MAKING IT HAPPEN

Hydrogen Valleys – Progress in an evolving sector

Clean Hydrogen Partnership

MISSION INNOVATION

AUTHORS

Uwe Weichenhain, Markus Kaufmann, Johannes Pfister,
Martin Scheiner (Roland Berger), Marcos Rubio Redondo (Inycom)

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CONTACT

Roland Berger
Markus Kaufmann
markus.kaufmann@rolandberger.com

Clean Hydrogen Joint Undertaking
info@clean-hydrogen.europa.eu
Clean Hydrogen JU, B-1049 Brussels

Mission Innovation Clean Hydrogen Mission
EC-MI-clean-hydrogen-mission@ec.europa.eu

It is encouraging to see that the interest in Hydrogen Valleys has increased so much over the past years. We now have globally around 100 Hydrogen Valleys on the platform, with more than double the number in Europe compared to 2022. It is internationally recognised that both supply and demand should be stimulated to roll out a global hydrogen economy. This is exactly the strength of the Hydrogen Valley concept: bringing together hydrogen production and end use in a thriving ecosystem. We must continue to foster partnerships, create synergies, share knowledge, and invest in research and development to bring Hydrogen Valleys from concept to reality.

Rosalinde van der Vlies
Clean Planet Director, DG RTD,
European Commission

As the global clean hydrogen sector matures, we are proud to see how Hydrogen Valleys are emerging globally and stand out as pivotal players driving progress and innovation at regional level. This report, which delves into over three years of data, is not only tracking the advancement of leading hydrogen projects worldwide. It also highlights the sector's growth, challenges, and the essential strategies needed to sustain momentum and achieve further milestones. The Clean Hydrogen Partnership has supported so far 16 projects across 15 European countries, representing an investment of over €1 billion, and will continue providing such support in line with the RepowerEU objectives. As part of our future plans, we're happy to announce that the activities of the H2v platform will continue under the upcoming Hydrogen Valleys Facility. The facility will also include project development assistance to support Hydrogen Valleys at different levels of maturity. It will also be used to gather and share knowledge and lessons learned from advanced Hydrogen Valley projects to benefit projects at earlier stages of development.

Mirela Atanasiu
Head of Unit Operations and
Communication,
Clean Hydrogen Partnership

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Abstract

The Hydrogen Valley platform is a global collaboration platform that promotes the development of integrated hydrogen projects and raises awareness of their role in the evolving and growing clean hydrogen sector among policy makers, industry and other stakeholders. It provides information on hydrogen flagship projects and serves as a hub for the most advanced Hydrogen Valleys worldwide. Having originated in Europe, the concept of Hydrogen Valleys has now gained global interest, with many regions developing similar projects. Today, nearly 100 Hydrogen Valleys globally are represented on the platform.

The www.h2v.eu platform supports the Mission Innovation 2.0's goal of reaching 100 Hydrogen Valleys worldwide by 2030 and contributes to the Clean Hydrogen Mission's objective of reducing end-to-end costs of clean hydrogen by 2030.

This report investigates the state of the clean hydrogen sector by analysing empirical evidence from Hydrogen Valleys globally over the last three years. The report discusses the development of the Hydrogen Valley concept and community as well as the necessary framework conditions for its development. Nevertheless, it also explores the more recent challenges faced by Hydrogen Valleys and the clean hydrogen sector as a whole and seeks to find forward looking solutions.

It does so by identifying success factors for complex hydrogen project development and by highlighting the remaining barriers to implementation that need to be overcome. The report concludes with a call to action for project developers, policy makers, and investors to continue advancing the hydrogen sector.

Overall, the report emphasises the importance of collaboration, adequate risk management combined with policy support, and investment to accelerate the global energy transition with the help of Hydrogen Valleys.

Executive summary

Analysing more than three years of Hydrogen Valley data, this report tracks the development of some of the most advanced hydrogen projects globally, also reflecting on the state of the entire clean hydrogen sector. It paints a nuanced picture of a maturing market, not without short-term challenges.

Hydrogen Valleys are progressing and evolving, as they move towards bigger and more complex interconnected supply chains, a focus on the decarbonisation of industrial clusters, and clean molecule export options to unlock a global commodity market. With increasing political ambition and public funds, the Hydrogen Valleys have grown in terms of installed clean (and mainly green) hydrogen production capacity as well as in overall investment – by no less than a factor of 4 compared to three years ago.

However, Hydrogen Valleys are also experiencing the currently challenging climate for large-scale decarbonisation investments first hand, a climate that is bringing about a "normalisation" of the clean hydrogen sector at large. Success rates of large-scale hydrogen projects are moving to levels comparable to other large-scale energy infrastructure, as developers still face substantial regulatory, commercial and technical challenges. Nevertheless, the Valleys have also proven to be resilient and adaptable.

But to keep the global momentum going, there are some winning recipes to accelerate Hydrogen Valleys, clusters, hubs, ecosystems or other "mini hydrogen economies" and ensure they continue to make a vital contribution to the evolving and growing clean hydrogen sector at large. Most importantly, Hydrogen Valley developers need to build bankable project de-risking frameworks to integrate entire value chains and collectively move them towards Final Investment Decisions. Moreover, they need success stories around real deployment at scale. Large(r) projects need to be built and run effectively. Together with continued public support in the pre-FID ("project valley of death") phase, even more regulatory certainty and meaningful improvements in permitting processes, Hydrogen Valleys can continue to be the accelerating factor for a new clean hydrogen sector.

The Mission Innovation Hydrogen Valley Platform is a global collaboration platform for all information on hydrogen flagship projects and aims to facilitate a clean energy transition by promoting the emergence of integrated hydrogen projects along the value chain as well as by raising awareness among policy makers, industry and other stakeholders. On the platform, the most advanced Hydrogen Valleys around the globe provide insights into their project development.

The Hydrogen Valley concept, initiated in Europe, raised interest all over the world and many geographies are developing similar concepts, so-called hydrogen hubs, hydrogen clusters or "Hydrogen Valleys". The platform supports the Mission Innovation 2.0's overall goal of reaching 100 Hydrogen Valleys by 2030. It also contributes towards the other activities of the Clean Hydrogen Mission, aiming to make clean hydrogen cost competitive to the end user by reducing end-to-end costs by 2030. Within its "toolbox"[1] section, the platform promotes useful information about other hydrogen tools and data sources, features the most recent and important studies from key players and organisations in the hydrogen world, and presents insights about and to the Hydrogen Valley platform stakeholders.

The Clean Hydrogen Partnership (JU) supports the European Commission in its co-lead role under the Clean Hydrogen Mission within the Mission Innovation 2.0. Following the lead of the European Commission, in 2020 the JU initiated the development of the Mission Innovation Hydrogen Valley Platform and by January 2021, after a thorough exercise of data collection, 34 Hydrogen Valleys were selected and went live on the platform. To date, close to 100 Hydrogen Valleys globally are represented on the Hydrogen Valley platform.

1 Hydrogen Valleys and the evolving clean hydrogen sector – Long-term prospects and short-term challenges

The global Hydrogen Valley landscape has evolved over the last two years. Since the publication of the first report on "Hydrogen Valleys – Insights into the emerging hydrogen economies around the world" in 2021, the concept has caught on globally with similar integrated clean hydrogen projects starting in the Americas, the Middle East and across the Asia-Pacific region. The Hydrogen Valleys on the platform are a representative sample of the most advanced clean hydrogen projects, a sample that serves as a solid baseline for analysing the medium- and long-term trends in the clean hydrogen sector (rather than the short-term "hype, doom and gloom"). In this spirit, this report tracks the sector developments since 2021 and takes empirical evidence from three years of data collection to paint a nuanced picture about the role of Hydrogen Valleys in the clean hydrogen sector and its current state. As several announcements of postponed projects and delayed targets have revealed over the last 6–12 months, the sector currently faces substantial challenges to deliver on the growth ambitions set by project developers and the hydrogen industry alike at the beginning of this decade. Nevertheless, the fundamental strengths of the Hydrogen Valley concept (pooling demand, sharing infrastructure, enabling larger-scale production, etc.) are stronger than ever.

Hydrogen Valleys represent large-scale, complex hydrogen projects that integrate the entire value chain while addressing multiple offtake sectors. Although Hydrogen Valley concepts are always adapted to cater to specific regional circumstances and the overall objectives of the Valley's stakeholders, there are common characteristics of what constitutes a Hydrogen Valley:

Large in scale: The project scope goes beyond mere demonstration activities and entails at least a two-digit multi-million EUR investment. It typically also includes several sub-projects that make up the larger Valley "portfolio".

A clearly defined geographic scope: Hydrogen Valleys are hydrogen ecosystems that cover a specific geography. Their footprint can range from a local or regional focus (e.g. a major port and its hinterland) to a specific national or international region (e.g. a transport corridor from port to port with specific customers targeted).

Broad value chain coverage: Along their geographic scope, Hydrogen Valleys cover multiple steps in the hydrogen value chain, ranging from clean hydrogen production (and often even dedicated renewables production) to the subsequent transportation, storage and distribution to offtakers.

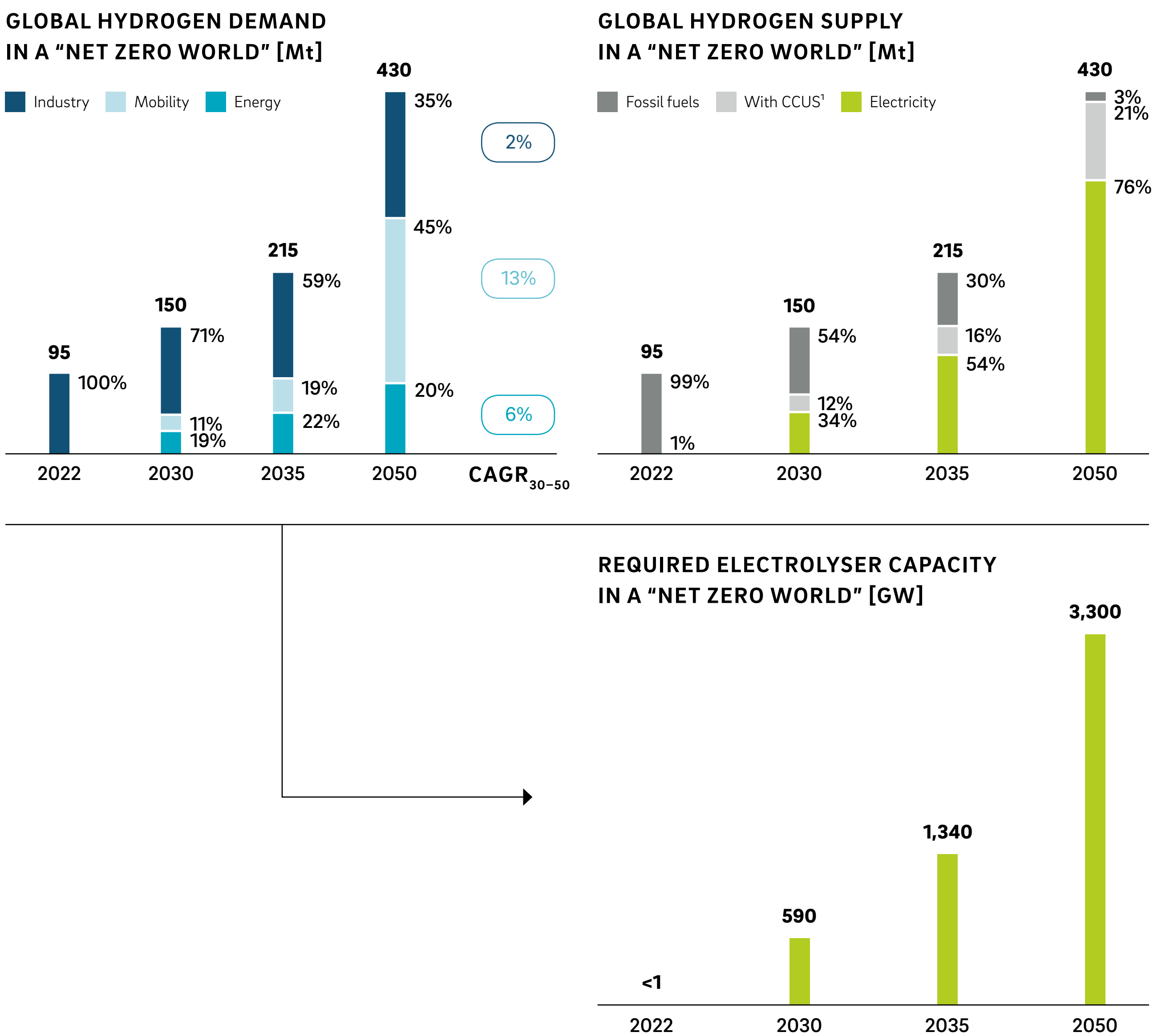
Multiple end uses: Hydrogen Valleys usually showcase the versatility of hydrogen by supplying several sectors in their geography such as mobility, industry and energy end uses. Thus, Hydrogen Valleys are ecosystems or clusters where various final applications share a common hydrogen supply infrastructure.

1.1 The evolving Hydrogen Valley landscape: More Valleys on a more global map

Hydrogen is widely recognised as a crucial element in climate action. In recent years, it has emerged as a prominent topic in discussions of the global shift from fossil fuels to the decarbonisation of industries, transportation and energy. It is a key pillar in achieving the global climate policy objectives outlined in the Paris Agreement, specifically in curbing global warming to levels significantly below 2°C compared to pre-industrial times.

Key industries like fertiliser or steel production need decarbonised hydrogen as clean feedstock; heavy-duty mobility users in trucking, shipping or aviation require a clean fuel where battery electrification is unable to meet operational needs. As a result, clean hydrogen consumption must significantly increase to meet global

A: Hydrogen demand, supply and resulting electrolyser capacity needs in the IEA's Net Zero Emission scenario



Source: IEA

1) Carbon Capture, Utilisation and Storage

decarbonisation objectives – not only in the long term but already in this decade[2]. → A

In addition, the current production of hydrogen heavily relies on fossil fuels. Less than 2% of global hydrogen production comes from "clean" production routes. In order to get to "net zero", especially green hydrogen supply – produced from renewable energy sources – will have to meet most of the growing demand. For that, an enormous build-out of electrolysers and corresponding renewable electricity production will be required.

The global clean hydrogen project landscape has rapidly grown worldwide since 2020, with green hydrogen project announcements alone now totalling ~1,600 projects and ~480 GW by 2030[3]. Europe is the most vibrant region in terms of number and capacity of announced projects, despite recently changing market conditions (higher financing cost, more expensive green electricity, higher electrolyser cost, disruptions in global supply chains, etc.).

Moreover, there is a strong and continuous political momentum behind hydrogen ambitions globally. Governments worldwide view hydrogen as a crucial enabler for decarbonisation and are actively pushing for its adoption. More than 40 national hydrogen strategies have been published to date, with Europe, North America and East Asia leading the way by setting more and more ambitious political targets for clean hydrogen and implementing supportive policies and regulation.

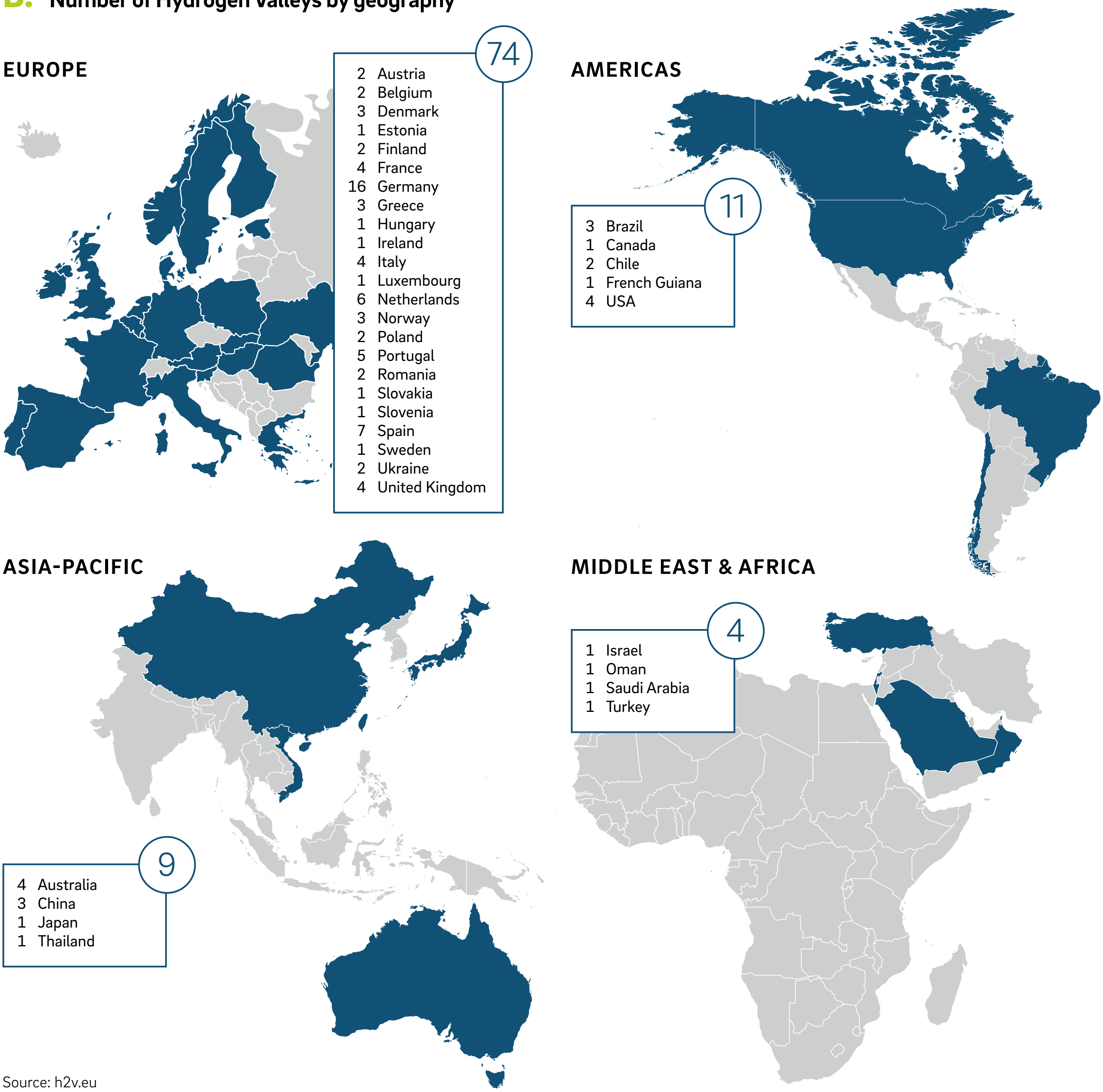
As the clean hydrogen sector is still ramping up, many developers have been creating regionally integrated hydrogen hubs, clusters, ecosystems – or simply "Hydrogen Valleys". These Hydrogen Valleys go beyond mere demonstration activities and act as stepping stones towards the full-scale implementation of the new clean hydrogen sector. The concept of Hydrogen Valleys is attractive for replication as a "blueprint" and aligns well with the industry's required scaling trajectory to mature clean hydrogen technologies, expand industrial supply chains and ultimately bring down costs. Over the past few years, the Hydrogen Valley concept has firmly established itself in the global funding and collaboration landscape, becoming a recognised term in the industry.

The number of Hydrogen Valleys around the world has grown significantly, from around 30 in 2021 to now almost 100. One goal of the Clean Hydrogen Mission of Mission Innovation is to facilitate the delivery of 100 large-scale integrated Hydrogen Valleys worldwide by 2030.

The growth of Hydrogen Valley announcements is also driven by specific policy support such as public funding and financing instruments. For example, following the EU Green Deal and the "Fit for 55" package, the "REPowerEU" plan aims to accelerate and expand renewable energy production and utilisation, including the use of clean hydrogen. One of the objectives of this plan is to double the number of Hydrogen Valleys in Europe by 2025. To back this up, REPowerEU made an additional EUR 200 m available for Hydrogen Valleys to be disbursed by the Clean Hydrogen Partnership[4].

Also on the Mission Innovation Hydrogen Valley Platform, most Valleys (by far) are located in Europe, reflecting the region's strong commitment to clean hydrogen development. Hence, while the Hydrogen Valley concept is gaining traction around the world, it remains, for now, somewhat Eurocentric. Of the 98 Hydrogen Valleys that participated in the survey, 76% are European, 11% are in the Americas, 10% are Hydrogen Valleys in the Asia-Pacific region and around 3% in Middle East and Africa. Within Europe, Valley developments now truly span the entire continent, including Central and Eastern Europe in addition to countries with a longer legacy of developing larger and more complex clean hydrogen projects such as Germany, the Netherlands,

B: Number of Hydrogen Valleys by geography



Source: h2v.eu

Spain or the Nordics. Beyond Europe, Hydrogen Valleys are becoming a global phenomenon, with integrated projects emerging on all continents and beyond the traditional hydrogen lead markets. → B

1.2 Challenging times for clean hydrogen: How Hydrogen Valleys adapt to a changing market environment

The Hydrogen Valley concept has been a success story since its inception. However, the respective projects are neither detached from larger sector trends nor from macroeconomic developments. Over the last two years, the clean hydrogen sector has not only experienced further acceleration but also faced substantial (and sometimes new) regulatory, commercial and technical challenges. Public information about delayed or even outright cancelled projects has spread quickly, especially in the last 6–9 months. Hydrogen Valley developers (just like any project developers) have had to adapt.

A MODEST BUT VISIBLE "REALITY CHECK" FOR HYDROGEN VALLEY AMBITIONS

From 2019 to the end of 2022, there was a clear push for decarbonised energy systems to strengthen autonomy from oil and gas exporting countries, largely in response to Russia's invasion of Ukraine. Economic policy agendas were further shaped by efforts to rebuild national economies after the COVID pandemic and brought along immense public investment in clean industries (e.g. ~EUR 28 bn in the green transition by the European Union so far[5]) as accelerators to the already existing commitment to the Paris pathway. However, in 2023, macroeconomic tides began to turn as financing costs rose and supply chains continued to be disrupted. As a consequence and as projects progressed through basic engineering, project CAPEX went up – with PEM and alkaline electrolyser unit cost increasing by approximately 15% on a global average (and for European projects sometimes 40–50%). Paired with increasing cost of green electricity, the anticipated decline in Levelised Cost of Hydrogen (LCoH) has not yet materialised. With landed cost and willingness to pay too far apart, developers are forced to postpone Final Investment Decisions (FIDs), resulting in many project delays. Especially project owners, developers and investors have become more prudent in balancing their portfolio. The sector-level outcome is an ongoing recalibration of clean hydrogen project portfolios that does not leave Hydrogen Valleys unaffected.

Despite these challenges, the dynamism of the Hydrogen Valley concept and stakeholder engagement has remained resilient. The Mission Innovation Hydrogen Valley Platform has won nine new Valleys over the recent months. Yet it's clear that the sector is consolidating. As is the case with energy infrastructure projects in general, not all clean hydrogen projects manage to progress beyond the concept stage (see chapter 2.1). Even in established (energy) infrastructure sectors, statistical success rates of pre-FID investment projects are typically not higher than 30–35%[6]. Evidently, the initial waves of big project announcements and investment promises have partly given way to the challenging reality of complex technology deployment. In addition, new issues such as permitting hurdles (see chapter 2.3) and problems of electrolysers and other core hydrogen technologies (see chapter 2.4) have become apparent in clean hydrogen projects and Valleys that have started operations.

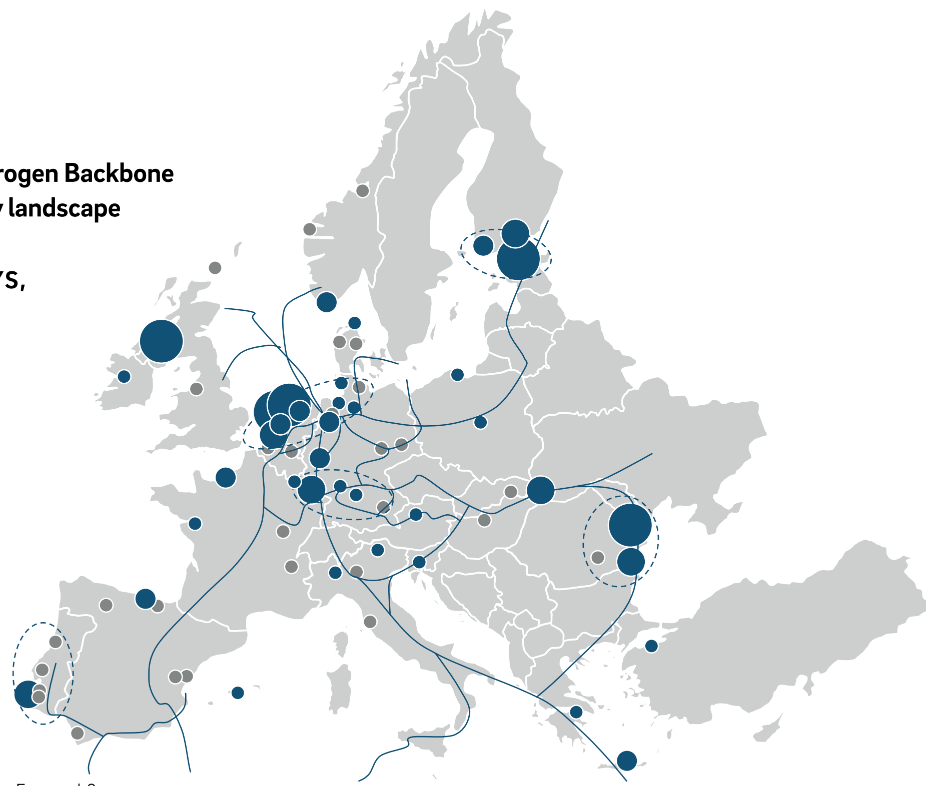
HYDROGEN VALLEYS AS THE "BLUEPRINT" TO UNLOCK THE HYDROGEN SECTOR AT LARGE

Despite these complexities, Hydrogen Valleys remain core pillars of the future clean hydrogen sector and help to bring down cost by pooling demand for larger-scale upstream production at lower costs. At the same time Hydrogen Valleys can successfully diversify risks by sharing infrastructure (e.g. pipelines, hydrogen refuelling stations (HRS)) and combining demand of multiple end users. They are strategically located in clusters of hard-to-abate industries, metropolitan regions, logistics hubs and at the most attractive renewables locations, as a closer look at the European Hydrogen Valleys on the platform and the plan for the European Hydrogen Backbone Initiative showcases easily. → C

Challenging hydrogen economics have nevertheless led to an evolution of the winning blueprints for hydrogen project development. Initially, Hydrogen Valleys were mainly strongly subsidised demonstration projects, such as the BIG HIT project[7] on Scotland's Orkney Islands. The next step in project development then aimed to increasingly unlock favourable economies of scale to bring down LCoH and move towards positive business cases with reduced public funding. New Valley concepts have scaled ambition, often beyond an immediate local/regional scope. While the initial valley concepts covered a captive project setting in a clearly defined regional scope, more and more Valleys now combine the decarbonisation of local industrial (and mobility) clusters with a perspective for exporting clean hydrogen or its derivatives to other demand centres. By "oversizing" own production and making use of favourable economies of scale (esp. renewable electricity input, electrolysers, conversion plants), the local business case turns positive under the assumption of also selling hydrogen to a broader market.

C: Mapping the European Hydrogen Backbone plans across the European Valley landscape

PLANNED HYDROGEN VALLEYS, PRODUCTION VOLUME [tpd]



Source: European Hydrogen Backbone, Hydrogen Europe, h2v.eu

Consequently, the hydrogen valley concept is evolving into a de-risking platform for larger-scale, phased (giga) project development. This new dimension adds complexity to Valley development, with more stakeholders involved across multiple project stages, more complicated financing concepts, the need for bulk hydrogen transportation solutions and additional offtakers on a global "commodity" market that only works by individualised transactions with limited demand side today. The large-scale production aspiration offers a perspective to drive down LCoH and supports the local business case. The local offtake secures a real implementation perspective for projects in the mid term and the operational basis for scaling. Scaling is usually pursued in a phased approach. The first mega Hydrogen Valley that has taken FID is a prime example of this development. The NEOM project[8] aims to establish low-cost green hydrogen for export, while adding capacity in additional phases that could serve local markets.

When looking at the Valley archetypes in the next chapter, this development interlinks archetype 2 and 3 and blurs the lines. On the one hand, adding this layer of complexity risks implementation delay, because even more preparation and planning is needed to orchestrate a multi-phased project with a national or even international market. On the other hand, the political environment is encouraging such larger initiatives by providing support to export and import infrastructure projects. Particularly new downstream policy support schemes (e.g. the auction mechanisms based on Contracts for Difference (CfD) by H2Global or the European Hydrogen Bank) are a key enabler for such more expansion-focused Valleys.

The lines between locally captive projects and export options are getting blurrier across the Hydrogen Valley landscape. It is, however, necessary to set clear priorities within the Hydrogen Valleys to successfully steer the projects through preparation and towards FID. A locally integrated project with the buy-in of local offtake is still a promising path for the de-risking approach given reasonable and stable conditions (e.g. acceptable LCoH). An additional export option can come on top with careful consideration of international fixed offtake.

1.3 Hydrogen Valley archetypes: The "blueprints" of the sector are maturing

Hydrogen Valleys continue to emerge as key initiatives to drive the clean hydrogen sector and ultimately the transition towards decarbonised economies further. The Valleys can be categorised in three archetypes, each with its own unique characteristics and objectives, reflecting also the diverse approaches within the hydrogen industry to serve different end uses, exploit different feedstocks and deploy different technologies. → D

Archetype 1 comprises rather local Hydrogen Valley initiatives that primarily address mobility applications such as heavy-duty truck or (urban) bus fleets. These projects are often long-standing "legacy Valleys", involve various stakeholders and are typically led by collaborations between the public and private sectors or regional authorities. Often initially starting as single-application mobility projects, they have expanded to a wider range of end use sectors. A key strategic element of these initiatives is the pooling of demand from fleet operators and other users. This shared use of technology and infrastructure allows for the growth of the electrolyser production unit or the hydrogen refuelling infrastructure, leading to a reduction in costs.

The centralisation of hydrogen production, consumption and infrastructure within a specific region allows these initiatives to achieve climate objectives, reduce local emissions and stimulate economic growth and job creation. Most archetype 1 Valleys are fuelled by green hydrogen produced either from local renewables or from green-PPA grid supply.

Over the last years, pure archetype 1 Valleys have become rarer, representing 39% of all Hydrogen Valleys on the platform, as industrial offtake increasingly shapes the creation of new clusters of hydrogen projects, with mobility users as a potential add-on.

Archetype 2 centres around medium-scale hydrogen production and consumption projects that primarily cater to industrial uses (representing 41%). These Hydrogen Valleys are key in decarbonising industrial feedstock and primarily serve large industrial consumers, such as steelmakers, (petro-)chemical players or fertiliser producers, which have a significant initial demand for clean hydrogen as a replacement for existing grey hydrogen supply – supported in some cases by demand-side regulation such as the RED III quotas in Europe.

These projects are typically constrained by the supply of renewable electricity due to existing grid constraints and available Power Purchase Agreements (PPAs). In some geographies, space constraints also present a natural limitation to the potential for on-site electrolysis. Another key hurdle is the seamless integration with other industrial processes, which requires careful planning and coordination.

D: Hydrogen Valley archetypes

ARCHETYPE 1
Small-scale, mobility-driven

- → **Rationale:** Pooling demand from mobility applications (truck fleets, bus fleets, etc.), shared use of refuelling infrastructure, scaling supply
- → **Capacity:** 5–20 MW electrolysis (typically grid power, with green PPA)
- → **Key challenges:** Many stakeholders involved (high complexity against comparatively low H_2 volumes)

40% of Valleys

ARCHETYPE 2
Medium-scale, industry-driven

- → **Rationale:** Decarbonising grey industrial feedstock with green H_2; anchor offtake from petro-chemicals, steel, etc.; mobility offtake as add-on
- → **Capacity:** 20–300 MW electrolysis (often grid power, with green PPA)
- → **Key challenges:** Regulation and power sourcing (e.g. EU RED II DA), seamless integration with individual processes, expansion limits

40% of Valleys

ARCHETYPE 3
Large-scale, supra-regional

- → **Rationale:** Building a local Valley with the ultimate ambition to export green molecules, connecting supply and demand across regions
- → **Capacity:** 500+ MW electrolysis (typically dedicated additional renewables)
- → **Key challenges:** Regulatory and other enablers for long-term offtake contracts, technology at scale, transportation

20% of Valleys

Source: h2v.eu, Roland Berger

Despite these challenges, these Hydrogen Valleys effectively leverage existing infrastructure around industrial sites, integrating hydrogen compression, storage and local transport solutions. The substitution of clean hydrogen for grey hydrogen usage is often the initial step, with potential expansion into other applications like mobility. This expansion is typically seen as an add-on because mobility can then benefit from cost-efficient hydrogen produced by large industrial electrolysers (up to several 100s of MW).

Driven by stricter CO_2 emission regulations, archetype 2 projects typically arise from private sector initiatives, either from the industrial consumers themselves or independent upstream developers seeking business opportunities in the clean hydrogen market.

In recent months, especially these archetype 2 projects have run into specific issues mirroring the main challenges and hurdles mentioned above. Examples include increasing PPA price levels, grid fees and connection cost as well as remaining regulatory uncertainties.

Archetype 3 (representing 20%) focuses on the development of large-scale hydrogen production, often export-oriented, aiming to connect regions with favourable production conditions to global demand centres. These projects are the largest in scale and their ultimate ambition is to export green molecules from Valleys to other markets. They plan to start with smaller local offtakers and gradually scale up for international trade. However, a challenge lies in the commercial de-risking and deployment of the technology at the scale of ultimately several GW of electrolysers (albeit typically in several build-out phases) or equivalent large-scale blue hydrogen production capacity.

Interestingly, Valleys under archetype 3 have acknowledged the significance of archetype 1 and 2 projects as an initial step in project development. They realise that establishing a Hydrogen Valley infrastructure and securing local offtakers is pivotal for the success of later scaling to international export.

Moreover, there's a discernible shift in archetype 1 projects towards industrial end use (archetype 2), moving away from an exclusive focus on mobility. Even though archetype 1 projects are typically smaller in size and scale, their industry and sector coverage mirrors that of a typical archetype 2 project. Hydrogen Valleys and hydrogen projects often adopt a phased approach. Furthermore, the potential for collaboration and interconnection between closely situated Hydrogen Valleys is substantial. Infrastructure connections, such as pre-existing pipelines or the creation of a new European Hydrogen Backbone, are vital in enabling this integration and foster the expansion of larger, interconnected Hydrogen Valleys.

Archetype 3 projects, the largest ones, are predominantly found in the Middle East, South America and North America, where underlying feedstocks (renewables, natural gas + CCS) are abundant. On the other hand, archetype 1 projects are primarily concentrated in Europe, which has a multi-decade legacy of hydrogen-based mobility (e.g. the most developed network of hydrogen refuelling stations globally). → E

Hydrogen Valleys show substantial commonalities all around the world, whether they call themselves ecosystems, hubs or valleys. They continue to offer a winning recipe for the deployment of clean hydrogen projects, even if individual initiatives differ slightly to match local preconditions. In the interests of scaling the clean hydrogen sector as a whole, the common experiences of the Valleys can help to push forward winning project development recipes and allow industrial supply chains to scale.

E: Hydrogen Valleys on the Hydrogen Valley platform

Australia
- CQ-H2 Hydrogen Hub
- Crystal Brook Hydrogen Superhub
- Eyre Peninsula Gateway
- Hunter Hydrogen Network

Austria
- WIVA P&G
- Hydrogen Industry Valley Austria

Belgium
- Flemish Hydrogen Ports Valley

Brazil
- H2BE
- Ceará – Green Hydrogen House
- Green Energy Park Piauí
- Solatio H2 Piauí

Canada
- Alberta Industrial Heartland Hydrogen Valley

Chile
- Green Hydrogen Antofagasta
- Green Hydrogen Magallanes

China
- Foshan Lake Hydrogen Valley Town
- Rugao Hydrogen Energy Town
- Zhangjiakou demonstration project

Denmark
- Cluster NorthH2
- CONVEY
- HyBalance

Estonia
- Hydrogen Valley Estonia

Finland
- BalticSeaH2
- Naantali Plant

France
- Normandy Hydrogen
- Regional Hydrogen Roadmap
- ZEV – Zero Emission Valley
- AdvancedH2Valley

French Guiana
- Centrale Electrique de l'Ouest Guyanais

Germany
- Clean Hydrogen Coastline
- doing hydrogen
- eFarm
- Grande Region Hydrogen EEIG
- H2NORD GmbH & Co. KG
- H2Rivers
- HY.City.Bremerhaven
- HY.Kiel
- hy.klettwitz
- HY.Waiblingen
- HyBayern
- Hydrogen Valley Emsland
- HyWays for Future
- LHyVE Leipzig Hydrogen Value Chain for Europe
- Norddeutsches Reallabor (NRL)
- REFHYNE 2

Greece
- H2CRETE
- TRIERES
- CRAVE-H2

Hungary
- Yellow Swallow

Ireland
- SH2AMROCK

Israel
- Southern Arava Hydrogen Valley

Italy
- H2iseO
- Hydrogen Valley South Tyrol
- HYPER
- TH2ICINO

Japan
- Fukushima Energy Research Field

Luxembourg
- LuxHyVal

Netherlands
- Djewels
- H2 Proposition Zuid-Holland
- H2-Fifty
- HEAVENN
- Hydrogen Delta
- Hydrogen Hub Noord-Holland

Norway
- H2 Valley Mid-Norway
- Hydrogen Hub Agder
- HyFuel AS

Oman
- Green Hydrogen & Chemicals Oman

Poland
- Amber Hydrogen Valley
- Mazovian Hydrogen Valley

Portugal
- Aveiro Green H2 Valley
- Galileu Green H2 Valley
- GREENH2ATLANTIC
- MadoquaPower2X (Sines Energy Hub)
- Sines Hydrogen Valley

Romania
- Green Hydrogen @ Blue Danube
- Hydro3D

Saudi Arabia
- NEOM GREEN HYDROGEN

Slovakia
- Black Horse

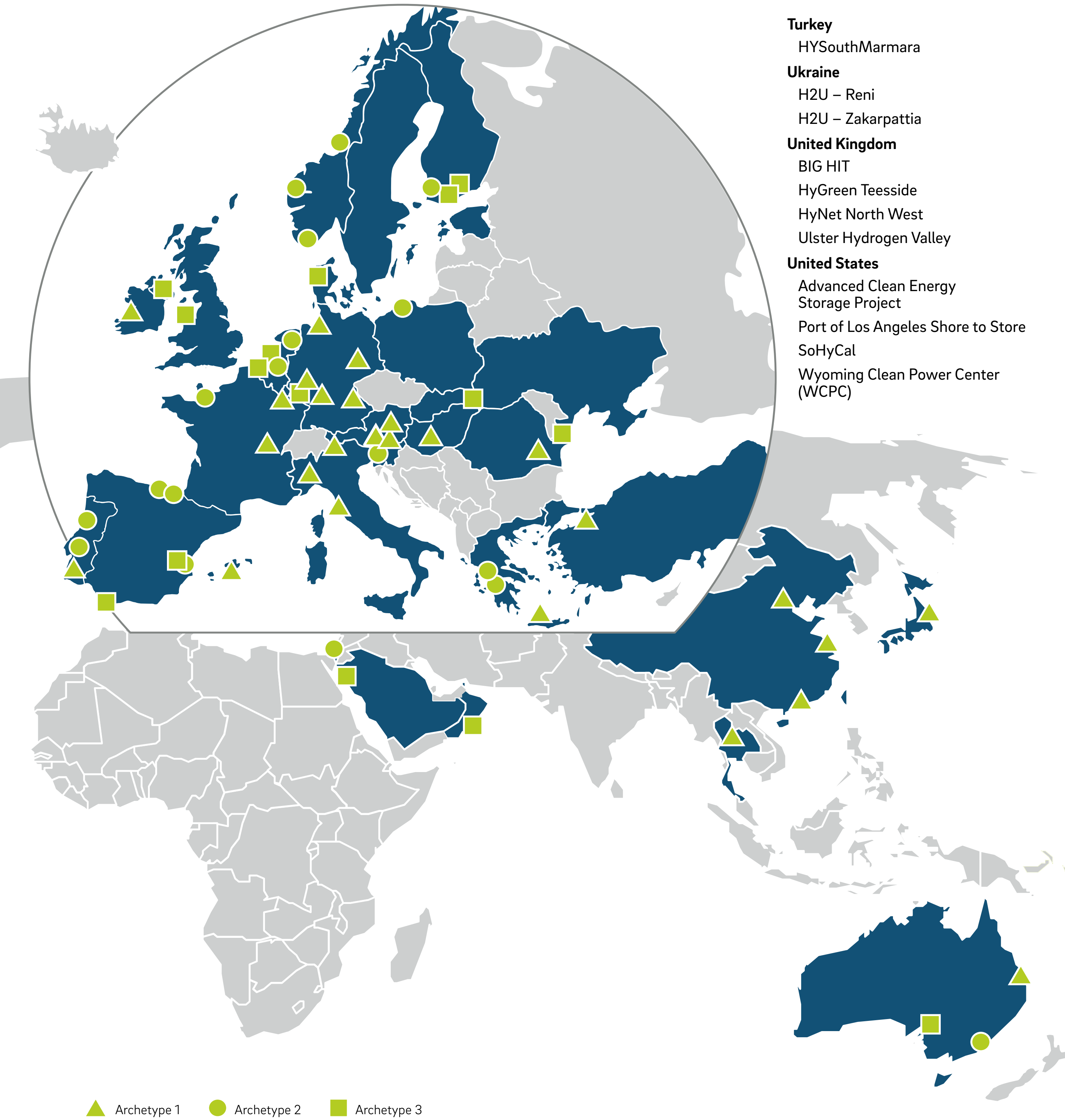
Slovenia
- North Adriatic Hydrogen Valley

Spain
- Basque Hydrogen Corridor BH2C
- BenortH2
- Green Crane (Western route)
- Green Hysland
- HyVal
- Andalusian Hydrogen Valley
- Orange.bat

Sweden
- Mid Sweden Hydrogen Valley

Thailand
- Phi Suea House Project

Source: h2v.eu, Roland Berger



Turkey
- HYSouthMarmara

Ukraine
- H2U – Reni
- H2U – Zakarpattia

United Kingdom
- BIG HIT
- HyGreen Teesside
- HyNet North West
- Ulster Hydrogen Valley

United States
- Advanced Clean Energy Storage Project
- Port of Los Angeles Shore to Store
- SoHyCal
- Wyoming Clean Power Center (WCPC)

2 Key Hydrogen Valley market developments – Empirical evidence across three years and 90+ projects

The Mission Innovation Hydrogen Valley Platform has now collected three years worth of project data to date, building a robust empirical basis to track key developments in the clean hydrogen sector that is particularly relevant for highly advanced, value-chain-covering hydrogen projects. The data reveals clear trends in project development and fleshes out success factors as well as common hurdles in an aggregated manner.

2.1 Overall trends: The progress of Hydrogen Valleys in recent years

Hydrogen Valleys are a key element not just in the growing clean hydrogen sector, but also in the energy transition at large – and are thus also affected by its wider geopolitical context. Hydrogen Valley developers' evolving motivation for pursuing their projects reflects the shifting macrotrends of recent years. → F

While climate action and industrial policy are still the overall prevailing drivers to promote Hydrogen Valleys (e.g. 4 out of 5 developers are driven by regional decarbonisation agendas), geopolitical conflicts and uncertainties have also underscored the need for diversification and resilience in energy supply chains. As a result, 55 percent of developers now see energy security as a main project driver and a top priority, compared to 42 percent in 2021.

Simultaneously, strategic investments in new business models have gained prominence among developers. Compared to 2021, around 38 percent more Hydrogen Valleys see this as an important project driver, addressing the long-term future of their business models (e.g. green heavy industries, green logistics hubs). The energy landscape is undergoing rapid transformation, and developers recognise the need to adapt and position themselves for success in the long run. By making the right strategic investments now, developers can future-proof their projects, reduce environmental impact and seize new market opportunities.

Hydrogen Valleys make up a dynamic and evolving landscape of projects – with initiatives progressing at different speeds and to different stages in the lifecycle. Three-quarters of the Valleys on the platform are yet to take a Final Investment Decision (pre-FID), but the community (and hence the "funnel" of new projects) continues to grow. Still, clearing the FID gate seems to have become the major hurdle for project advancement. The underlying reasons are manifold and chiefly concern the lack of effective de-risking frameworks or highly individualised de-risking approaches with high transaction costs. Development capital needs are substantial (real money needs to be spent), as multi-million or even multi-billion euro investment decisions with 15–20 year payback time need to be prepared. (Pre-)FEED studies, detailed cost estimates, and pre-contractual offtake arrangements need to be produced. Moreover, accessing subsidy schemes and building up capable developer teams takes time and requires funding. In this phase, most Valleys walk through the infamous "valley of death" and only a subset are pushing through.

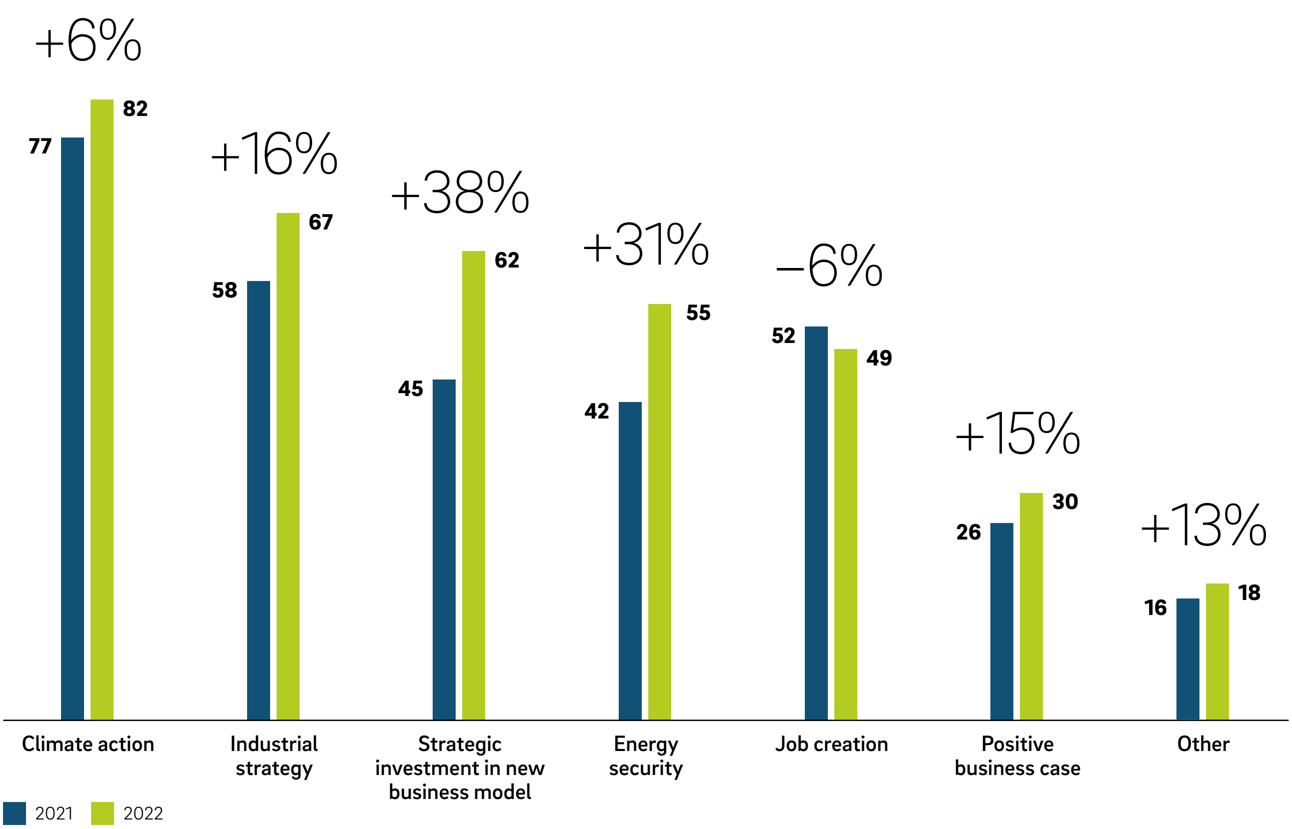
Nevertheless, there is also an increasing share of projects moving into the construction and operations phases, indicating progress in the implementation of hydrogen initiatives overall. Currently, 17 Hydrogen Valleys are in the construction phase or already fully operational. Looking ahead, several Valleys expect to commence operations in 2025 and 2026; the next two years will determine what the overall deployment trajectory for the rest of the 2020s might look like. → G

From a value chain perspective, the Hydrogen Valleys mirror a balanced portfolio of different archetypical projects. The majority build on green hydrogen production from PEM or alkaline electrolysers. Only nine Valleys have indicated their plans to produce blue hydrogen, building steam methane reformers (SMRs) and carbon capture units. The Valleys overall state large supply ambitions, with cumulative plans to bring up to 4 Mt of clean hydrogen to the market in the second half of the decade – with their first operational production stages alone. In the final build-out, they even aspire to further expand production by a factor of 4. With the currently shifting market environment, it will be necessary to track the developments closely, while anticipating delays and even some scale-back of ambitions.

In the midstream segment, there has been no substantial evolution of Hydrogen Valley designs over time noted. Approaches to transportation and storage are consistently combining larger-scale infrastructure

F: Underlying drivers for valley development

Question: "What are the main drivers for your project?"[1]



Source: Clean Hydrogen JU, Roland Berger

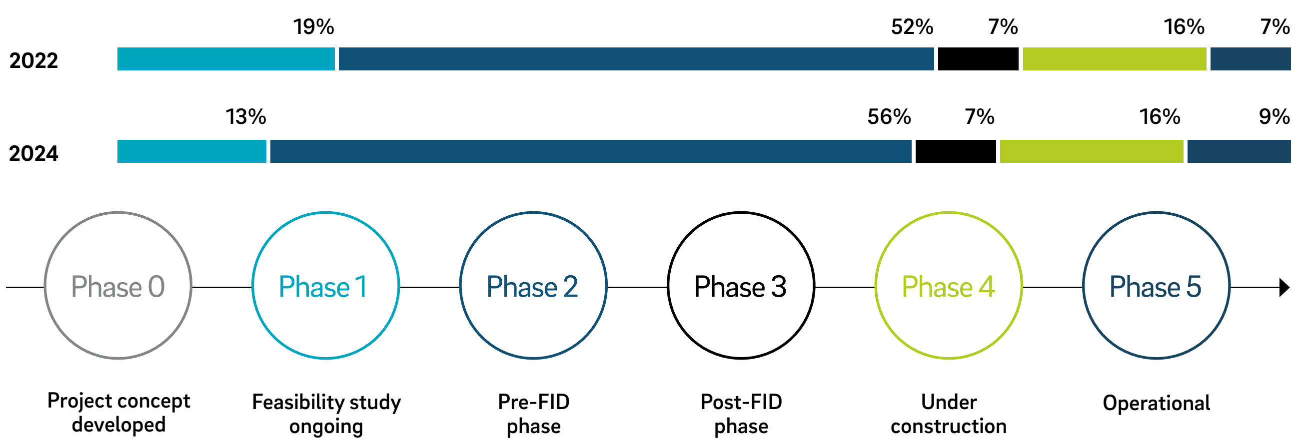
1) Multiple answers possible (n_{2021}=31, n_{2024}=87)

assets for bulk offtake with cylinder and trucking solutions for more distributed use cases. One notable difference is an increase in the importance of shipping. With maturing project blueprints and the ambition to lower LCoH through scale, more export-oriented Valleys have been put forward that rely on large-scale infrastructure to connect not only to the local or regional offtake but also to international markets. The increase in shipping as a mode of hydrogen transportation (now prevalent in 33% of all Valleys surveyed) further highlights the industry's progression towards Valley archetypes 2 and 3, where larger-scale projects and international supply chains play a larger role. Ammonia as a key hydrogen derivative and a hydrogen transportation carrier has gained particular momentum in this context.

Finally, the offtake sectors that Valleys tackle have also remained consistent over the years. Legacy applications in mobility (e.g. urban buses, trucks) still play an important role, and decarbonisation of local/regional transport is a key concern for around 80% of the Valleys. However, while heavy-duty road mobility use cases still dominate as early mover offtakers, 35% of mobility-focused Valleys now also target the decarbonisation of the shipping sector. → H

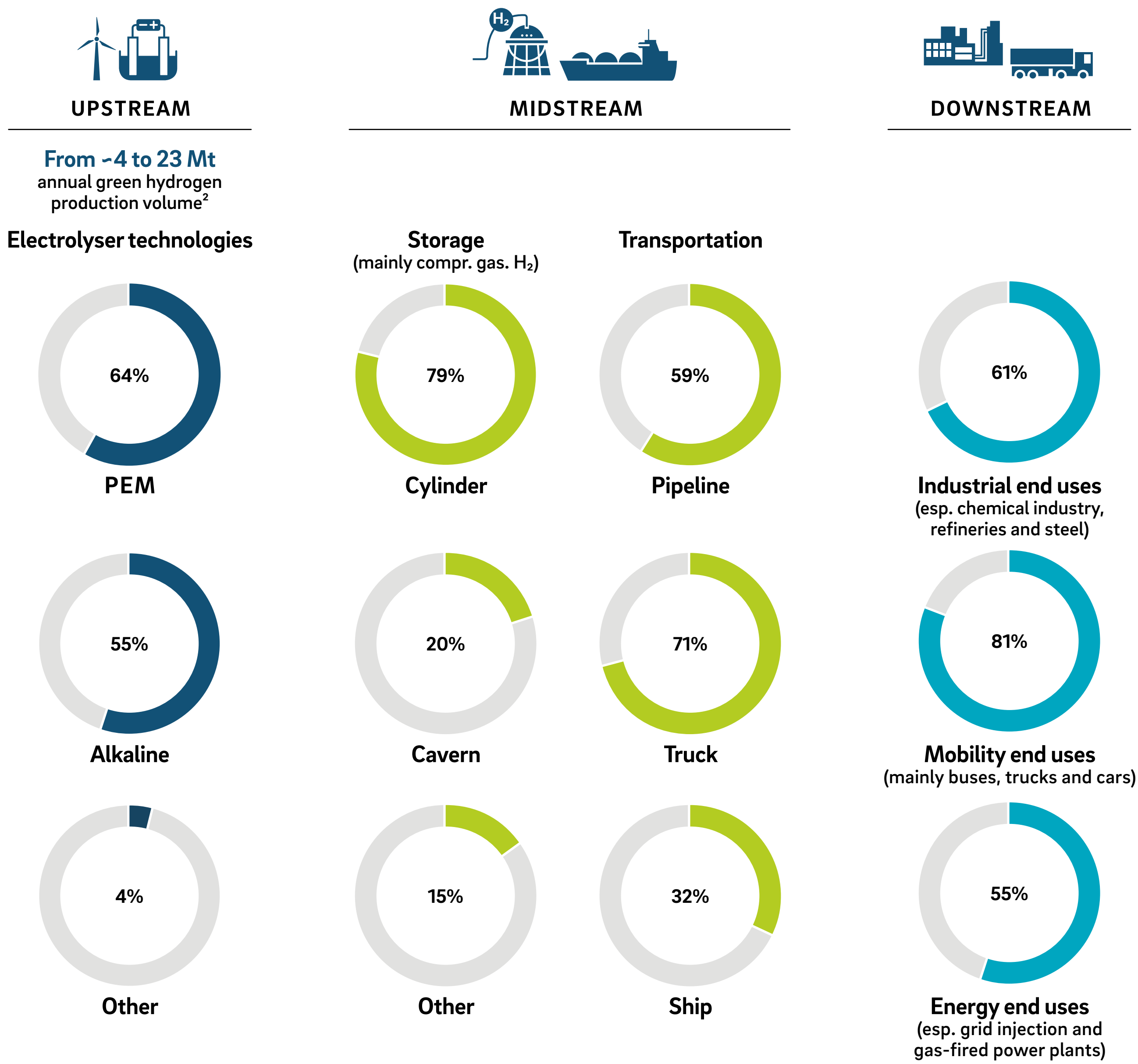
Industrial offtake strongly focuses on hard-to-abate feedstock uses of hydrogen, well in line with recent trends in flagship clean hydrogen offtake announcements and the results of the European Hydrogen Bank's pilot auction outcomes. 61% of all Hydrogen Valleys plan to serve such industry segments. Energy end uses also play a stable role in Hydrogen Valleys: As the gas grids and gas-fired power plants are already able to take on shares of hydrogen, such offtake routes are often integrated in the overall Hydrogen Valley approach to secure flexible but reliable offtake. Because of their high legacy volumes, the need for decarbonised H_2 is poten-

G: Status of Hydrogen Valleys along the project lifecycle



Source: h2v.eu, Roland Berger

H: Technology deployments inside Hydrogen Valleys along the value chain[1]



Source: h2v.eu, Roland Berger

1) Multiple answers possible 2) From initial volume in the first year to reaching maximum build-out stage

tially large and therefore a great fallback option for excess production.

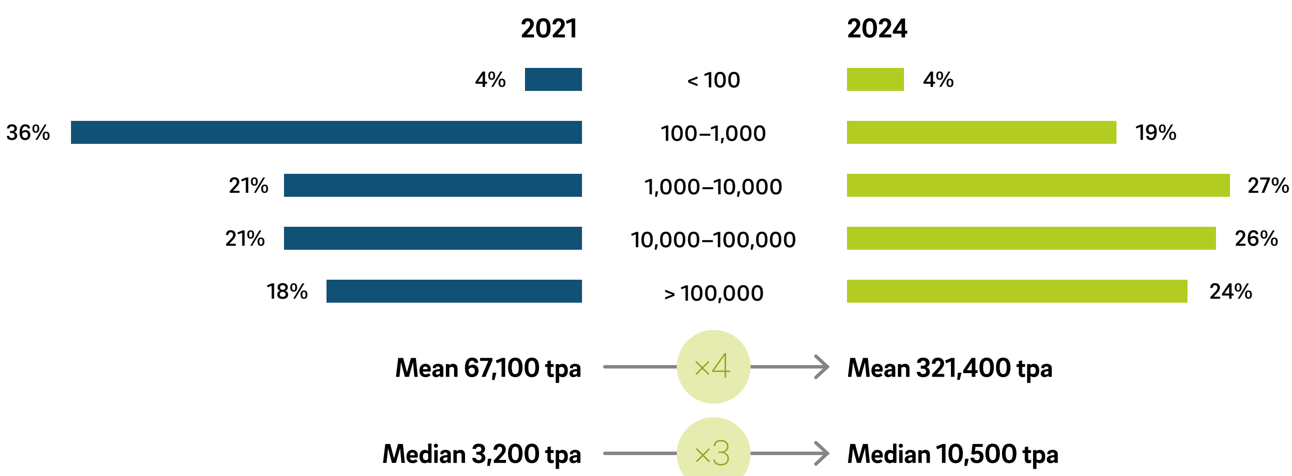
One notable development is the growing size of Hydrogen Valley projects represented on the platform, with an increasing number of initiatives with a production volume exceeding 10,000 tons of hydrogen per year. The median size of a Hydrogen Valley has grown by nearly a factor of 3 from 3,200 tons per year to over 10,500 tons per year. However, it is important to acknowledge that projects vary in size across different regions, with significant additions of large-scale projects in Southern Europe, the US and the Middle East. → I

As Hydrogen Valleys expand and benefit from larger production capacities, they can leverage economies of scale to drive down costs. The average (anticipated) clean hydrogen production cost of all surveyed Hydrogen Valleys decreased from EUR 6.4 per kg in 2021 to EUR 6.1 per kg in 2024. One notable development is the increase in Valleys estimating their LCoH to be in the range of EUR 4–6 per kg, indicating a growing number of projects aiming for more cost-efficient production. While this still falls short of the more aggressive cost-down curves clean hydrogen projected at the start of the decade[9], it reflects the current upward pressures on LCoH (rising cost of green electricity, rising electrolyser cost, contingency layers in EPC structures, etc.). Nevertheless, it also points to the fact that already every fifth project plans to operate within the IEA's anticipated price corridor of below 4 EUR/kg. → J

Overall, Hydrogen Valleys appear to be a reasonable indicator of where the clean hydrogen sector stands commercially. The sector is moving towards scale and is experiencing not uncommon hurdles on the way to mass deployment.

I: Planned hydrogen production volumes from Hydrogen Valleys

Question: "How much hydrogen is produced within the project per year?" [tpa][1]



Source: h2v.eu, Roland Berger

1) $n_{2021}=29$, $n_{2024}=74$

2.2 Winning recipes: Success factors for integrated hydrogen project development

The main ambition of the www.h2v.eu platform is to enable shared learning to support the development of the clean hydrogen sector. Sharing lessons learned and best practices is one key element that helps to disseminate the information needed for replication. This chapter thus looks at some of the most relevant factors that can help advance Hydrogen Valleys. If these pieces of a Valley puzzle come together, projects have a good chance to reach an FID and actually get built. The lessons learned in this report originate from an in-depth best practice analysis with successful project developers; more details on individual cases can be found on the h2v.eu platform[10].

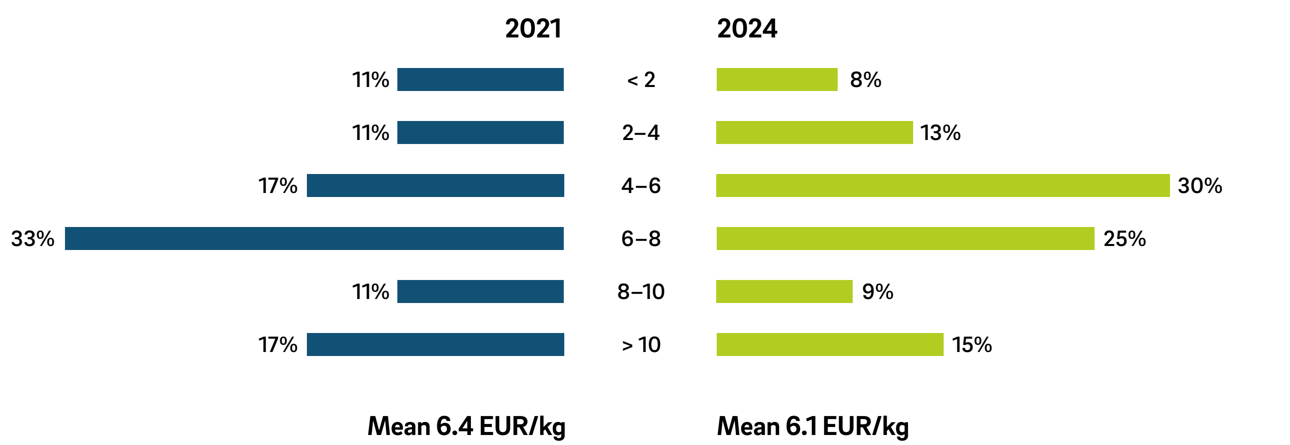
Although Hydrogen Valleys represent a diverse set of integrated clean hydrogen projects, they share common success factors. This shared experience allows for the exchange of knowledge and best practices among project developers, fostering collaboration and accelerating the development of Hydrogen Valleys as a whole.

77 percent of Hydrogen Valleys see their business model development as their most important overall success factor, followed closely by securing funding for the collective investments (76 percent). For project developers, this means setting up sound commercial structures (defining the commercial relationships, allocating economic risks and rewards among all parties, etc.) and building bankable (project) financing concepts. → K

Project structuring factors: Hydrogen Valleys (as integrated clean hydrogen projects) face different risk profiles at different stages of the value chain (upstream, midstream

J: Anticipated cost of hydrogen production

Question: "What is your (anticipated) average cost of green H_2?" [EUR/kg][1]



Source: h2v.eu, Roland Berger

1) n_{2021}=18, n_{2024}=53

and downstream), requiring tailored commercial structuring and individualised contracting strategies.

Successful project structuring means successfully allocating risks to the project parties best placed to manage them – and ultimately designing contractual structures as instruments to prescribe the risk allocation and enable investments up and down the value chain.

Green hydrogen projects have particular risk profiles that set them apart from other energy asset investments. Project developers often come from the oil and gas or renewables sectors where projects have some similarities but also significant differences. → L

One key difference is the existence of infrastructure as a key enabler to connect supply and demand. Unlike renewables projects that can connect to an existing (and expanding) power grid, hydrogen infrastructure still needs to be built (pipelines, terminals, storage sites, etc.), creating a special type of interface risks for project developers. In addition to infrastructure challenges, there are also higher and more pertinent technology risks in hydrogen projects, because key technologies such as electrolysers or fuel cells are still commercialising and industrialising (especially as far as their deployment at larger scales is concerned).

Given these unique risks, developers need tailored mitigation strategies – up and down the clean hydrogen value chain.

Firstly, any hydrogen project and any Hydrogen Valley starts with identifying (and ultimately securing) offtake. The level of firmness in offtake commitments (from Memoranda of Understanding or Letters of Intent towards Term Sheets and ultimately Binding Agreements) is what separates early-stage from advanced projects. Here, proximity to large anchor offtakers can be an important de-risking element as nearby offtakers depend less on their own or third-party investments in transportation infrastructure. Offtake can be further de-risked with the help of demand-side public support schemes to bridge the gap between a developer's landed cost and an offtaker's willingness to pay gap. Many

K: Key success factors when developing Hydrogen Valleys

Question: "What are the key success factors for the preparation phase?"[1]

Source: h2v.eu, Roland Berger

1) Top 5 answers from survey; multiple answers possible; n=61

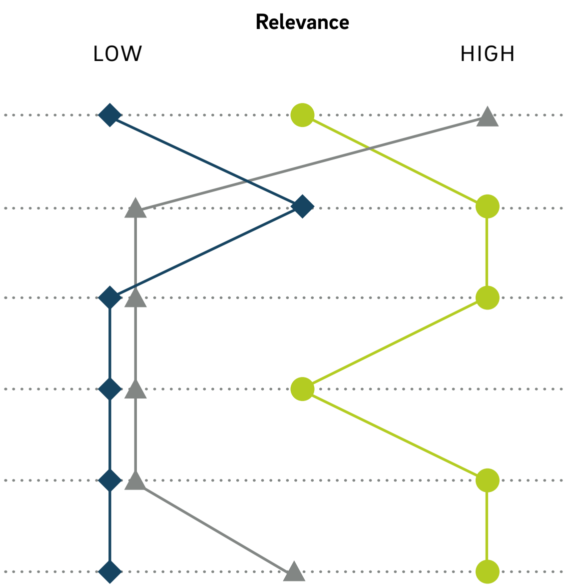
Hydrogen Valleys build their commercial structure and offtake strategy around demand-side policy measures, such as Contracts for Difference, public auctions or quotas.

Secondly, upstream clean hydrogen production needs to be set up competitively, i.e. for low-cost production. One key success factor is access to efficient and high-capacity-factor renewable energy sources (from within a Hydrogen Valley or via grid supply) or competitive natural gas sources coupled with easy-to-access CCS potential, enabling lower-cost clean hydrogen production at scale.

Thirdly, at the midstream part of the value chain, Valleys need to develop mature and cost-competitive transportation solutions, including conversion and storage, especially if the project doesn't operate in a fully captive setting. Long-term agreements for transportation are a key project structuring element.

L: Key project risks compared to other energy asset investments

Assessment of relevance of risks per energy project type



Risk types	Key rationales for assessment of green H_2 project risks
Political / regulatory	First H_2 policies in place; consistent funding mechanisms and regulation (e.g. across countries) missing
Commercial	Long-term H_2 offtake agreements key, but limited willingness to pay for clean H_2; also, limited profitability
Technology	No long-term track record for use of H_2 technology in large-scale project settings, thus uncertainties/risks
Construction	Limited track record, but emerging EPC landscape (can leverage skills from other energy projects)
Operation & maintenance	High performance risks (e.g. efficiencies, failure rates, maintenance) given no proven track record
Environment & safety	No consistent environmental & safety standards in place; high flammability of H_2 as a threat

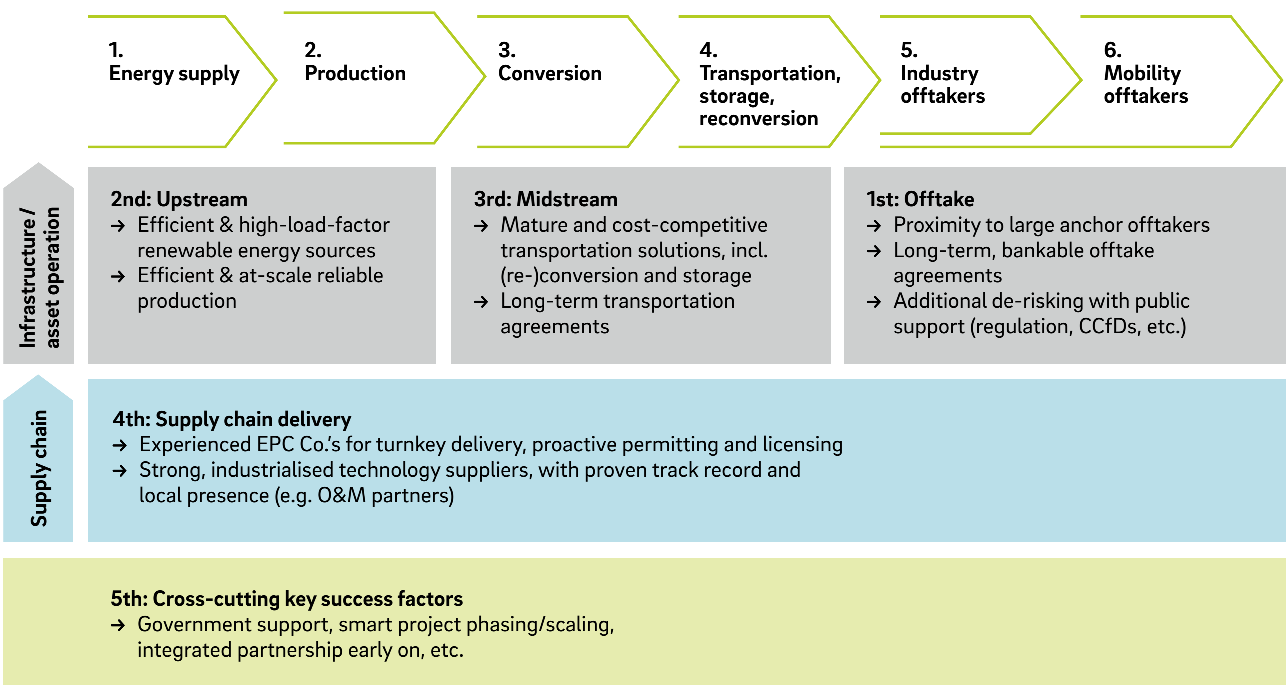
Green H_2 projects   Other renewable energy projects (e.g. PV)   Oil & gas projects

Source: h2v.eu, Roland Berger

Aside from the flow of electrons and molecules along the hydrogen value chain, the industrial supply chains of the required equipment are another critical element for project success. Here, it is essential to mobilise experienced EPC contractors for turnkey delivery and ensure that proactive permitting and licensing processes are in place, where authorities are engaged early on. Additionally, strong technology suppliers with a proven track record (and ideally local presence) are critical for moving projects to FID and implementing them in time, in budget and to spec. Lastly, effective government support is an underlying and cross-cutting success factor (e.g. by setting strategic directions for the hydrogen sector or supporting with specific public funding schemes), as are smart project phasing/scaling and integrated partnership models across project stakeholder groups. → M

Once a commercial structure has been defined, it needs to be cast in firm contractual arrangements that legally link the different elements in the closed ecosystems that are Hydrogen Valleys: In the case of green Hydrogen Valleys, these include most importantly offtake (via Hydrogen Purchase Agreements, HPAs), renewable electricity input (often via Power Purchase Agreements, PPAs), and transportation (via transpor-

M: Key success factors for integrated green hydrogen projects

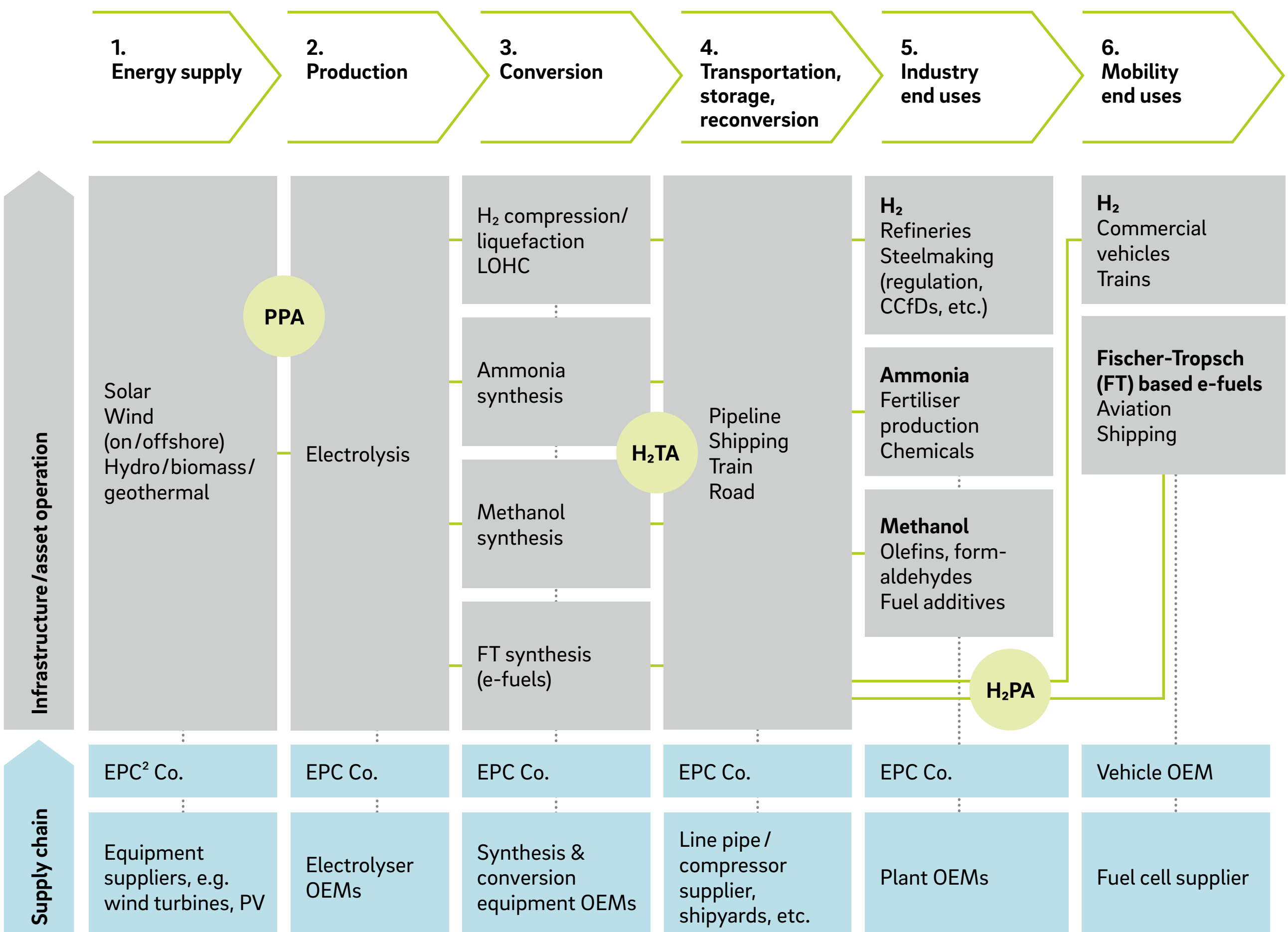


Source: h2v.eu, Roland Berger

tation agreements to guarantee physical delivery of product, HTAs). → N

One recurring approach adopted by early promoters of Hydrogen Valleys to deal with the underlying complexity of commercial structuring is insourcing. Eliminating complexity by covering all necessary value chain steps and / or value adding functions like EPC or operations and maintenance in one organisation helps to streamline processes and to effectively manage project implementation. On the flip side, this approach is

N: Key building blocks of integrated green hydrogen projects (non-exhaustive)[1]



Source: h2v.eu, Roland Berger

1) Key long-term take-or-pay contracts: Power Purchase Agreement (PPA), Hydrogen Purchase Agreement (HPA), Hydrogen Transportation Agreement (HTA); 2) Engineering, Procurement and Construction

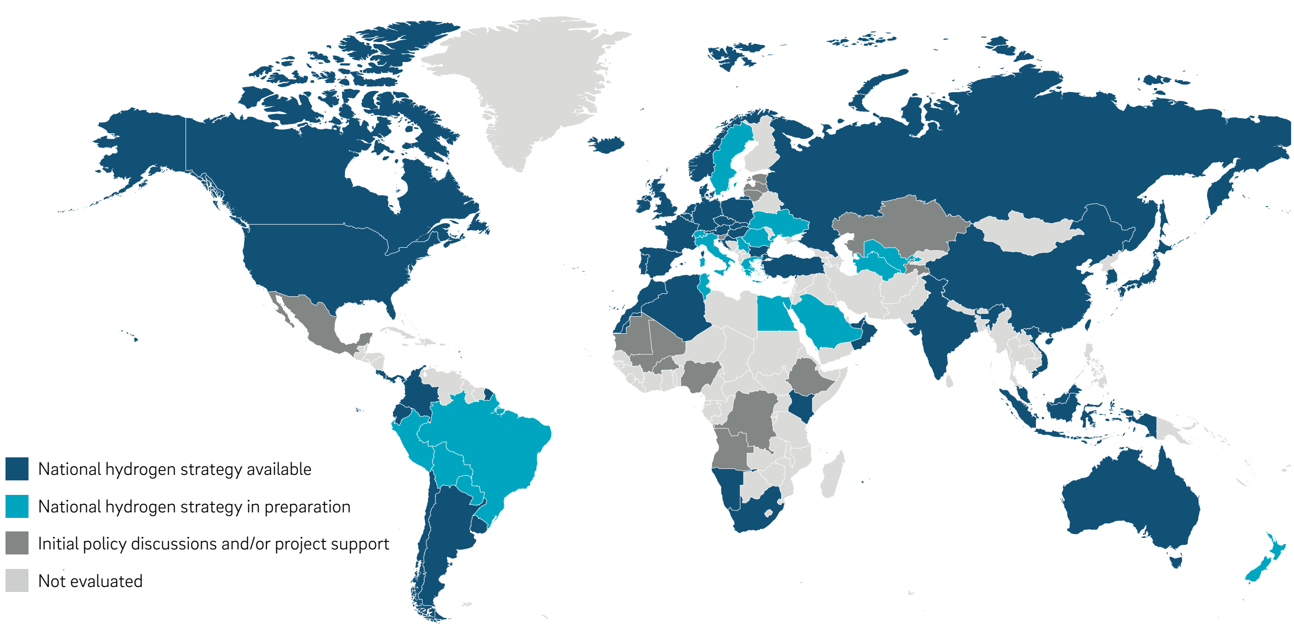
limited when it comes to large projects at scale except for a few players in the market. It benefits market players that can offer fully integrated solutions.

(Project) financing factors: When the commercial structures (offtake agreements, transportation agreements, etc.) successfully de-risk the investments up and down the value chain, Valleys can take the next step and seek debt financing for their projects. Here, within the offtake-related agreements, potential lenders pay particular attention to pricing formulas, delivery schedules, and force majeure risks – in particular when developers seek limited/non-recourse project financing. Other key areas of concern for lenders are:

- Technology risks (e.g. mitigated by performance guarantees)
- Regulatory/policy/subsidy-related support
- Developer credit and balance sheet strength
- Offtaker credit and balance sheet strength
- Public/sovereign guarantees

While many Hydrogen Valley developers confirm that there is a lot of money chasing viable investment opportunities in clean hydrogen (even with a particular risk appetite), the fundamental requirements for energy infrastructure funding and financing need to be met.

O: Global status of national hydrogen strategies



Source: World Energy Council, IEA, Roland Berger

2.3 Policy environment: Evolving government support for Hydrogen Valleys

Historically, the policy environment in clean hydrogen lead markets (e.g. the European Union, the United States, Japan, Korea, China) has consistently shaped the advancement of the entire sector. Since the beginning of the decade, global government efforts to promote clean hydrogen have seen unprecedented progress.

THE ENERGY TRANSITION NEEDS CLEAN HYDROGEN AND GOVERNMENTS ARE SHOWING MORE AND MORE COMMITMENT

A few years ago, the global hydrogen policy map was quite empty. Today, more than 40 countries have passed a national hydrogen strategy, including not only every major industrial nation but also many emerging markets. The strategies combine ambitious clean hydrogen targets for consumption, production, investment, and value creation, driven by both climate action and industrial policy objectives. → O

In one of the lead markets, Europe, green hydrogen has gained strong political momentum, and targets for electrolyser build-out have doubled in many countries since their initial announcement. In addition, Member States back up their targets with more and more specific policy measures, such as national funding schemes and implementation of EU Directives. EU policy also plays a big role in supporting Hydrogen Valleys and hydrogen projects at large, most notably RED III and the REPowerEU package. RED III and RePowerEU create mandatory regulated markets that are providing an important and effective "signal" for offtakers and their sourcing efforts from green H_2 producers (considering European sectors with a willingness to pay at the moment). The EU's post-Ukraine REPowerEU package includes a "Hydrogen Accelerator"[11] that aims for 10 Mtpa of domestic renewable hydrogen production by 2030 (+100% of previous target), plus an additional 10 Mtpa of renewable hydrogen imports. This initiative is expected to trigger the necessary electrolyser build-out of 65–100 GW[12] by 2030 and increase EU electrolyser manufacturing capacity to 17.5 GW p.a. by 2030.

In addition to Europe, the US is catching up fast: The Inflation Reduction Act (IRA) with its Hydrogen Hubs program (administered by the Department of Energy and mirroring the European Hydrogen Valleys initiatives) makes for a strong hydrogen policy push on the other side of the Atlantic, mirroring closely Europe's efforts and solutions. Although the hubs are at the beginning of the project lifecycle and final regulatory details on the Production Tax Credits (temporal, spatial matching, additionality, etc.) are still in the making, the policy environment has become significantly more supportive of Hydrogen-Valley-like initiatives.

Another example of a 360-degree approach of supporting clean hydrogen projects – from production to offtake – is Austria and its promotion of Valleys/Hubs in Australia. The Australian Hydrogen Hubs Program is an important pillar of the Australian Government's National Hydrogen Strategy, aimed at supporting the development of hydrogen technology and infrastructure. The Australian Government is investing AUD 526 m[13] in support of the development of seven regional hydrogen hubs initiatives across Australia. In Korea and Japan, there are individual approaches to drive the hydrogen market in sub-sectors through CfD schemes, especially in power generation.

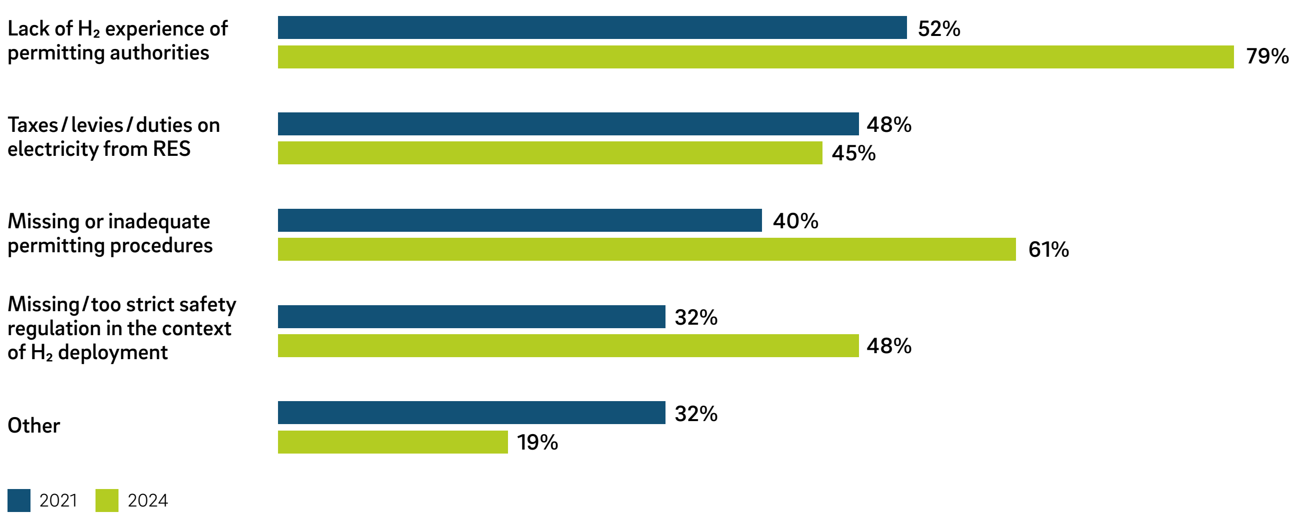
Hydrogen Valley developers continue to stress the need for supportive policies and regulations. CAPEX funding programs, OPEX subsidies and other policy enablers are frequently mentioned as important enablers for Hydrogen Valleys. Non-European Hydrogen Valleys specifically highlight grants from local governments. Moreover, established hydrogen strategies at a regional, national or even supranational (e.g. European Hydrogen Strategy) level play a significant role by signalling political commitment. Many Valleys highlight the positive influence of these strategies and recognise the resulting political support from local and national ministries as essential.

CUMBERSOME PERMITTING PROCESSES EMERGE AS THE BIGGEST HURDLE TO VALLEY IMPLEMENTATION

As the Hydrogen Valley developments progress along the project lifecycle, they encounter more and more practical implementation challenges to energy infrastructure projects. An increasingly critical hurdle to executing clean hydrogen projects in time is permitting and authorisation processes (e.g. environmental impact assessments, public consultation processes, construction permits, operating licences). Hydrogen Valley developers now consistently feedback their growing struggles to obtain permits and licences in time for project implementation according to schedule. And as more project developers enter the permitting phase of their project, it becomes obvious that current permitting and authorisation processes are not suited to meet the needs of many first-of-a-kind clean hydrogen project developments, also in the context of rapid expansion of other clean energy sub-sectors (e.g. onshore and offshore wind, utility-scale PV). For example, some Hydrogen Valley developers report approval times of more than one year only for their environmental impact

P: Key regulatory hurdles to Hydrogen Valley development

Question: "What are the main regulatory hurdles that you have to overcome?"[1]



Source: h2v.eu, Roland Berger

1) Multiple answers possible; n_{2021}=25, n_{2024}=62

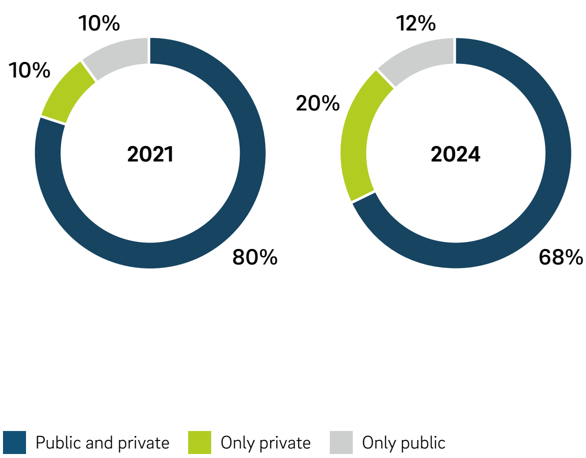
assessment – a challenge not uncommon in the overall energy transition. → P

Especially the lack of experience of permitting authorities with clean hydrogen projects, technologies and companies appears to be one cause of delays. Many local and regional authorities are not used to authorising permits for hydrogen production, infrastructure or end-use applications. In 2021, more than half of Hydrogen Valleys already anticipated this as a key challenge; now one in four Valleys rank it as a critical public-sector hurdle to project execution. Furthermore, the permitting procedures themselves are often not fully in place yet or at least perceived to be inadequate for Hydrogen Valleys, which 60 percent cite as an additional barrier (an increase of around 20 percent compared to 2021).

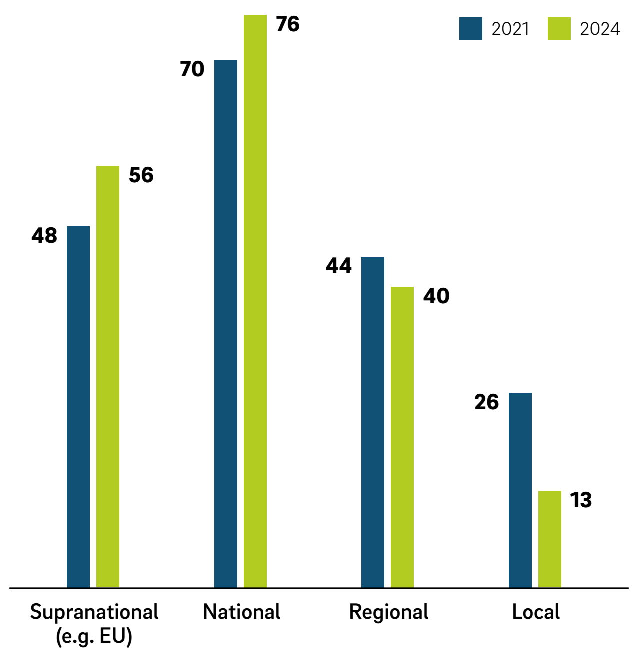
Almost half of Hydrogen Valleys still see taxes, levies and charges on electricity from renewable energy sources (for green hydrogen production) as a major obstacle to project development, given that cost of electricity is the largest cost driver of green hydrogen production cost.

Q: Funding and financing structure of Hydrogen Valleys

Main sources of funding and financing
Question: "What are the main sources for your budget?"[1]



Share of projects with public funding
Question: "What are the main public and private sources for your budget?"[2]

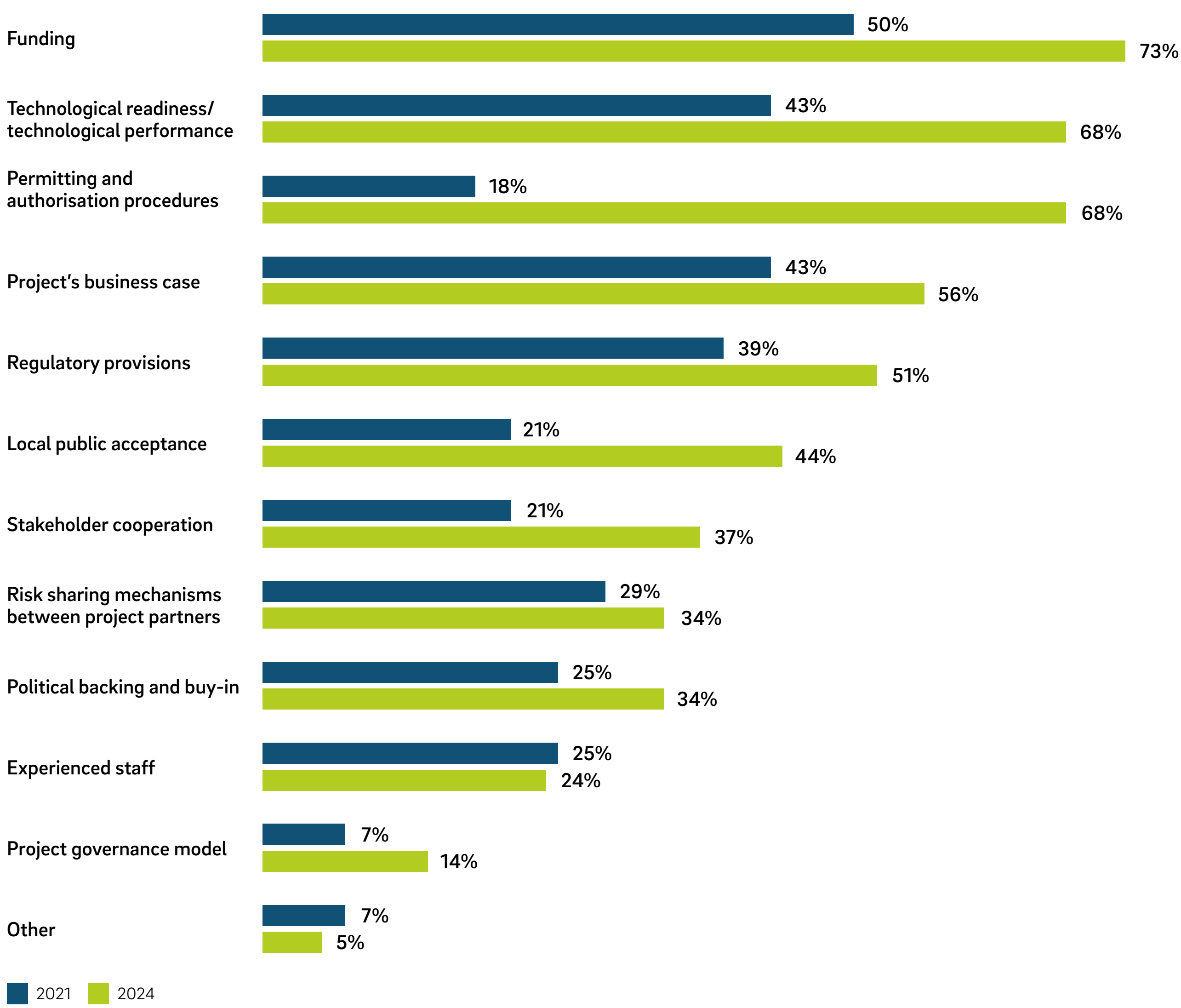


Source: h2v.eu, Roland Berger

1) Multiple answers possible, $n_{2021}=30$, $n_{2024}=89$ 2) Multiple answers possible, $n_{2021}=27$, $n_{2024}=70$

R: Main hurdles and barriers for Hydrogen Valleys in the preparation phase

Question: "What are the main preparation hurdles that you have to overcome?"[1]



Source: h2v.eu, Roland Berger

1) Multiple answers possible, n_{2021}=28, n_{2024}=60

PUBLIC CO-FUNDING OF HYDROGEN VALLEYS IS STILL COMMONPLACE, BUT PRIVATE INVESTORS ARE GAINING IMPORTANCE

Since the beginning of the decade, the share of purely privately-financed Hydrogen Valleys has doubled from 10 percent to 20 percent today, a sign that private investors see a stand-alone business opportunity in clean hydrogen and in particular in integrated projects along the value chain. However, nearly 70 percent of Hydrogen Valleys still include both a public as well as private funding entity and public budgets continue to be a driving force behind many projects. Funding from public institutions typically covers only a portion of project costs (often 20–30 percent). The public funding sources have diversified in recent years. The share of projects with public funding at regional and local level has decreased (at local level significantly), reflecting a trend away from archetype 1 Hydrogen Valleys with a very local scope towards more regionally integrated Valleys around industrial clusters (archetype 2). → Q

2.4 Remaining barriers: Finding room for improvement

Even though there is now almost half a decade of collective Hydrogen Valley development experience, developers still face common challenges and hurdles today (to varying degrees). Overall, obtaining funding remains the most common barrier for Hydrogen Valley development, as mentioned by 73 percent of Hydrogen Valleys that were surveyed for this report. The most prevalent hurdles for Hydrogen Valleys in this regard are tapping into public funding schemes, concluding offtake contracts and unlocking private investment, while mastering technological readiness and dealing with regulatory provisions are also commonly highlighted. → R

From the analysis of global Hydrogen Valleys, key common barriers for projects en route to Final Investment Decisions can be clustered into three categories: technology, project execution and contracts & regulation. → S

CLEAN HYDROGEN TECHNOLOGY

Nearly 70 percent of Hydrogen Valleys (still) identify technological maturity and/or availability as a hurdle to developing their projects. This pain point has evidently become more significant over the years: 43 percent in 2021 vs. 68 percent in 2024 of Hydrogen Valleys saw this as a main concern.

One of the key issues is the lack of sufficient operational proof points of electrolysers at scale, particularly at multi-MW and GW scale. Currently, many technologies and OEMs have a limited operational track record, and performance guarantees are hard to compare to other energy equipment classes (e.g. regarding efficiency over lifetime, system lifetime, system availability, etc.). Additionally, Hydrogen Valley developers are aware of public news of electrolyser performance issues, even in smaller-scale projects.

Supply chain constraints are another critical technology barrier. On the one hand, many equipment and component classes still have structurally lean supplier bases, and on the other hand, global geopolitical disruptions have caused shortages in critical material and sub-component supplies in recent years. The need for a coordinated capacity ramp-up of OEMs and suppliers at multiple tiers is also proving to be a bigger challenge for electrolysers and fuel cells than anticipated by project developers and industrial players alike. All these developments hinder the development and deployment of hydrogen projects.

Furthermore, the low Technology Readiness Level (TRL) of critical applications for hydrogen transportation and end use poses a challenge. Technologies such as ammonia cracking and LOHC (Liquid Organic Hydrogen Carriers) have not reached a high level of technology

S: Key hurdles for green hydrogen projects en route to Final Investment Decisions

1 TECHNOLOGY

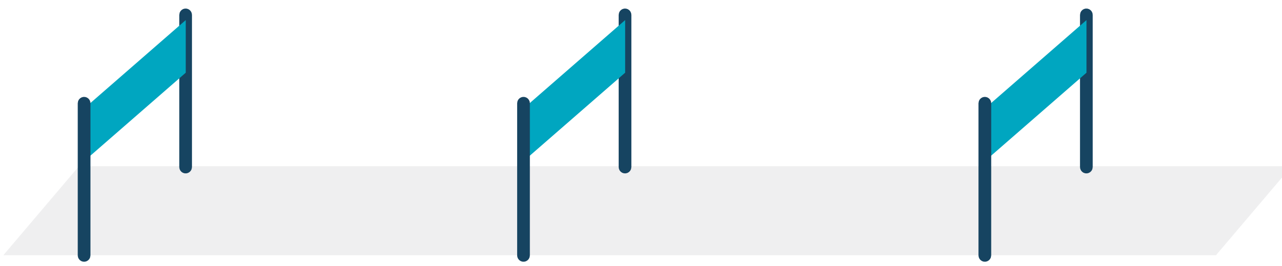
Concerns around maturity (or even availability) of key technologies at Valley scale

2 PROJECT EXECUTION

Delays in build-out of renewables as well as permitting/licensing barriers

3 CONTRACTS & REGULATION

Missing commitments & regulation for bankable long-term offtake agreements



- → Insufficient operational proof points of electrolysers at scale (beyond multi-MW scale)
- → Supply chain constraints given global geostrategic disruptions as well as need to coordinate capacity ramp-up
- → Low TRL of critical technologies for H_2 transportation (e.g. NH_3 cracking, LOHC) or end use (e.g, H_2 DRI, NH_3 in shipping)

- → Lack of authorities' experience, standards, staff, etc. now facing first-of-a-kind green molecule projects
- → Slow build-out of PV, onshore wind, offshore wind, etc. capacities (esp. in Europe) can prove challenging for Valleys

- → Lack of (or adverse) green H_2 product standardisation / certification (even in EU)
- → Lack of supporting policies and regulation (e.g. expansion and increase of CO_2 pricing, green quotas and CCfDs) – hence, willingness to pay remains elusive and many regulatory markets (vs. voluntary markets) remain bottlenecked
- → Over-complex public funding regimes (e.g. with opaque rules of combining funds) to close remaining funding gap

... in a higher-interest-rate market environment, project funding and financing becomes an increasingly significant hurdle as well

Source: h2v.eu, Roland Berger

maturity (especially when deployed at scale), making their implementation and integration into hydrogen projects more complex. Similarly, technologies like hydrogen-based DRI (Direct Reduced Iron) and ammonia in shipping are still at lower TRLs and have not been deployed at scale, underlining the importance of further technology development and successful initial deployments. Here, Hydrogen Valleys trailblaze the frontier of clean hydrogen technology commercialisation.

CLEAN HYDROGEN PROJECT EXECUTION

Hydrogen Valleys also faces significant structural barriers in project execution, including delays in the build-out of renewables and challenges in obtaining permits and licences in a timely manner (see chapter 2.3 on permitting).

Another challenge is the slow build-out of renewable energy capacities (mostly solar PV, onshore and offshore wind) and the delayed expansion of the power grid, especially in Europe. De-bottlenecking green electricity supply and infrastructure would have a significant positive impact on many Hydrogen Valley initiatives, in terms of schedule and cost.

CLEAN HYDROGEN REGULATION AND ECONOMICS

Another key obstacle for green hydrogen projects en route to Final Investment Decisions is the lack of commitment and conducive regulatory frameworks for bankable long-term offtake agreements. As long as clean hydrogen projects serve a very nascent market and thus remain captive, the upstream producer of clean hydrogen will require binding long-term offtake commitments from a reliable offtaker to take an FID and secure financing for their investment. While a lack of clear and supportive regulation defining green hydrogen used to be a dominant obstacle, the past 12–18 months have brought about more clarity in this regard, with, for example, the EU's RED II Delegated Act now in place and similar provisions in final alignment in the US. These regulations create a clearer understanding of what constitutes green hydrogen. In addition, policy makers have advanced other offtake-related regulatory enablers, including quotas (e.g. EU RED II and RED III), public auctions or CfD schemes. Despite these advancements, developers of Hydrogen Valleys continue to grapple with the complexity of public funding instruments, such as overly complex CAPEX funding schemes. Simpler approaches, such as tax incentives, tend to be perceived as more effective.

However, policies and regulation are not the only remaining set of barriers. The recent rise in financing costs, marked by higher interest rates, has become a significant issue for Hydrogen Valley developers, as it puts additional upward pressure on LCOH. Moreover, there's a persistently high level of uncertainty surrounding the availability of midstream clean hydrogen infrastructure. Hydrogen pipelines are expected to become a fully-regulated sector in many geographies, depending on a clear framework for remuneration of system operators and likely additional CAPEX supports. Often, neither upstream nor downstream clean hydrogen project developers can assume the risk of infrastructure availability in hydrogen purchase agreements. Consequently, this risk lies with the pipeline operators or ultimately the public sector.

3 The next level for Hydrogen Valleys – A call to action

While the Hydrogen Valley community can now look back on several years of experience in developing integrated hydrogen projects, many Valleys are still at early stages of their project lifecycle and most of the difficult work towards commercial operations lies ahead. Moreover, the key stakeholders behind Hydrogen Valleys play a pivotal role in advancing the entire clean hydrogen sector. It is on them to create the progress and success stories needed to achieve scale.

3.1 Developers: Delivering, delivering, delivering – and learning from one another

Developers are at the forefront of realising any hydrogen ambition. Looking at the landscape of Valleys, the challenges differ for those that are very advanced with their project developments and those that are just starting out on their journey to establish a Hydrogen Valley. With only 32% of projects on the Mission Innovation Hydrogen Valley Platform having reached FID and representing just c. 6% of total production volume (indicating that mainly the smaller-scale first movers are under construction or operational), the "followers" and not the first movers represent the majority of the Valley community.

ADVANCED DEVELOPERS / FIRST MOVERS NEED TO WRITE REAL IMPLEMENTATION SUCCESS STORIES

First, for advanced Hydrogen Valley developers, actual project delivery (even a "Phase 1" of an eventually bigger Valley development) has become the top priority. Full delivery to commercial operations means mastering the full project lifecycle and completing the learning journey from concept to commissioning. For these developers, focusing on delivery also means continuously prioritising and streamlining their Valley developments to ensure an efficient allocation of resources. Especially the changing and more volatile market environment might cause developers to reassess the breadth of their portfolio. Pinpointing the factors that are the winning preconditions for real implementation success becomes increasingly important. For example, developers need to take the evolving policy support schemes in different geographies into account and analyse portfolio effects in order to accelerate and decelerate different projects. Other distinguishing factors for one Valley development over another might include:

- → Demand-side policy measures support for the decarbonisation of specific clean hydrogen end uses
- → Ease of permitting and authorisation procedures
- → Favourable RES input factors and limited constraints to RES build-out
- → Availability of dedicated hydrogen infrastructure

Second, excellence in managing large-scale CAPEX programs also needs to move into the spotlight for advanced Hydrogen Valley developers. Especially the frontrunners in large clean hydrogen project deployment are often incumbent energy organisations. Together, international energy majors are key stakeholders in more than 50% of all Hydrogen Valley projects around the world. To keep the envisioned market acceleration dynamic alive, these advanced developers need to standardise hydrogen asset deployment. The year 2030 is an upcoming milestone for the hydrogen sector and the market is yet to see the post-FID advancement of more than 90% of Hydrogen Valleys that have estimated their commercial operations date (COD) before 2030. Key elements of large-CAPEX excellence include value engineering of projects, proactive permitting and stakeholder management, smart procurement strategies (especially for critical hydrogen equipment), and the build-up of capable developer teams.

Third, operational Hydrogen Valleys need to focus on backstopping and showcasing the performance and reliability of key hydrogen technologies, as a signal to the wider sector and as a source of learning for other developers. Developers as well as industrial players (OEMs, EPC companies, O&M service providers, etc.) need to focus on making the first Hydrogen Valleys work in practice – with delivery dates, operational availabilities, efficiencies over lifetime, CAPEX and OPEX levels, etc. all in line with developers' expectations.

NEW DEVELOPERS NEED TO CENTRE THEIR HYDROGEN VALLEYS AROUND VIABLE HYDROGEN END USES AND CLEAR OFFTAKE POTENTIAL

Hydrogen Valley developers need to identify and secure reliable offtake potential in their regions; they also need to support offtakers in their commitment process. In the currently supply constraint and captive market environment for clean hydrogen, projects only get implemented if they have firm offtake commitments secured. Moreover, willingness to pay for clean hydrogen is still limited, and only starts to increase thanks to clearer regulatory signals and increasing voluntary demand. It therefore becomes an artful craft to embed Hydrogen Valleys in firm regional offtake constructs that allow for reliable project advancement. Developers are the key platform to aggregate the committed demand side and the competitive production routes. However, beyond obvious large point emitters with hydrogen as a decarbonisation option (e.g. direct reduced iron – DRI – in steel making), there are two markets to navigate: the regulatory driven market around mandates and quotas for hydrogen usage as well as the voluntary market, based on hydrogen as a competitive choice. The developers have a key role to play in not only constructing the business case for the production project, but also supporting potential offtakers in their journey to build a successful business case with hydrogen as a clean fuel or feedstock. This means navigating the complex regulatory frameworks as well as the heterogeneous subsidy landscape. Active market making, even addressing niche markets, is required when developing viable Hydrogen Valley concepts. → T

To allocate different risks, developers also need to build their Hydrogen Valleys on successful de-risking structures that are prescribed by binding long-term contracts between all involved parties – the functional toolkit to bring together offtakers, hydrogen producers, transporters and technology partners.

Hydrogen Valleys at the beginning of the project lifecycle also need to capitalise on the lessons learned from other developers in terms of partnering set-up, coalition building and Valley governance. Valleys need to strike the right balance between assembling many private and public stakeholders in a region and limiting complexity of aligning and managing different commercial interests. Here, Valleys have opted for different governance vehicles depending on regional legacies and project circumstances, including MoU-based company-to-company relationships, inter-company working groups, full project consortia, regional industry associations, public-private partnerships, etc.

3.2 Policy makers: Supporting clean hydrogen projects in general, and Hydrogen Valleys in particular

Since the beginning of the decade, the clean hydrogen policy landscape overall as well as policies and regulations specifically promoting Hydrogen Valleys have substantially progressed, in terms of ambition levels, funding levels and diversity of policy instruments. However, as the persistent barriers to the realisation of Hydrogen Valleys reflect, continued policy support in various areas of project development will be required. This support needs to encompass both specific measures aimed at Hydrogen Valleys (e.g. facilitating the creation of Hydrogen Valleys in specific regions, Valley-focused

T: Project risks along the Hydrogen Valley lifecycle

H_2 project phase

H_2 project development | **H_2 project construction** | **H_2 project operation**

FID[1] **RTB[2]** **COD[3]**

Key risks per value chain step

Commercial risks

- Lack of suitable offtaker willing to pay additional cost for "green premium", increasing commercial risk
- Insufficient cost reduction of components, increasing total project costs and reducing profitability

Construction risks

Delays and cost overruns due to, e.g.:

- Higher complexity for integration of renewable energy and H_2 components
- Delayed permitting and licensing
- Overall inexperience of EPC Co.'s in designing and executing more complex green H_2 projects

Operational risks

Breakdown and interruptions, e.g.:

- Efficiency losses (e.g. stack degradation)
- Downtime due to failure of electrolyser, more frequent and longer maintenance work
- Higher transmission and distribution losses due to leakage

Decreasing purity of H_2 due to microbial activities

Technology risks

- Longer than expected time to bring H_2 technology at scale to commercial level, potentially non-availability of technology at construction start
- Less favourable tech. characteristics than expected in feasibility studies, potentially delaying / stopping project

Environmental and safety risks

- Fire and explosions (mix of different gases in electrolysers, ignition of leakages, ...)
- Added HSSE risks associated with key H_2 derivatives such as NH_3, MeOH, SNG, e-fuels

Source: h2v.eu, Roland Berger

1) FID = Final Investment Decision 2) RTB = Ready-To-Build 3) COD = Commercial Operations Date

innovation policy, Valley-focused public funding instruments) as well as policy instruments supporting clean hydrogen projects more generally (e.g. incentivising clean hydrogen offtake, enabling project financing, lowering permitting burdens). In addition to that, there are specific preconditions that are essential to making the entire energy transition work. Most importantly also for Hydrogen Valleys: The availability of green electricity needs an enabling environment to accelerate at scale.
For policy makers at different levels, the following priorities have crystallised from the analysis of the success factors and barriers of Hydrogen Valley development around the world.

1. SPECIFIC POLICY SUPPORT FOR HYDROGEN VALLEYS

Supporting the initiation of new Hydrogen Valleys, especially in emerging clean hydrogen geographies and sub-sectors (supranational, national and regional levels of government): Governments have played a key role over the last years in supporting the initiation and conceptualisation of Hydrogen Valleys, mainly via specific funding instruments. Examples include CAPEX funding schemes at EU level (i.e., the Clean Hydrogen Partnership's calls for Hydrogen Valley proposals under Horizon Europe, the EU's Framework Programme for Research and Innovation 2021–2027) and EU Member State level (e.g. national calls for Hydrogen-Valley-type regional initiatives in Germany, France, Italy or the Netherlands), but also the US DoE Hydrogen Hubs program. Policy makers should continue to use such funding schemes to incentivise the creation of integrated clean hydrogen projects along the value chain and provide targeted funding upstream, midstream and downstream. Particular attention should be placed on enabling first-of-their-kind Hydrogen Valleys in new geographies, further increasing the scale of Hydrogen Valleys as well as connecting existing and new Hydrogen Valleys with one another by linking them to larger corridors of shared clean hydrogen infrastructure (e.g. pipelines, seasonal storage, refuelling station networks).

Supporting the project preparation of Hydrogen Valley en route to FID (supranational, national and regional levels of government): In the last two years, only a handful of Hydrogen Valleys succeeded in moving past the FID milestone into implementation. In the same timeframe, more than EUR 7.5 bn was dedicated to and partly made available for funding Hydrogen-Valley-like clean hydrogen projects by the European Commission and the US Government alone. Evidently, the question of how public funding can have the most impact should needs to be revisited. Specifically, public support schemes should move beyond CAPEX subsidies or OPEX support and take on a more holistic perspective that also includes development assistance (especially for projects in less advanced clean hydrogen geographies and sub-sectors). In Europe, this type of assistance has for example already contributed to an acceleration in the deployment of renewable energy soutions and energy efficiency measures in the building sector[14]. In the US, the Department of Energy's Hydrogen Hubs program qualifies external support for the acceleration of project development as fundable project investment[15].

Facilitating dialogue and best-practice sharing among Hydrogen Valley developers (supranational levels of government): Policy makers should also continue to provide platforms for Hydrogen Valley developers to exchange lessons learned and best practices. Here, global state-to-state initatives like Mission Innovation (in particular its Clean Hydrogen Mission) or the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) should continue to play their part. At the European level, cross-border dialogue is already very active and should be further supported at EU level in the future.

2. GENERAL CLEAN HYDROGEN POLICY PRIORITIES WITH A SIGNIFICANT IMPACT ON HYDROGEN VALLEYS

Implementing demand-side policy measures to incentivise clean hydrogen offtake (supranational and national levels of government): While CAPEX subsidies for clean hydrogen production projects have been the predominant “legacy” public support scheme, instruments focusing on suppliers’ OPEX or offtakers’ willingness to pay have increasingly become the focus of clean hydrogen policy. In Europe, the mandatory and penalty-enforced RED III quotas for 42% clean H_2 use in industry and the transportation and aviation sector sub-targets[16] will establish clear transition pathways for green hydrogen offtakers – and increase their willingness to pay. Moreover, instruments such as the EU Hydrogen Bank or the H2Global auction schemes can be effective approaches to bridging the gap between landed clean hydrogen cost and willingness to pay. Policy makers need to strike the right balance between supply-side support and demand-side incentives; implementing Hydrogen Valleys (in particular larger ones) will require both.

Accelerating permitting procedures for clean hydrogen projects (national, regional and local levels of government): Governments need to make good on their promise to accelerate permitting processes for real implementation progress. Even though there are encouraging signs of increased political will in Europe (e.g. RED III’s simplification of renewable acceleration areas or the application of simplified environmental standards), the perceived “permitting burden” for Hydrogen Valley developers is still substantial. Here, cutting red tape and streamlining administrative processes can have a direct and measurable effect on speeding up real implementation of projects. Specifically, Hydrogen Valley developers highlight the following areas for improvement: centralising permitting processes in single (“one-stop shop”) authorities, increasing coordination among all permit-related governmental agencies, combining procedures for construction permits and operating licences, fast-tracking environmental impact assessments, digitising permitting processes (especially enabling online submissions of application documents), and building up capabilities and capacities of permitting authorities.

Overcoming the remaining barriers to clean hydrogen technology commercialisation with continued research and innovation support (supranational and national levels of government): While clean hydrogen technologies have made significant progress in recent years on their pathways to commercialisation and mass deployment, in terms of increasing performance and reducing cost, clean hydrogen research and innovation support remains a key priority for governments. In light of the consistent feedback that technology readiness continues to be a barrier to project implementation, Hydrogen Valley developments will particularly benefit from continued public (and private) R&I investments in the following areas: scaling technologies via industrialised manufacturing (e.g. design-to-manufacturing for electrolysers and fuel cells), lowering the cost of technologies by structurally reducing direct material costs (e.g. from platinum-group metals in electrolyser and fuel cell stacks), increasing system efficiencies and system lifetimes and commercialising critical midstream clean hydrogen applications at scale (e.g. ammonia cracking).

4 The Hydrogen Valley platform – Come and join us!

4.1 www.h2v.eu; The global platform for Hydrogen Valleys

The Hydrogen Valleys platform intends to feature new, recently emerged Hydrogen Valley projects from around the world. It is looking to continuously showcase all major developments in this part of the growing and evolving clean hydrogen sector.

If a Hydrogen Valley project or initiative meets the criteria as set out below, please get in touch to have your Valley added to the global list of leading integrated hydrogen projects and claim the benefits that come with joining a global developer community. → U

All projects at project development stage from around the world are encouraged to reach out to join the platform. By participating in the further development of the Hydrogen Valley platform, project developers play a significant role in promoting the emergence of other hydrogen projects and thereby facilitating the global clean energy transition as such. Above that, these projects will join an exclusive group of other leading hydrogen projects who can actively collaborate and exchange best practices.

4.2 Interested? How to join the platform

If you are interested, please get in touch regarding your Hydrogen Valley via https://h2v.eu/join-us or send an email to H2V@clean-hydrogen.europa.eu!

The fit of the hydrogen project will be evaluated against the Hydrogen Valley definition. Once this is done, each valley is invited to complete a comprehensive survey on project fundamentals, technologies deployed, project development overall, financial aspects as well as hurdles and key success factors. Afterwards, the project will be featured on the platform. Furthermore, all Hydrogen Valleys on the platform will receive an H2.0 Valley Certificate. They are thus recognised and certified by Mission Innovation and the Clean Hydrogen Joint Undertaking as a global Hydrogen Valley flagship initiative.

U: Key characteristics of a Hydrogen Valley

1. **Broad value chain coverage**
Covering multiple steps of the value chain from hydrogen production to storage, transport and offtake

2. **Supply of more than one end use**
Showcasing the versatility of hydrogen by supplying more than one end-use or application in the mobility, industry and energy sectors

3. **Geographically defined scope**
Creating hydrogen ecosystems that cover a specific geography, from local/national activities to international outreach

4. **Large in scale**
Setting up two-digit multi-million EUR investment projects that are beyond mere pilot/demo projects and are scalable or replicable

5. **Project feasibility**
Projects have to be under real project development, i.e. advancing on a feasibility study

6. **Clean hydrogen production**
Following a zero/low-carbon hydrogen production pathway

Source: h2v.eu, Roland Berger

FOOTNOTES

1) Toolbox | H2Valleys
https://h2v.eu/toolbox
2) International Energy Agency (IEA)
3) Roland Berger Hydrogen Project Database (Project announcements by 2030 – Including Green H_2 projects at very preliminary studies or at press announcement stages)
4) REPowerEU | European Commission
https://ec.europa.eu/commission/presscorner/detail/en/ip_22_3131
5) Recovery and resilience facility | European Commission
https://commission.europa.eu/document/download/9c4a7536-a906-4468-9a49-ef2c901fb0fd_en?filename=RRF_Mid_term_Report_2024_v9.pdf
6) Harvard Business Review, 2021; Merrow, 2012
7) Hydrogen valleys | BIG HIT (Building Innovative Green Hydrogen Systems in Isolated Territories)
https://h2v.eu/hydrogen-valleys/big-hit-building-innovative-green-hydrogen-systems-isolated-territories-0
8) Hydrogen valleys | NEOM GREEN HYDROGEN
https://h2v.eu/hydrogen-valleys/neom-green-hydrogen
9) With expectations ranging from EUR 1.7 to 4.0 per kg by 2030 (International Energy Agency (IEA), Hydrogen Review 2023)
10) Best practices | H2Valleys
https://h2v.eu/analysis/best-practices
11) Hydrogen | European Commission
https://energy.ec.europa.eu/topics/energy-systems-integration/hydrogen_en
12) Depending on the electrolysers' capacity factors
13) ~EUR 324 m
14) Through the ELENA (European Local Energy Assistance) program
15) Department of Energy
16) Renewable Energy Directive | EUR-Lex European Commission
https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L_202302413

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