Accelerating the transition to a hydrogen economy: Achieving carbon neutrality* (Vol. 3, pp. 283–302). Elsevier. https://doi.org/10.1016/B978-0-443-24002-7.00005-7

Gioia, D. A., Corley, K. G., & Hamilton, A. L. (2013). Seeking qualitative rigor in inductive research: Notes on the Gioia methodology. *Organizational research methods*, 16(1), 15-31. https://doi.org/10.1177/1094428112452151

Gioia, D. (2021). A systematic methodology for doing qualitative research. *The Journal of applied behavioral science*, 57(1), 20-29. https://doi.org/10.1177/0021886320982715

Joint Research Centre. (2025). *Water electrolysis and hydrogen in the European Union: Status report on technology development, trends, value chains and markets*. Clean Energy Technology Observatory, Publications Office of the European Union. https://doi.org/10.2760/7797181

Kanellakis, M., Martinopoulos, G., & Zachariadis, T. (2013). European energy policy—A review. *Energy Policy*, 62, 1020–1030. http://dx.doi.org/10.1016/j.enpol.2013.08.008

Quitzow, Rainer, Yana Zabanova, Almudena Nunez, Ines Bouacida, Michał Smoleń, Wojciech Żelisko, John Szabo et al. "The Geopolitics of Hydrogen, Volume 1: European Strategies in Global Perspective." (2024).

Shirizadeh, B., Ailleret, A., Guillon, A., Bovari, E., El Khatib, N., Douguet, S., Bou Issa, C., Brauer, J., & Trüby, J. (2023). Towards a resilient and cost-competitive clean hydrogen economy: The future is green. *Energy & Environmental Science*, 16(12), 6094–6109. https://doi.org/10.1039/d3ee02283h

Tomomewo, O. S., Bade, S. O., & Benarbia, A. (2026). A cross-regional analysis of policies, regulations, and incentives from the United States, the European Union, China, and Australia for shaping hydrogen economy. *Applied Energy*, 406, 127240. https://doi.org/10.1016/j.apenergy.2025.127240

Vankayala, S., Singh, V., Sriprasath, V. J., & Dhiman, B. (2025). Trends, challenges, and opportunities in the global green hydrogen value chain: A comprehensive bibliometric and thematic analysis. *Sustainable Futures*, 10, 100966. https://doi.org/10.1016/j.sftr.2025.100966

Vezzoni, R. (2024). A "return of the state" in energy transitions? The making of a hydrogen economy in the European Union. *ZFW – Advances in Economic Geography*, 68(3-4), 195–212. https://doi.org/10.1515/zfw-2024-0050

Vivanco-Martín, B., & Iranzo, A. (2023). Analysis of the European strategy for hydrogen: A comprehensive review. *Energies*, 16(9), 3866. https://doi.org/10.3390/en16093866

Zabanova, Y. (2024). The EU in the global hydrogen race: Bringing together climate action, energy security, and industrial policy. In *The Geopolitics of Hydrogen: Volume 1: European Strategies in Global Perspective* (pp. 15-47). Cham: Springer Nature Switzerland.

AUTHOR

Dimitri Gagliardi

Manchester Institute of Innovation Research, AMBS,

The University of Manchester